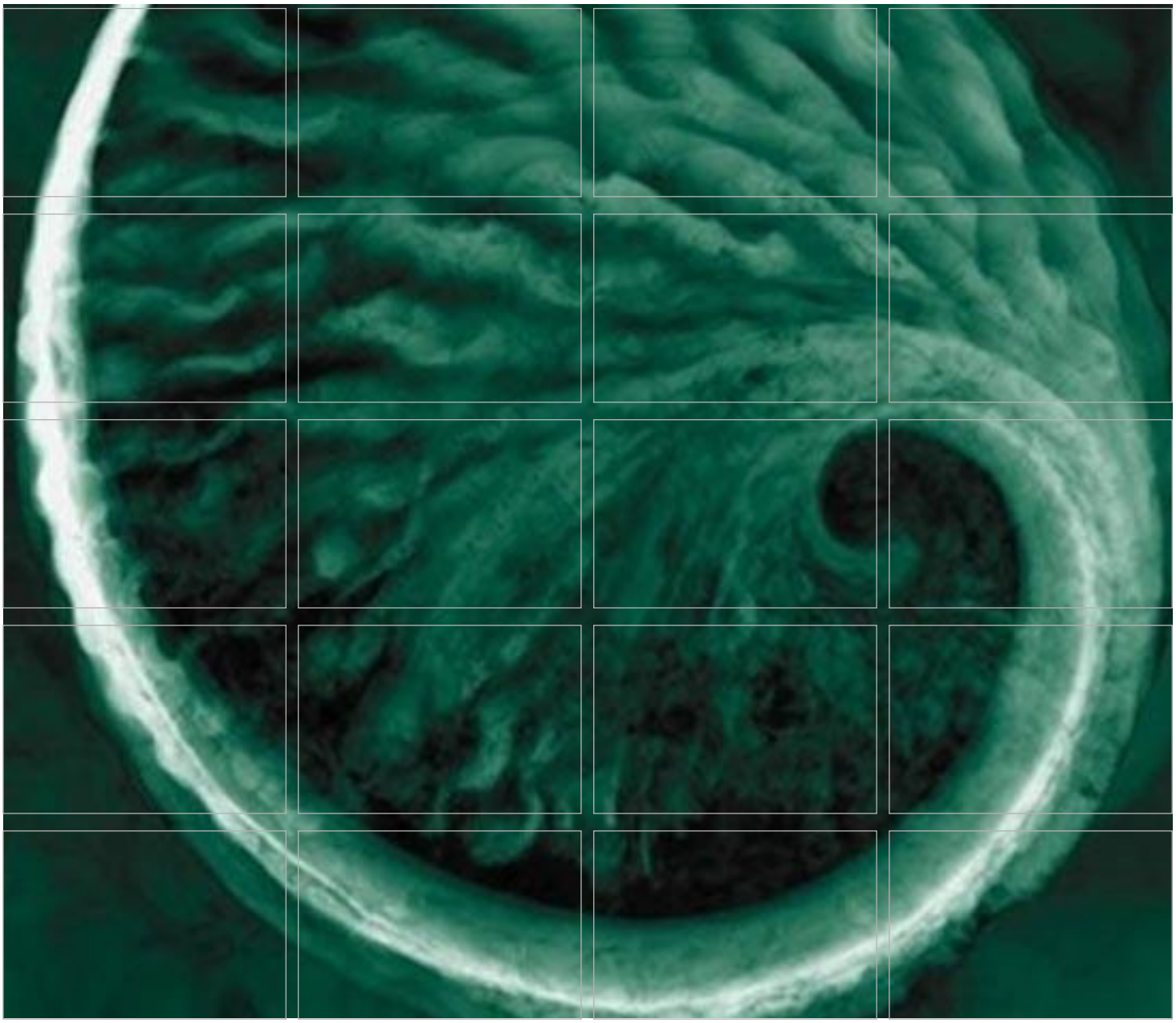

Life Cycle Assessment of Used Oil Management

Prepared for the American Petroleum Institute

Final

January 2017

Environmental Resources Management (ERM)

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American Petroleum Institute

Life Cycle Assessment of Used Oil Management

Date

10th January 2017

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For and on behalf of
Environmental Resources Management

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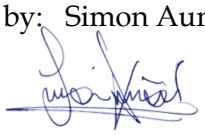
Signed: 

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Date: 10th January 2017

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EXECUTIVE SUMMARY

Arrangements for the management of used oils (sometimes called waste oils) from a range of sources including vehicle and industrial applications need to be made in all countries. Poorly managed used oil can cause considerable environmental harm. Properly managed used oil is a valuable resource that can be used as a feedstock for base oils or other products, predominantly fuels.

This life cycle assessment (LCA) builds on and extends the work done for the state of California (CalRecycle) by the University of California Santa Barbara (UCSB) in 2013. The study benefitted from input from CalRecycle, UCSB researchers, and other stakeholders. The LCA has been critically reviewed.

This study appraises used oil generation in California, in 2010. However, its key lessons and findings are relevant to other time periods, states and countries. In particular, the study concludes that:

- the impacts of the used oil management system are greatly affected by the amount of uncollected and improperly disposed used oil;
- increasing collection results in reduced impacts;
- for a given collection rate, the environmental impacts, and the benefits achieved, of alternative dispositions (beneficial uses) for used oil are highly sensitive to several key factors -- particularly the mix of virgin products displaced by those from the used oil management system and the level of pollution control that is used, especially for combustion of Recovered Fuel Oil (RFO is used oil burned, typically with minimal pre-treatment); and
- no single disposition shows consistently lower impacts under all conditions, with greater benefits generally flowing from increasing collection, rather than from changing disposition.

This work shows clearly that the assumptions made with respect to displacements and pollution control can change completely the results (i.e. which treatment route has the lowest impacts) of an LCA. Where pollution controls are good and effectively applied, fuel use as RFO can have lower impacts than processing to base oil (re-refining). The displacement of dirtier fuels by energy products from used oil also favors use as a fuel. Conversely, in situations without good pollution control, or where cleaner fuels are displaced, reprocessing to base oil or a distillate fuel will often be better.

As the products displaced cannot be controlled, and levels of pollution may be difficult to influence, the clear message for policy makers and regulators is to increase collection rates. Any reduction in collection rates, however this is caused, should be avoided. This is because the benefits of collection are clear and no one single disposition can be said to result in a clearly and consistently better environmental profile for the whole system in all situations.

It follows that a mix of recovery routes, with appropriate controls on the processes and product uses, can deliver the same or greater benefits as employing a single route. Although not explicitly considered in this study, a mix of treatment options may also offer system resilience and the advantages of flexibility. Consequently, policies that encourage a healthy portfolio of beneficial used oil dispositions (e.g. those that do not ban or punitively disadvantage one treatment option over another) and that may therefore lead to an increase in the overall market demand for used oil, could, in turn, deliver increased collection rates, resulting in an overall significant reduction in environmental impacts

Also, as shown by UCSB, there is no inherent advantage for '*closed loop*' recycling over '*open loop*' recycling (e.g. re-refining to base oil over fuel use), when all of the products are used. To protect the environment, the actual performance of each element of the system needs to be controlled to ensure minimum and acceptable impacts for the system.

Several previous LCAs have not dealt transparently, nor well, with these inherent uncertainties. This has led to potentially misleading conclusions suggesting that one treatment option has clear advantages. Whereas, in fact, the ranges of potential impacts overlap and depend crucially on regulation and performance at each stage, with the benefits accruing dependent on the displacements that may occur. By excluding improperly managed used oil, the most important impacts can be overlooked.

This LCA shows clearly that: improving collection yields important benefits; the choice of disposition is less important; and the impacts depend critically on ensuring effective control at each stage. The aim for a policy maker should be an efficient used oil management system, with maximum collection rates, treatment routes for all used oil arising and effective pollution controls at each stage.

SUMMARY REPORT

Introduction

Used oil (sometimes called waste oil) from vehicle lubrication and a wide variety of industrial applications is a major liquid waste stream. If not managed properly, used oil can cause significant environmental problems. However, it can also be a valuable resource. Some can be regenerated and reused and much is reprocessed or re-refined into either: a variety of fuel products; or base oil.

Used oil is classified as hazardous waste in many countries and in the state of California (CA), whilst this is not the case in virtually all other US states. For many years, there has been considerable debate about the relative merits of alternative beneficial uses of used oil. Many life cycle studies have been conducted, with conflicting results.

CA has a well-established system for the management of used oil. In 2009, Senate Bill 546 (Lowenthal) included a number of changes to the applicable system of fees and incentives and mandated that CA's Department of Resources Recycling and Recovery (CalRecycle) carry out a Life Cycle Analysis study. This was to combine an environmental life cycle assessment (LCA) and an economic analysis of the used oil management system, in order to provide any recommendations necessary to promote the increased collection and responsible management of used oil.

Consequently, in 2011, a team from the Donald Bren School of Environmental Science and Management at the University of California Santa Barbara (UCSB) was commissioned by CalRecycle to undertake a LCA of used oil management. The LCA (1), referred to as 'Phase I', had a number of acknowledged limitations. To address this shortfall, the American Petroleum Institute (API – a stakeholder in the Phase I LCA) commissioned **this Phase II LCA** to aid policy makers by addressing the limitations acknowledged, increasing transparency, simplifying the results presentation, and more fully exploring the implications of the uncertainties and choices of assumptions that were made in Phase I.

This Phase II LCA was undertaken in conformance with the International Standard for Life Cycle Assessment (ISO14040 and ISO14044) and was subject to a critical review by a panel of experts:

- François Charron Doucet, Scientific Director, Groupe AGÉCO (Chairman);
- Christopher Loreti, Principal, The Loreti Group;
- Keith A. Weitz, Environmental Scientist, RTI International; and
- Richard P. Zink, Chief Process Engineer, Process Engineering Associates, LCC.

(1) Life Cycle Assessment of Used Oil Management in California. Pursuant to Senate Bill 546 (Lowenthal), R. Geyer et al. CalRecycle, July 29, 2013.

The panel's review confirmed that the Phase II study complies with the requirements of the ISO standard, recognized the robustness of the scientific approach used and its utility for responding to the used oil management issues posed by the SB546.

Used oil management in California

The Phase I report estimated that 113 000 (metric) tonnes of the 435 000 tonnes of used oil generated in CA in 2010 were burned, dumped or landfilled instead of being collected and managed formally. The majority of the collected used oil was processed into MDO (marine diesel oil), believed to be used mainly by shipping. A smaller fraction was processed to lubricating base oil. Some used oil was used as fuel (recovered fuel oil [RFO]) and some exported out of California. It was noted that the volumes produced and processed varied from year to year, depending on a number of factors, and that volumes had reduced compared to the earlier years of the century.

Goal of the study

The goal of this Phase II LCA was to conduct a comprehensive LCA of used oil management. The study specifically addresses the following questions:

- what are the environmental impacts if policy changes resulted in different used oil collection rates; and
- what are the environmental impacts if policy changes resulted in changes to the amounts of used oil going to different recovery options?

The functional unit defined in Phase I is also used in this Phase II LCA:

The formal and informal management of all used oil generated in CA during one calendar year

System Boundary

Figure 1 presents a summary diagram for the system studied in this Phase II LCA, indicating the system boundaries.

The Phase II LCA considers the most common types of recovery:

- reclaiming of used oil to recovered fuel oil (RFO);
- reprocessing to a marine diesel oil product (MDO);
- reprocessing to vacuum gas oil (VGO); and
- regeneration to produce a 're-refined base oil' (RRBO).

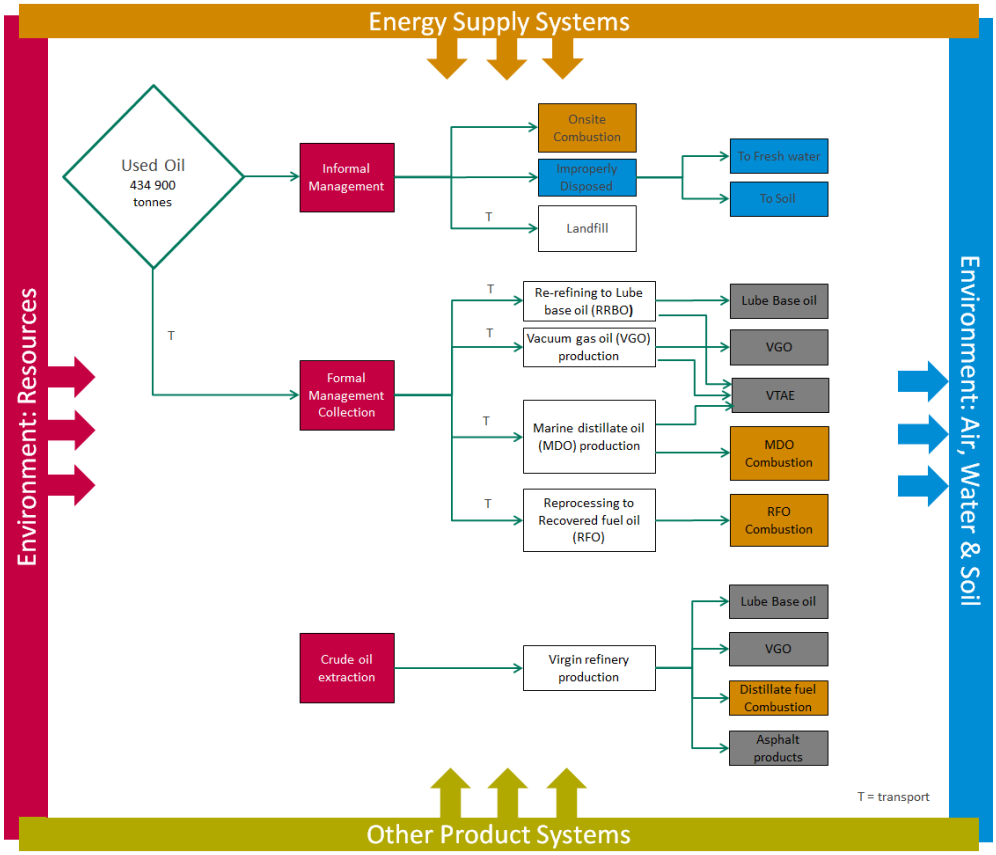
This Phase II LCA employs a 'system expansion model' that accommodates the functionality of the products produced by each system (e.g. fuels and lubricant base oils). This ensures that the function delivered by each system is constant and comparable, i.e. that as more used oil is collected and recovered into new

products, the equivalent product output from the virgin refinery system is reduced.

This differed from the Phase I approach, which used an 'avoided burden' for each product output from each system.

The Phase II approach avoids: (a) the perception that increasing the quantity of used oil generated is beneficial for the environment; and (b) the implication that efforts to reduce such used oil generation would be detrimental. It also makes the comparisons among options more useful, showing that there are always impacts incurred by used oil management and that it is the scale of these impacts that should be compared.

Figure 1 Used Oil Management - System Boundaries



The Phase I baseline scenario and alternative dispositions have been appraised through 'extreme scenarios', where all used oil was assumed to be collected and treated by a single management route. We added reprocessing to VGO, as the application of this route is increasing elsewhere in the US.

The scenarios considered were as follows.

- 'Baseline' – the proportion of used oil sent to each formal and informal waste management option is fixed as per 2010 values in CA.

- 'Extreme RFO' – all used oil produced in CA is reprocessed into RFO. All used oil produced is collected, and no used oil is managed informally.
- 'Extreme MDO' – all used oil produced in CA is reprocessed into MDO. All used oil produced is collected, and no used oil is managed informally.
- 'Extreme VGO' – all used oil produced in CA is reprocessed into VGO. All used oil produced is collected, and no used oil is managed informally.
- 'Extreme RRBO' – all used oil produced in CA is re-refined into RRBO. All used oil produced is collected, and no used oil is managed informally.

A number of uncertainty analyses are undertaken so as to understand the influence of key assumptions on the results, and how variation in these might change apparent preferences among treatment options. The most important uncertainties appraised were:

- the product substitutions that are assumed, in particular the fuels considered; and
- the level of pollution control that is applied to the combustion of RFO.

Previous work, including Phase I, showed how sensitive the results are to these assumptions. Since at least the products displaced are typically beyond the control of the policy maker, it is essential to appreciate how these uncertainties can affect the results of the comparisons.

The assessment does not include an economic appraisal of the options, nor consider processing capacity and infrastructure needs. The study does not consider capacity restrictions or the impact of creating capacity. The findings of this study will need to be interpreted in the context of available and projected capacity for the different used oil management routes.

Twelve indicators of environmental impacts have been applied, quantifying the potential contribution to each impact category of each of the scenarios. The assessment does not predict impact *per se*, but instead provides a relative measure of the potential contribution that might be made by each scenario, process, and environmental flow. This is a feature of the LCA method.

It is important to recognize that there is significant uncertainty associated with impact assessment methods and that these continue to develop. Any LCA must be seen in the light of inherent modelling uncertainty and caution used in considering its results.

The environmental indicators and impact categories used to appraise each scenario are as follows:

- Acidification (TRACI 2.1);
- Ecotoxicity (TRACI 2.1);
- Eutrophication (TRACI 2.1);
- Global warming (TRACI 2.1);
- Human health, particulates in air (TRACI 2.1);

- Human toxicity, cancer (TRACI 2.1);
- Human toxicity, non-cancer (TRACI 2.1);
- Ozone depletion (TRACI 2.1);
- Smog (TRACI 2.1);
- Fossil fuel depletion (TRACI 2.1);
- Abiotic depletion, elements (CML 2001); and
- Abiotic depletion, fossil fuels (CML 2001).

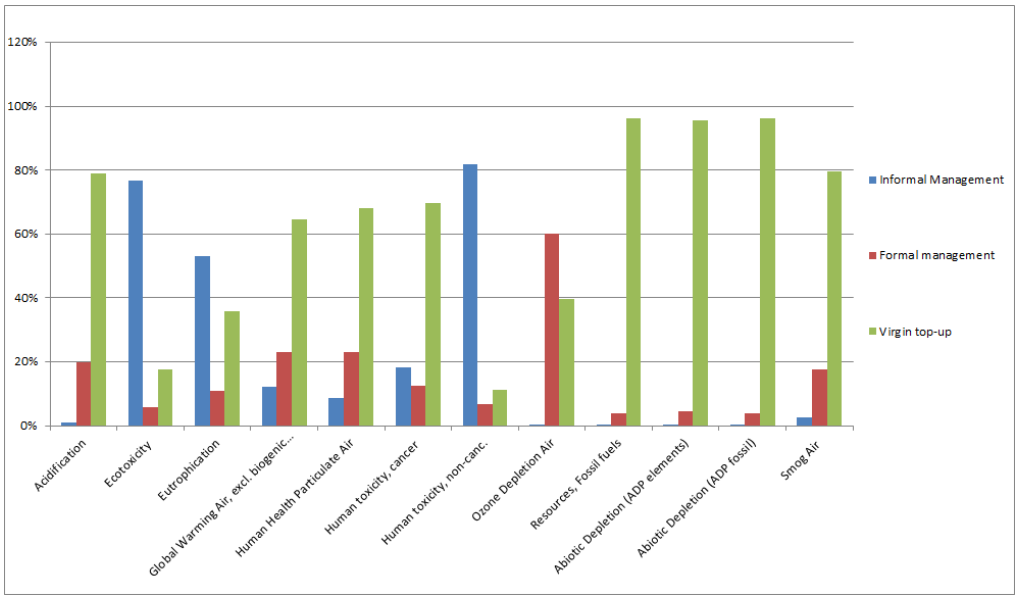
Results

This Phase II study report provides Life Cycle Impact Assessment (LCIA) results for each scenario and for the uncertainty analyses. The key contributions to each impact are identified in terms of the emissions, i.e. which substances make the contribution, and their sources from within the system studied.

In the baseline scenario, the carbon footprint (1) associated with management of the 435,000 metric tonnes of used oil generated (and the virgin fuel top-up to meet the constant commercial market) in California in 2010 was ~ 2.8 million metric tonnes CO_2e and the associated fossil fuel depletion was ~ 57 million MJ.

The contributions of formal management, informal management (improper disposal), and virgin top-up (according to impact category) are also provided. *Figure 2* presents the contribution analysis for the Baseline scenario. This highlights the significant contribution of uncollected used oil (informal management) to the ecotoxicity, eutrophication and human toxicity impact categories.

Figure 2 Baseline scenario impact contribution

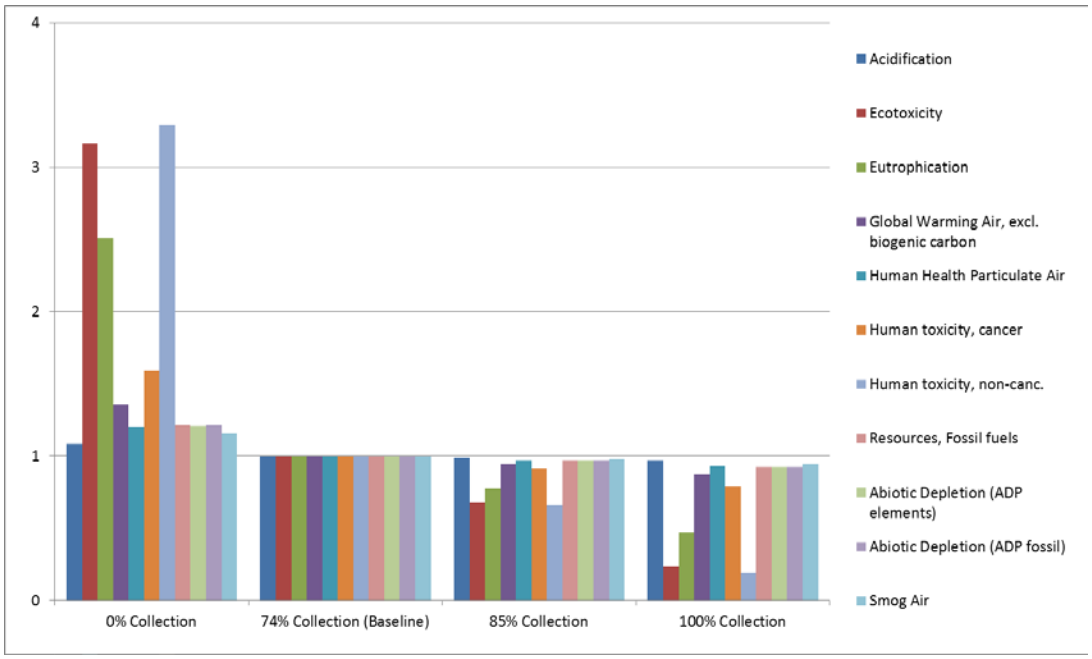


(1) Greenhouse gas emissions expressed in carbon dioxide equivalents

Figure 3 shows the consequence for the Baseline scenario of altering the collection rate to 0%, 85% and 100%. Reducing collection would result in a significant increase in environmental impact, while increasing collection would reduce the environmental impact.

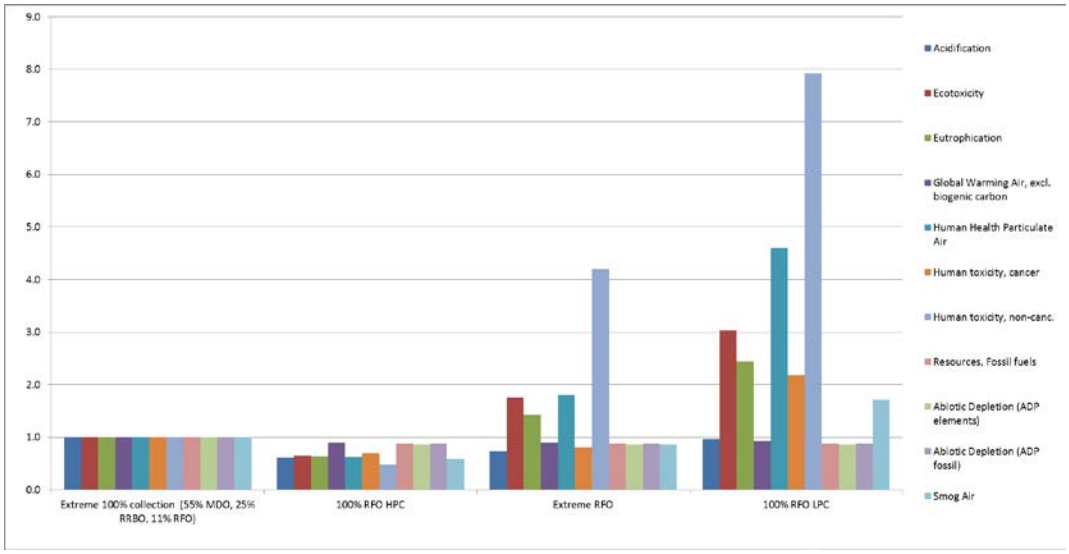
Increasing collection from 74% to 85% and maintaining the same disposition for collected oil as the Baseline will deliver a saving of 149 000 tonnes CO_2e and 1800 TJ of fossil reserves. The most significant benefits are seen for the eco-toxicity and human toxicity impact categories. This reduction is associated primarily with avoiding the release of metal and organic compounds to water and soil from the informal management of used oil.

Figure 3 Alternate Collection Rates (relative performance where 1=Baseline)



Alongside results for the 'pure' extreme scenarios, the impact results for a number of sensitivity analysis scenarios are also presented. *Figure 4* shows the significance of pollution control for recovered fuel (RFO) combustion for the Extreme RFO scenario compared to the 100% collection and Baseline scenario disposition. *Figure 4* demonstrates that combusting RFO with high pollution control will result in RFO performing better than the Baseline disposition of collected used oil.

Figure 4 ***Pollution control sensitivity for Extreme RFO scenario (relative performance, where 1=Extreme collection with Baseline disposition)***



Another area of significant uncertainty examined in the sensitivity analyses is the fuel substitution that is assumed to occur as a result of used oil management. *Figure 5* clearly reinforces the work of previous LCAs in demonstrating that, for fuel-based systems, the pollution-related environmental impacts are highly dependent on the virgin market that is affected by production of secondary products. A dramatic increase of the acidification and the human health (particulate) impact categories is seen if the defined energy market is satisfied by coal.

Figure 6 and *Figure 7* summarise the result for all of the scenarios for the global warming and resource depletion impacts, demonstrate the benefits of increasing collection rate, and how the impact profiles of the different recovery routes overlap.

Figure 5 *Relative effect of the choice of substituted fuels – Extreme RRBO (relative performance, where 1=Extreme RRBO)*

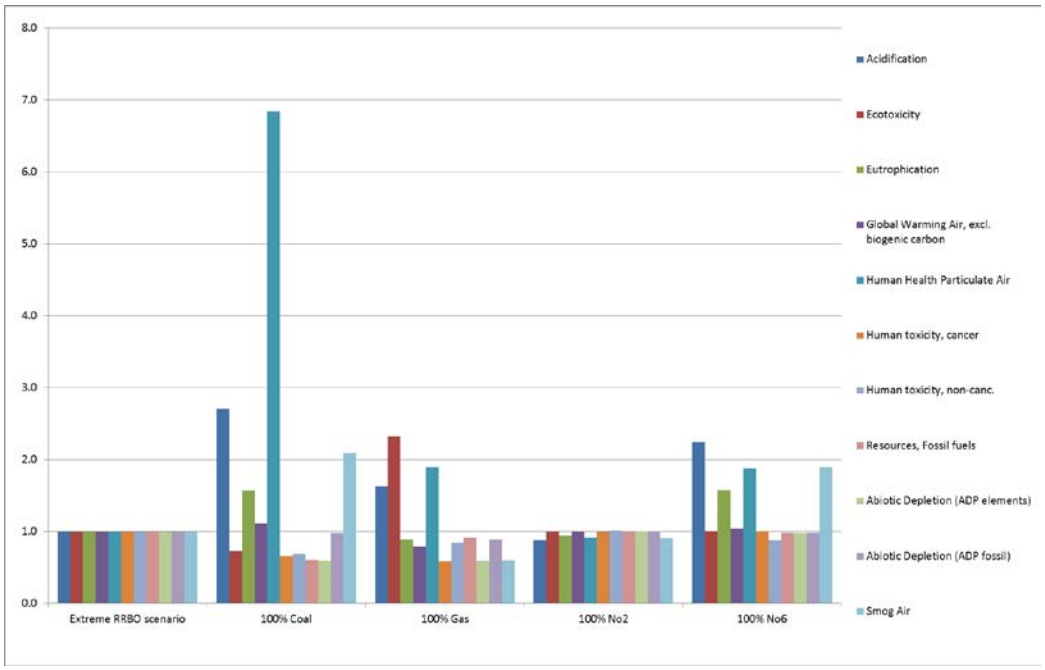
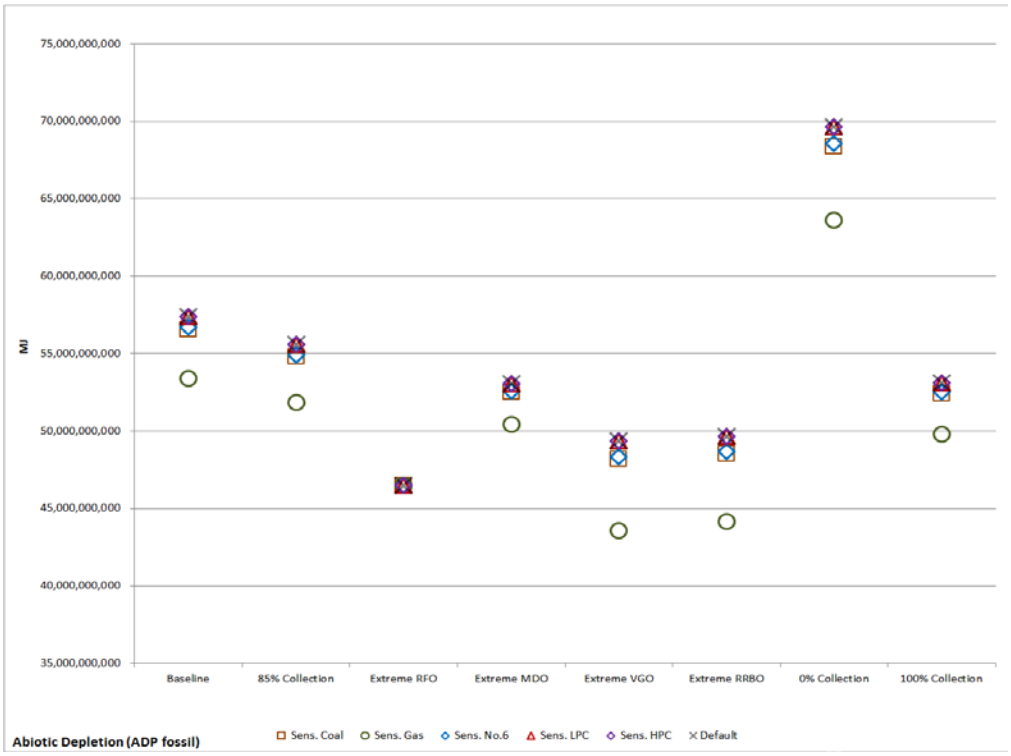


Figure 6 *Comparison of all scenarios for global warming*

Figure 7 Comparison of all scenarios for abiotic depletion (ADP fossil)



Conclusions

This report provides a detailed ISO 14044-compliant LCA of used oil management in California in 2010 and a number of disposition scenarios. These were selected to assess:

- key uncertainties, including those beyond the direct control of a policy maker;
- the effect of changing collection rates;
- the relative effects of alternate reprocessing routes;
- alternative conventional/virgin product displacement; and
- levels of pollution control.

The assessment does not include an economic appraisal of the options, nor consider processing capacity and infrastructure need. The findings of this study will need to be interpreted in the context of available and projected capacity for the different used oil management routes.

In order to provide some context, the analysis estimated that, in the Baseline case, the direct formal and informal management of the approximately 435 000 metric tonnes of dry used oil generated each year in California contributed:

- less than 0.25% to total reported acidification and climate change impacts for California; and
- 0.06% or below of smog, abiotic depletion and human health particulate impacts.

As expected, it is a small contributor to total pollution.

The use of system expansion rather than an avoided burden approach enabled a meaningful analysis of the effects of increased collection rates to be made. The scenarios and sensitivity analyses undertaken make transparent the significance of the assumptions made and therefore help to avoid any bias (inadvertent or deliberate) that can affect the interpretation of previous studies.

Among other things, this study highlights the importance for policy makers of scrutinizing LCA studies with an appreciation of uncertainty and the limitations of the analyses, and of interpreting used oil LCA study results within these constraints. When comparing beneficial uses, differences are often small and highly sensitive to the assumptions that must be made in conducting a study and the data employed by it.

The results show clearly that increasing rates of used oil collection results in benefits, through reduced environmental impacts, for the system as a whole and for all of the impacts considered. This finding is clear and consistent, despite the associated uncertainties.

This analysis shows that the improper disposal of used oil (i.e. uncollected oil) increases resource depletion (through requiring more virgin product make-up to satisfy demand) and has the potential to cause significant environmental impacts. Inevitably, there is uncertainty with respect to the fate of uncollected, improperly disposed, used oil and the potential impacts depend on the way that it is disposed. Disposal, through dumping which leads to water contamination, results in high impacts.

The uncertainty analyses showed that several factors had a very significant effect on the study results and might change the apparent preferences among treatment options.

The most important uncertainties, and areas of potential bias, that were identified are:

- the product substitutions that are assumed, in particular the fuels; and
- the level of pollution control that is applied to the combustion of RFO.

Key assumptions that have been built into previous LCA models can introduce bias and obscure the fact that the results can be driven by assumptions that cannot be delivered or reasonably be assumed to be constant.

For example, the fuel market is international and a wide range of fuels can be used in many process configurations to deliver the market-demand for energy.

These configurations may use different systems and very different levels of pollution control. This can give a misleading impression that one route is clearly 'better' than others, although this will depend to a considerable degree on the actual substitutions and technologies employed in any jurisdiction, and which change over time and among geographies.

This Phase II work builds on, and strongly supports, the Phase I work of UCSB and others, showing that there is no inherent advantage for a 'closed loop' recycling route over an 'open loop' recycling or recovery route for resource consumption- or pollution-related environmental impacts, provided that there are markets for all of the products. The comparison depends instead on the relative impacts at each stage of the life cycle (production, collection, reprocessing, use). In this case, there is no scientific basis upon which to favor materials recycling, provided there is demand for all of the resulting products and environmental impacts are controlled at each stage of the cycle.

In this study, alternative used oil dispositions have been appraised through 'extreme scenarios', where all used oil was assumed to be collected and treated by a single route. This approach removed the effect of collection rate and improper disposal, while serving to highlight differences among the disposition options.

This analysis shows that no one single disposition can be said to result in a clearly and consistently better environmental profile for the whole system in all situations. Put another way, on environmental grounds, a mix of recovery routes, with appropriate controls on the processes and product uses, can deliver the same benefits as employing a single route. In addition, although not explicitly considered in this study, having a mix of treatment options may also offer system resilience and flexibility benefits.

In developing policies that would favor one or more disposition routes over others, it is important that supporting studies are tailored to the pertaining specific circumstances and take account of inherent and any unavoidable uncertainty in order to reach sound conclusions. The apparent advantages of one route over another may depend entirely on factors beyond the control of a policy maker.

The delivery of any useful product (whether this is RFO, RRBO, MDO, VGO or VTAE) will both deliver benefit and incur some environmental impact, through process operation, in each case. All are preferred compared to no beneficial reuse (i.e. informal disposal). Key levers to increase the benefits and reduce the impact of each route can be identified. These include:

- maximizing the yield of product recovery;
- ensuring efficient pollution abatement (directly reducing releases to the environment);
- ensuring that contaminated streams are appropriately managed and contaminants effectively trapped and excluded from the environment; and

- the use of secondary fuels to displace more polluting conventional fuel combustion processes.

The overall impacts from the use of RFO depend very strongly on the levels of pollution control that are in place at the point of use. High pollution control (such as burning in a well-controlled cement kiln or asphalt plant with effective pollution controls) can result in RFO having lower impacts in many categories than the alternative treatment routes such as RRBO.

Conversely, low levels of pollution control (such as burning with no dust or acid gas controls) can lead to the highest impact in certain categories. Consequently, the impacts from the RFO route depend to a significant extent on the pollution controls at the point of use, rather than impacts at the point of production. Comparative impacts are also strongly driven by the fuels that are substituted in the market.

Impacts from processes that distill used oil, including RRBO production, MDO (or equivalent) and VGO, and that concentrate contaminants in the heavy residue stream (known as VTAE), would increase significantly if the VTAE stream were not managed in such a way as to prevent release of those contaminants to the environment (such as by burning, rather than being blended into asphalt products).

When considering the system as a whole, it is clear that increasing collection yields significant benefits despite the inherent uncertainties. It follows that policies that lead to increased collection will reduce impacts and therefore that policies, market conditions, or technology constraints that might inadvertently decrease collection would increase impacts.

In addition to meeting its goal, this Phase II study offers lessons, data, and a model that can be readily applied beyond California (with suitable modifications and adaptions to local conditions) to inform considerations with respect to used oil management and the types of control necessary to deliver the maximum environmental benefits from management approaches.

A key lesson for any interested party, regulator or potential policy-maker is the need for a clear appreciation of the circumstances that will be found in a given jurisdiction. With different context, different energy markets, different levels of pollution control and different used oil compositions the preferred options can be expected to be different. The used oil system is a complex one, with multiple sources of waste. A robust and well-designed system able to cope with all of the oil is important. The duties and markets for lubricants and industrial oils are changing, and the products will adapt to meet these changing demands. The changes in the composition and volume of used oil that result need to be taken into account in planning effective policies for used oil management that minimize environmental impact.

Critical Review Statement

Date: December 9th, 2016

Review commissioned by: American Petroleum Institute

Title of the study: Life Cycle Assessment of Used Oil management- Final draft – November 2016

Authors: Environmental Resources Management (ERM)

Review committee:

- François Charron-Doucet, Scientific Director, Groupe AGÉCO (Chairman)
- Christopher Loreti, Principal, The Loreti Group
- Keith A. Weitz, Environmental Scientist, RTI International
- Richard P. Zink, Chief Process Engineer, Process Engineering Associates, LCC

Scope of the review

The aim of this critical review is to ensure that the LCA report complies with the requirements of the ISO 14044 standard, which stipulates that:

- the methods used to carry out the LCA are consistent with this international standard;
- 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 interpretations reflect the limitations identified and the goal of the study, and;
- the study report is transparent and consistent.

The critical review process was performed concurrently with the LCA study and is based on the ISO 14044 standard - section 6.3. The critical review process did not include a thorough review of the LCA model developed with GaBi software or an analysis of individual datasets. Still, the overall plausibility of the results was assessed.

Conclusions of the critical review

The critical review committee recognizes the high quality of the report and the robustness of the scientific approach used in this study. The report is well written, clear and transparent. The authors have demonstrated an excellent understanding of the LCA methodology and the tools used in this study, including the GaBi software and the life cycle impact assessment (LCIA) methods. The results and conclusions are deemed robust and are used in a manner consistent with the goals of the study.

The committee is of the opinion that the objectives of the study, which are to address a number of the limitations, improve transparency and increase the utility of the model developed in the Phase I LCA study, have been achieved. Used in conjunction with the Phase I report, the Phase II report will help better respond to the used oil management issues posed by the SB546 (Lowenthal) legislation in California.

Verdict

The critical review committee confirms that the *Life Cycle Assessment of Used Oil management – November 2016* study complies with the requirements of the ISO 14044 standard.

François Charron-Doucet, Eng. MScA

Scientific Director
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Encl.: Critical Review Report (December 5th, 2015)

The state of California (CA) has a long-established system for management of used oil (UO). In 2009, Senate Bill 546 (Lowenthal) included a number of changes to the system of fees and incentives and mandated that CalRecycle carry out a Life Cycle Analysis (combining an environmental life cycle assessment (LCA) and an economic analysis) of the used oil (UO) management system. SB546 also required that stakeholders be given the opportunity to provide input on the Life Cycle Analysis. Through its Used Oil Task Force (UOTF), the American Petroleum Institute (API) has been active as a stakeholder in this initiative since 2011.

In early 2011, CA's Department of Resources Recycling and Recovery (CalRecycle) commissioned the Donald Bren School of Environmental Science and Management at the University of California Santa Barbara (UCSB) to develop a LCA of UO, as required in SB546. When it was drawn to a conclusion in 2013 as required by SB546, this LCA (herein referred to as the 'Phase I' LCA [(1)]), had produced a highly complex and data-dependent model.

The model was not transparent and the results were extremely sensitive to:

- changes in assumed product displacements;
- used oil composition and disposition; and
- combustion emissions.

However, CalRecycle staff was aware of several limitations in the model arising from difficulties in defining all aspects of the system, missing or questionable data and reliance on a number of assumptions. These were acknowledged by CalRecycle in Appendix A of the Used Oil Lifecycle Assessment Report to the Legislature and elsewhere. API had also identified a number of other limitations. Consequently, API commissioned, with the knowledge of CalRecycle and UCSB, further work designed to address key limitations and to more fully evaluate the implications of the uncertainties and choices of assumptions that were made in assessment of options for managing used oil. Some of the key limitations included:

- lack of data;

- resource depletion impacts not being addressed;

(1) Life Cycle Assessment of Used Oil Management in California. Pursuant to Senate Bill 546 (Lowenthal), R. Geyer et al. CalRecycle, July 29, 2013.

- lack of transparency,
- limited consideration of possible displacements;
- mass balances being omitted and some flows not tracked through adequately;
- the overstatement of difference due to the combination of negative and positive results as a result of displacement;
- complexity of modelling in the light of data limitations and uncertainty.

In the light of these limitations, interpretation of the Phase I LCA study by policy makers was difficult.

API commissioned Environmental Resources Management (ERM) to build on UCSB's work to address a number of the limitations, improve transparency, and increase the utility of the model.

The underlying objective of this work was to develop a model that more completely responded effectively to questions of used oil management posed by the SB546. The study also needed to provide a clear exploration of the tipping points in the model to show how several strong influencers can change outcomes for various possible situations. Ultimately, it is anticipated that this body of information can be used to appropriately guide future legislation in CA and elsewhere.

The study has been supported by a project stakeholder group made up of members of the API UOTF and CalRecycle, NORA (industry recycling association involved with used oil), and others. Throughout the project PD Consulting worked with ERM to provide advice and input on the design, implementation and reporting of the work in the role of independent technical consultant to API.

2.1 CRUDE OIL AND USED OIL AS FEEDSTOCKS FOR PETROLEUM PRODUCTS

It is beyond the scope of this report to provide a detailed description of the complex field of petroleum products (including those that provide lubrication) and the raw materials for producing such products (including crude oils and used oils). However, a little background information will provide context for policy makers and other readers.

There is a large range of petroleum products that are traded all over the world, and serve markets globally.

Two fundamental types of petroleum products are: fuel/energy products, and lubrication products. In the context of this LCA, it is instructive to understand that these two types of petroleum products can be derived from alternate raw materials, including: crude oils, and used oils.

A primary oil refinery uses a series of chemical and physical processes to convert the crude oil raw material into, often, both types of petroleum products (sometimes along with asphalts and chemical feed stocks.) The products from a primary oil refinery are often called "virgin" products.

A re-refinery (or reprocessing plant) uses fewer chemical and physical processes to convert a used oil raw material into, typically, a more focused/limited set of petroleum products.

There is a large range of petroleum products that serve markets globally and used oil is a minor flow in comparison with total petroleum product output. Market demand for petroleum products (fuel and lubrication) is not affected by the feedstock that is used to produce it (be it from crude oils or from collected used oil), or by the rate of collection of used oil.

Said another way, if more of the market demand for lubricants is met by rerefined used oil, and less or no fuel is produced from used oil, then more virgin fuel production is required to compensate to meet commercial demand and vice versa.

This concept is illustrated in *Figure 2.1.*

Figure 2.1 Market demand concept

	Petroleum Product Demand	
	Fuel/Energy Products	**Lubrication Products**
Scenario 1	From used oil	From crude oil
Scenario 2	From crude oil	From used oil

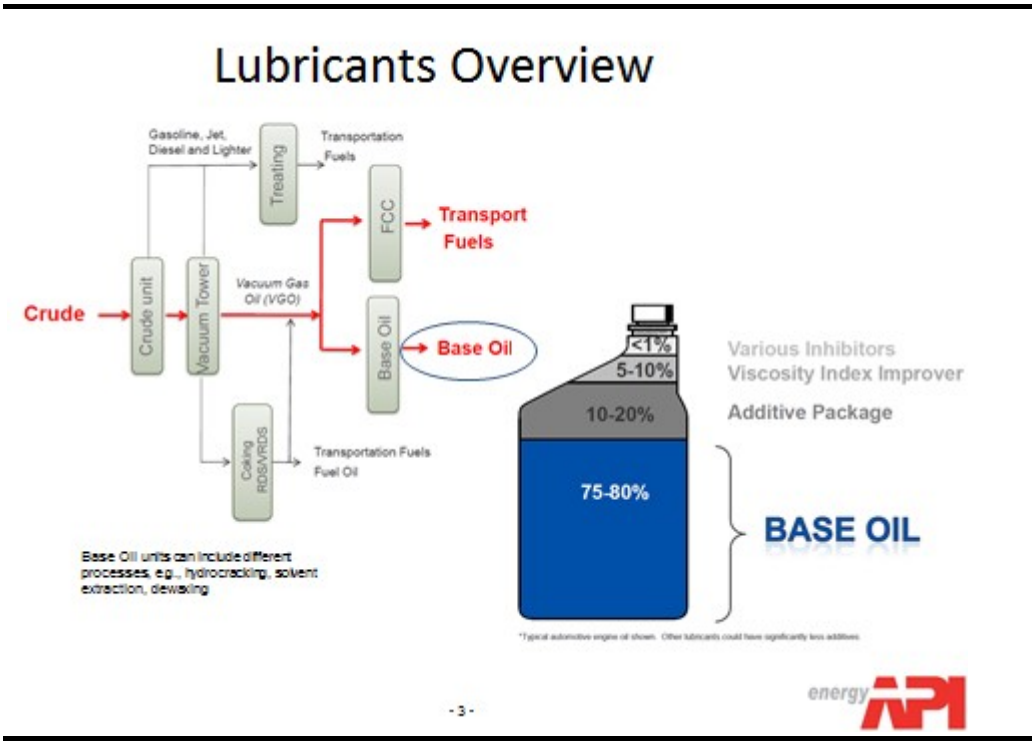
Regarding lubrication products, lubrication is an essential function in the modern world and a huge range of such products is available to serve a wide range of functions for both vehicular and industrial equipment.

It is important to remember that the technology of lubrication is evolving with new products being developed and new demands being placed upon

products. Different lubricant products may have quite different properties depending on their ultimate application. The different end-use applications will give rise to different amounts of used oil which may vary in qualities and composition.

Lubricants are typically formulated using a 'base oil' and additive package, see Figure 2.2. There are a number of different base oils that, with performance testing, can be used for different lubricant formulation purposes. At the time of writing, most base oils are derived from crude oil through primary oil refineries. As noted above, all primary oil refineries produce a range of petroleum products, typically including fuel/energy petroleum products, such as jet fuel, gasoline, diesel, and heating oil. However, not all refineries produce base oils, and different base oil refineries produce a number of grades of base oil.

Figure 2.2 ***Lubricant production overview (source API)***



Base oils are often classified by API group number. Formulators will select a particular base oil and additive package to deliver a product that meets required performance specifications, and, subject to Original Equipment Manufacturer (OEM) performance verification testing, there are many variations possible. However, there is a worldwide trend away from group I base oils to group II and increasingly to group III and IV, as applications become more demanding and higher performance is required. This trend is

stronger for automotive lubricants than for industrial and marine lubricants. (See *Table 2.1* for group definitions).

Worldwide, more production capacity is being built for base oils in the group II and above categories, and group I capacity is being reduced.

Table 2.1 API Base Oil Categories

Base Oil Category	Sulfur (%)	Saturates (%)	Viscosity Index
Group I (mineral, solvent refined)	> 0.03	< 90	80 - 120
Group II (mineral, hydrotreated)	< 0.03	> 90	80 - 120
Group III (mineral, hydrocracked)	< 0.03	> 90	> 120
Group IV (synthetic)	PAO Synthetic Lubricants		
Group V (synthetic)	All other base oils not included in Groups I, II, III or IV		

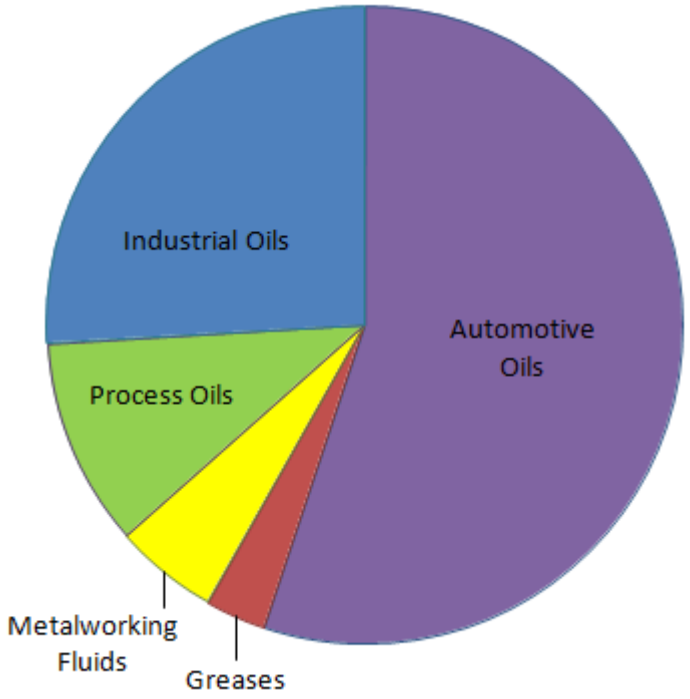
Source: API Base Oil Standards (American Petroleum Institute, 2007)

2.1.1 Lubricants and Industrial oils

There are many different terms in use to describe and classify lubricants and related products. California has legal definitions of used oil and splits of automotive/engine lubricants and industrial oils (more detail can be found here: http://www.dtsc.ca.gov/informationresources/upload/rag-usedoilforgenerators.pdf) . The exact mix of applications will vary from country to country and within a country and the volumes and types of used oil generated will depend on the particular country under consideration and should be taken into account by a policy maker.

In terms of the overall market automotive oils usually exceed industrial oils, process oils, metalworking fluids and greases as illustrated below.

Figure 2.3 Typical split of overall global market (source "Lubes 'n Greases")



2.1.2 *Used oil*

Used oil is usually defined as automotive lubricant or industrial oil that has served its purpose and is removed from equipment. Clearly, in addition to drained used oil there may be losses in use. For example:

- in internal combustion engines some oil enters the combustion chamber and is burned;
- many processes will show some degree of leakage with drips onto the ground;
- with others there is considerable loss in use – such as chain saw oil; and
- in some processes, lubricants may be totally consumed – for example in 2-stroke engines.

In this work, we are concerned with used oil generated that could be collected and recovered. Losses in use are not considered and additional work would be needed to address the environmental impacts of these losses.

Up to now, bio-based base oils (often esters derived from plant-based oils) have not formed a significant part of the market and therefore of the used oil stream. It is beyond the scope of this work to consider how used oils from bio-based base oils or vegetable oils should or could be managed. Used oil is sometimes referred to as waste oil.

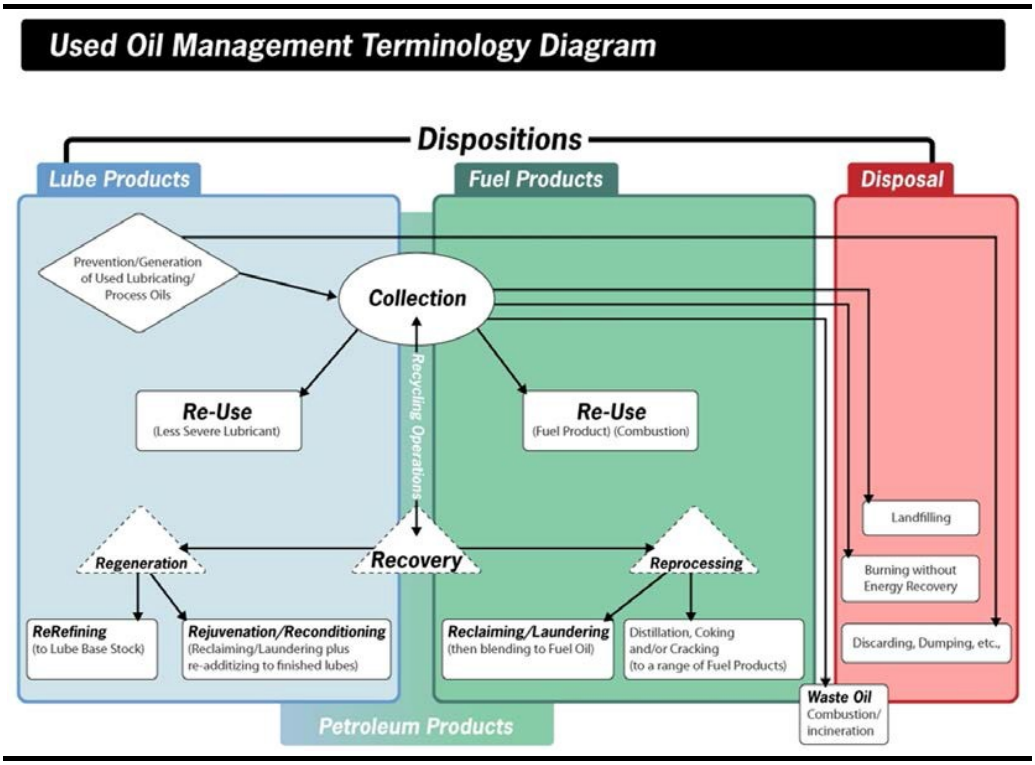
Transformer and electrical oils tend to be a specialty market and these are excluded from analysis here.

Some used oils may have become contaminated through mixing with waste streams, such that they should not be collected and processed with the used oil stream. It is important that care is taken to segregate used oil streams from waste fluids to ensure that used oil for collection and processing is not adulterated or contaminated in such a way as to render it unsuitable for re-use or recovery.

2.1.3 *Processing and recovery of used oil*

As noted earlier, and illustrated in *Figure 2.4*, used oil is a valuable resource that can be used as a raw material for a variety of petroleum product purposes.

Figure 2.4 Used Oil Management Terminology Diagram (Source: Earth911.com)



Historically, much used oil has been re-used or reprocessed for its energy content and burned as a fuel/energy petroleum product. This has happened either on site, with minimal or no reprocessing, or off-site, with some reprocessing.

In some countries used oil may be used for space heating, for example, at a vehicle repair workshop. A number of purpose-designed combustion systems are available and in use in such workshops.

The reclaiming of used oil to recovered fuel oil, sometimes known as recycled fuel oil (RFO), that is made available to the market is common across the world. The production of RFO typically involves minimal processing even given that the product would usually have to meet a set of specifications to allow it to be used in suitable processes.

In the US, the largest use of RFO, historically, was reported(1) to be as a fuel for the production of 'hot mix asphalt'. RFO may also be used in larger combustion plants such as power stations. Some RFO may be blended with conventional fuels and sold into the fuel market where this is permitted.

Other potential used oil disposition pathways include production of a distilled fuel – such as the marine diesel oil product (MDO) in California. In the United Kingdom, processed fuel oil (PFO) is made through non-distillation pre-treatment of used oil to reduce contaminants to meet required specifications.

Used oil may also be regenerated to produce a 're-refined base oil' (RRBO). A number of re-refinery processes have been developed and applied over the years using different process technologies. These range from relatively simple acid-clay processes producing, often, low quality base oils, to state of the art distillation and hydrotreating systems that consistently produce group II base oils. The base oils can be used in a range of applications and would be blended with suitable additives by formulators to meet required specifications for automotive or industrial lubricating oils.

A recent trend has been the increasing production of vacuum gas oil (VGO) from used oil. This process involves distillation. The VGO may be sold as a feedstock to a primary oil refinery or may be sold to the fuels market.

It is important to recognize that not all used oil will be suitable for all types of recovery and it is important to match the feedstock and control quality of the process feed to ensure effective performance and reduce adverse effects on process operation and product quality.

(1) U.S. Department of Energy - Office of Fossil Energy Used Oil Re-refining Study to Address Energy Policy Act of 2005 Section 1838

In this work, as in previous LCAs on used oil, a number of theoretical scenarios will be examined where all the used oil generated is assumed to be sent for recovery to a single reprocessing technology. A reader should be aware that this is a simplification in order to both highlight the environmental impact differences among the scenarios, and to illustrate potential longer-term impacts of specific regulatory regimes that could give preference to one disposition.

In reality, some fraction of the used oil stream may not be suitable for recovery by all the possible regeneration or reprocessing technologies. A realistically viable used oil management system must make allowance for environmentally sound treatment of all of the used oil generated.

2.1.4 Volumes of used oil generated

In considering a used oil management system (or making changes to an existing system), sufficient information is needed on the volumes of used oil arising.

As noted above, the amount of used oil that is generated and may be collected for reprocessing will depend on the particular market that is being considered and the mix of different processes that are served by the market. Importantly, the volumes, the mix and the quality of used oil can be expected to change over time.

CalRecycle noted that a number of trends could be identified, and forecasting volumes of used oil is difficult. We do not attempt to forecast volumes in this work, but advise a policy maker to consider future developments – such as:

- increasing quality demands in many applications (impacting on additives and base oil quality and source);
- developments in base oil production – including bio-based base oils;
- trends to longer drain intervals;
- developments in technology affecting quality and quantity of generated used oil;
- industrial filtration systems that extend the usable life of the original fresh oil; and
- other developments in the lubrication technology and chemistry that will affect composition.

Exact volumes of used oil generated are not known. So estimates have to be made. These estimates are usually based on sales of automotive lubricants and industrial oils and estimates of losses in use – the difference being generated used oil. Information on sales and specific applications is often incomplete and estimates are necessarily uncertain.

This difference approach was taken in Phase I. The economic consultant to CalRecycle, ICF Incorporated, L.L.C (ICF), and the LCA consultant, UCSB, drew upon work by Kline (2012) for sales and uses and likely used oil generation. The generation of used oil was compared against estimates of used oil collected and processed (drawn from a materials flow analysis carried out by UCSB) to give an estimate of uncollected or informally managed used oil in California.

Exact information on the volumes of used oil generated and collected is not needed to facilitate a comparative evaluation of the lifecycle impacts attributable to increasing collection rates and/or different dispositions of used oil.

Therefore, no further analysis is made here of these estimates from the Phase I study. However, it is important to recognize the uncertainty inherent in the estimates. The assessment of policies to change rates of collection should be informed by consistent and reliable estimates of the volumes and fates of used oil.

2.1.5 Treatment of used oil in California

For this analysis, we used the information gathered by UCSB for the treatment of used oil in California. As above, the exact volumes are less important than the trends and the effects of assuming changes in treatment.

It is important to note that while a base year of 2010 was selected, there has been considerable variation in the flows of used oil and the mix of treatments in California over the years. The UCSB work did not explicitly assess the effect of these inherent variations (uncertainty) in either the total of used oil generated nor the disposition (mix of treatments) applied, although this would be useful information to understand the effect of proposed policy changes against the background of changes that happen in the system, regardless of policy changes.

2.1.6 Application of the used oil LCA beyond California

The work done by UCSB focused on the used oil generated in California. Used oil is generated in all countries of the world and it is inevitable that

readers and policy makers from other areas and countries will be interested in the results of this analysis.

To this end, we have considered those aspects of a used oil LCA that may be generally applied and tried to distinguish aspects that are specific to this analysis and to the situation in California.

When looking beyond California, it is important to bear in mind that the mix of processes generating used oil may sometimes be very different and that the quantities and composition of the used oil may therefore vary considerably compared to California in 2010. Similarly, the collection systems may be quite different in both structure and detail.

Important differences may be seen in technologies for recovery of used oil and using used-oil derived petroleum products. California has stringent environmental standards and comprehensive permitting designed to ensure that environmental releases and impacts are minimized and effectively controlled. So processing and use is likely to be with highly controlled, well operated plants with high levels of pollution control.

The informal management of used oil is another area that is likely to be a source of significant differences among geographies and result in significant variation in impacts. When addressing informal management, it is important to consider differences associated with the following: (1) dumping or draining of used oil directly onto the ground or into water courses, (2) the disposal of used oil into the regular solid waste stream (eg regulated landfills), and (3) on-site combustion of used oil (eg for space heating). Put simply, used oil that is disposed in a controlled landfill can be expected to have lower impacts than used oil dumped on the ground, or dumped into water courses and drains.

2.1.7 Previous studies

In addition to the Phase I study, there have been a number of LCA studies that have addressed used oil management and the benefits of re-refining and reprocessing as fuel. A selection is summarized in *Table 2.2.*

These studies, despite their limitations and differences, highlight the significance of: displaced product systems; used oil composition; and levels of pollution controls.

Table 2.2 Summary of previous studies

Title	Authors	Year	Scope	Conclusions
Ecological and energetic assessment of re-refining used oils to base oils: Substitution of primarily produced base oils including semi-synthetic and synthetic compounds.	Institute for Energy and Environmental Research (IFEU), Heidelberg	2005	Investigation of the relationship between impacts of virgin base oil production in comparison to re-refining of used oil, and of combustion in comparison to re-refining of used oil. The scope was "re-refinable used oil" in Europe (~25% of the total generated). The study appraised five re- refining technologies. Virgin lubricant base oil production was a mix of polyalphaolefin (PAO) and base oil produced by conventional solvent extraction route. The report has been peer reviewed and is transparent in its documentation of data and modelling approaches.	Re-refining of otherwise uncollected used oil is favorable over virgin lubricant base oil production (i.e. impacts are lower to produce base oil from used oil that is free of burden). Displacement of PAO significantly influences the advantage of re- refining. Results comparing RFO versus re- refining showed each could be better and depended strongly on fuel type displaced.
Life Cycle Assessment of a waste lubricant oil management system Int J Life Cycle Assess (2013)	Pires, A. & Martinho, G.	2013	Comparison of 15 management alternatives and alternative systems in use in Portugal. No primary data were collected. An 'avoided burden' approach taken. Virgin base oil, pet coke in cement kilns and electricity displacement were considered.	Both re-refining and energy recovery as a fuel were considered to be good recovery options depending on impact reviewed. Results highly sensitive to substitution. Re-refining is seen as preferable by reference to the Waste Framework Directive hierarchy.
Used lubricating oil management options based on life cycle thinking - Resources, Conservation and Recycling 53 (2009) 294-299	Vorapot Kanokkantapong et al.	2009	Evaluation of six management scenarios in Thailand for the treatment of collected used lubricating oil for their environmental impacts based on a life cycle approach. Acid clay and solvent extraction are the treatment processes for the recovery of recycled used oil. The other four scenarios were energy recovery: small boiler, vaporizing burner boiler, atomizing burner boiler, and cement kiln. Only	Preference for the acid clay re-refining process as it only produces high environmental impact for acidification. Cement kiln combustion leads to lowest impact for global warming potential and heavy metals, due to complete combustion of organic compounds together with capture of heavy metals in mortar during cement reaction. Note that limited scope and impact categories do not fully reflect the issues that need to be assessed.

Title	Authors	Year	Scope	Conclusions
			four impacts appraised, limited release points and transparency.	
Environmental Assessment of Used Oil Management methods, Environmental Science & Technology vol. 38, NO.2, 2004	Bob Boughton, Arpad Horvath	2004	Assessment of comparative impacts of three alternative management methods: Re-refining to produce lube oil base stock, distillation of used oil to produce MDO and burning untreated used oil/RFO with no pollution controls. No impacts from asphalt flux by-product.	Re-refining and distillation are significantly better management practices than combustion of used oil as fuel with no pollution controls. Highlighted zinc as major contributor. Used oil composition is a key driver.
LCA of a spent lube oil re- refining process. Computer Aided Chemical Engineering 21 · December 2006	Tom Kalnes et al.	2006	Comparison of the HyLube™ re-refining process in the European market with the impacts of burning the used oil in cement kilns. Avoided burden approach taken and substitution for coal, heavy fuel oil (HFO) and natural gas were considered.	The greatest benefit for climate change is for the case of used oil combustion with coal displacement. The next best is re-refining, followed by fuel oil displacement. The least desirable is natural gas displacement. Re-refining shown to deliver larger benefits for acidification and resource depletion.

2.1.8 *Closed loop versus open loop recycling*

As part of their work on the used oil LCA, UCSB assessed the relative merits of 'open' and 'closed' loop recycling(1). Their analysis shows that, provided the demand for the secondary resource equals or exceeds the supply, open and closed loop recycling lead to the "same amount of primary resource consumption" and "In summary, we (UCSB) conclude that closed loop recycling has no intrinsic higher environmental benefit than open loop recycling."

The relative environmental performance then depends on the environmental performance of the alternative recovery technologies and use options for the petroleum products produced.

The UCSB team published and developed this analysis in the 2015 paper 'Common Misconceptions about Recycling'(2) .

Their analysis shows that, where products of reprocessing or re-refining do not exceed the market demand for petroleum products, there is no fundamental environmental benefit from simply recycling waste back into the same product. The actual comparative environmental impact will depend on the processes, yields and pollution controls applied to each option. In the case of used oil, there is no inherent or automatic benefit to recovery to base oil as compared to VGO or fuel products; each processing system and use should be compared to evaluate relative impacts. Of course, if the volumes of recovered petroleum products exceed the market demand, then this must be reflected in the analysis.

The markets for base oil, VGO and fuel products generally far exceed the supplies of these products that can be satisfied through processing used oil. However, if a market is constrained to a small locality, this may not be the case. Usually, each of these products can be readily traded, both nationally and internationally, accessing much larger markets.

Because of unavoidable losses, consumption in use, incomplete collection of used automotive lubricants and industrial oils, and re-refining yields of RRBO less than 100%, a large part of the market demand for base oil will always be satisfied through production of virgin base oil from a primary crude oil refinery.

2.2 *BUILDING ON PHASE I*

This LCA prepared for the API (hereafter referred to as the 'Phase II' LCA) builds on the work previously performed in Phase I. In order to achieve as much comparability as possible, the intention was to develop further the

(1) Appendix E, Life Cycle Assessment of Used Oil Management In California, contractor report University of Santa Barbara, July 29, 2013
(2) R Geyer et al, Common Misconceptions about Recycling, Journal of Industrial Ecology, October 2015

Phase I model in order to address limitations in the work and to increase the functionality of the model.

UCSB developed the Phase I model using a combination of publicly available information and proprietary data gathered from re-refiners and re-processors with a focus on CA. The latter are subject to non-disclosure agreements, and therefore cannot be released to the public. For this reason, UCSB generated a 'Public Model' in the GaBi LCA software where proprietary data were aggregated and slightly modified with the intention of preventing third parties from being able to reverse-engineer the model and obtain confidential operational data.

After receiving the Phase I Public Model, ERM performed a series of analyses to determine what differences there might be between the impact assessment results obtained with the Public Model and the results obtained with the original model as published in the Phase I LCA report(1) .

Set up with identical boundary conditions and parameters, ERM observed deviation in the results across all impact categories (irreproducible outputs were encountered when using the UCSB LCA model to run the same scenarios with the same input data), which triggered an investigation by both ERM and UCSB on behalf of CalRecycle.

ERM determined that the source of the differences was primarily due to two factors:

- *first*, the GaBi v6 database (used both by UCSB in Phase I of the LCA, and by ERM in Phase II of the LCA) was updated by PE International from Service Pack 22 to Service Pack 24 in December 2013(2) , resulting in a number of changes in flows, environmental quantities, impact characterization factors, etc; and

- *second*, UCSB had modified the re-refining modelling to protect proprietary information, which caused a certain deviation in overall results.

The larger of the two effects was due to the database update. This resulted in differences of 20+% in some calculated results. It is important for a reader of any life cycle report to be aware that simple things such as a model update can result in apparently very significant changes in calculated results. Since the update is not transparent (a user does not know what data have been updated or how), great care needs to be exercised in interpreting results that may be from different models or different versions of the same model.

(1) Life Cycle Assessment of Used Oil Management in California. Pursuant to Senate Bill 546 (Lowenthal). CalRecycle, July 29, 2013.
(2) Currently service pack 29 http://www.gabi-software.com/fileadmin/GaBi_Databases/GaBi7.1_changelog_SP29_jan2016.pdf

Other problems were encountered with the public GaBi model. In particular, ERM observed that the use of the global parameter functionality in GaBi resulted in unstable results. If global input parameters were modified using a global parameterized approach (for example to move from one scenario to another) and then returned to the original input values, the output results did not go back to the same output values. This suggests that great care needs to be taken when using the GaBi software for complex models with a global parameterized approach. Of course, it is not possible to tell whether the same problem affected the results generated in the Phase I project.

In addition, having access to the public model allowed access and inspection of more data which were hidden from a reader of the Phase I LCA public report. A key discovery was that there was a serious problem with the water balance in the public (and, we assume, the original) model. As noted, there was not complete information available on the composition of the materials handled at each stage of the used oil management system and reflected in the model. Assumptions had to be made about composition and water content.

Unfortunately, the assumed water content can have a very significant impact on the data and on calculated impacts, the largest source of error being the inconsistent treatment of volume received by each process and where processing burdens are directly driven by volume received.

The original model could not be consistently balanced for water. The likely cause of the problem was the use of confounding datasets that were based on dry used oil (eg process yields) and then applied to wet used oil volumes.

There was no clear and consistent pattern, but the upshot appears to be that some processes in the model were producing more product than is possible and others less than was realistic. The resulting bias in the Phase I model was found to cause variation of more than 20% for some impact indicators as a result of the combination of the avoided burden approach and processing requirements.

2.3 DEVELOPMENT OF THE MODEL

The following issues were addressed with model changes where feasible.

2.3.1 Structure

In Phase II, we moved to a system expansion model that accommodated the functionality of the products produced by each system and ensured that the function delivered by each system was constant and comparable. This accommodation differed from the Phase I approach, which attributed an avoided burden for each product output from each system. The primary reason to do this is one of presentation, so as to avoid having negative numbers in the results (which have previously been interpreted as processes or scenarios resulting in environmental impacts less than zero), see *Figure 2.5*.

Negative numbers and the potential for a zero value are conceptually challenging and make interpretation difficult, particularly for those key users of the report who are not well schooled in the nuances of LCAs. This is especially true when considering a sector such as management of used oil, which must have an environmental impact, albeit the impact might be less than an alternate waste management or primary production systems.

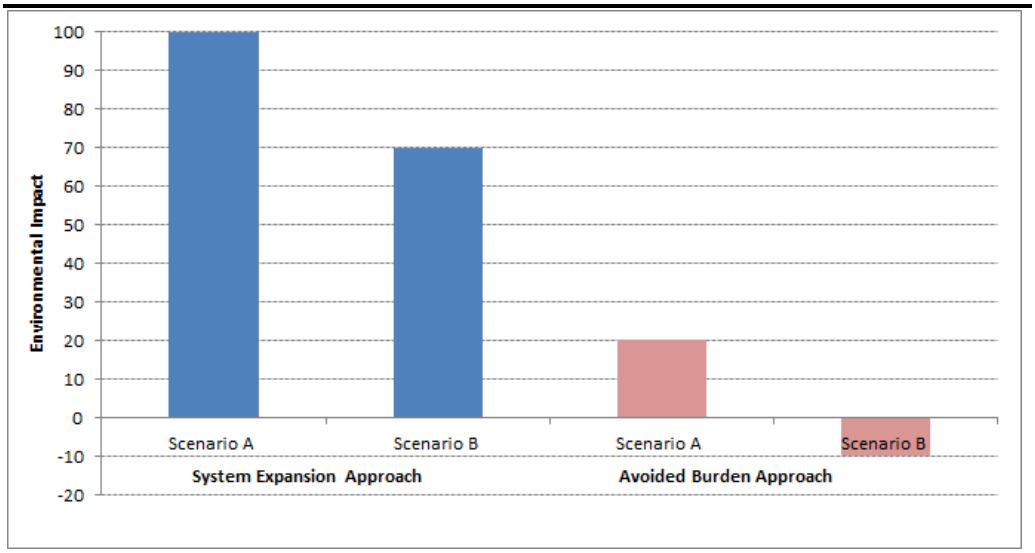
This approach avoids giving: (a) the mis-perception that increasing the quantity of used oil generated is beneficial for the environment, and (b) the erroneous implication that efforts to reduce such used oil generation would be detrimental.

That said, the system expansion approach and the inclusion of the broad range of functions in each scenario does mean that the impact contribution from management processes which operate on used oil will be placed in the context of a total impact including the other affected functions.

The context relates to the full portion of the fuel and lubricant product supply system that can be affected by the efficacy (collection rate) and disposition choices (eg re-refining to lubricants versus reprocessing to fuels) of used oil management.

However, there is the consequence that, the relative contribution of impacts directly from processes managing used oil is reduced.

Figure 2.5 ***Illustration of the system expansion (product supply) and avoided burden approaches***



2.3.2 *Allowing different burdens for processing options*

In Phase I, burdens were fixed for used oil processing and treated as a black box, i.e. the data were obscured from a reader by being rolled up (so that process emissions were combined with the burdens for the upstream production of all the electricity, gas and chemicals required). In practice, the

facilities processing used oil can have a range of burdens reflecting different process technologies, different levels of pollution control, different yields and different fates for by-products and wastes.

It was not possible in this work to investigate the full range of variation for processing facilities. Future work should take care to ensure that the data reflect the range appropriate for the instance being studied (i.e. reflecting the actual plant, process and pollution controls intended, be they good or bad).

2.3.3 *Allowing different burdens for production of virgin products*

Just as different used oil re-processing facilities will have a range of configurations and, therefore, a range of burdens, the same is true for the production of virgin fuel and lubricant petroleum products from primary (virgin) crude oil refineries. Usually, the burdens associated with 'displaced' products are fixed in any given LCA study. This masks very considerable variation that may be met in practice.

This is particularly significant for a policy maker, since neither the actual displaced product nor the facility that made it may be known (and they may likely change over time in ways that cannot be controlled). For internationally traded commodities such as fuel and lubricant petroleum products, this is particularly important, since displaced product may come from distant refineries that have different pollution controls, process configurations and available crude oil slates.

Unfortunately, it was not possible to fully account for these variations in this work. The only range evaluated, in Phase II, was that represented by a comparison of US versus California burden data for products.

Clearly, a much wider range should be applied to account for this inherent uncertainty.

2.3.4 *Ensuring that fates of used oil and products were considered consistently and completely*

In order to complete a fair comparison of options for treatment of used oil, it is important that each element of the model is handled consistently.

Two significant problems were apparent in the Phase I model, in this regard. Firstly, some flows were not assessed at all. For example, although contaminants released directly to air via combustion were assessed, those captured by pollution control devices were not. In Phase II, we have tracked contaminants (as far as reasonably possible) through to final fate. As an example, for contaminants captured by pollution control equipment, their fate in landfill has been included in Phase II.

Distillation of used oil tends to concentrate the contaminants in the heavy fraction – referred to in this work as vacuum tower asphalt extender (VTAE)(1). UCSB assumed that this was always used in road building and that the contaminants were fully sequestered in these roads. Thus, they assumed that there were no environmental impacts. We are aware that some US states have been concerned with the use of VTAE and restrictions have been discussed. In order to understand the potential impacts from these contaminants, this was not disregarded and Phase II tested the effect of burning these heavy streams (a practice that may occur in some places at least some of the time).

It was also clear that there was no consistent balancing across all processes. In some, contaminants could not be accounted for in process outputs. In phase II, we worked to ensure that, as far as the data allow, important contaminants were tracked and mass balances completed across process steps.

It was not possible to ensure that datasets for every process were exactly comparable. LCA inventory datasets have very long lists of pollutants and these are not consistent (so a pollutant may be reported for one process, but no data are available for another). This is also the case with some datasets here such as combustion processes.

There are great difficulties in ensuring completely consistent treatment of some pollutants – data are lacking on many organic emissions from most processes for example.

2.3.5 Uncertainty Assessment

UCSB ran many sensitivity analyses and presented the findings. In Phase II, we have done the same.

An important difference in this work is that we try to separate the effects of uncertainty resulting from those aspects that a policy maker cannot control.

We believe that it is important that a policy maker has a clear understanding of:

(a) the degree to which the findings of an LCA are reliable and robust, and

(b) how impacts that might result from deliberate changes imposed on a system (eg new regulations, resulting in changes in disposition) compare against inherent uncertainty and variation resulting from factors over which no control can be exercised.

For example, it is not possible for a policy maker to determine exactly what products will be displaced by products from used oil processing. Re-refined base oil may displace group I or group II virgin base oil that is produced

(1) This follows the NORA notation

locally or in far off primary oil refineries. Fuel products made from used oil raw materials may have a wide range of possible applications at home and abroad and may displace a wide range of alternative fuels, through the use of existing equipment able to operate with the fuels or by influencing equipment changes and fuel switching.

UCSB in Phase I clearly illustrated that the assumed displacements for fuel could change the rank order of processes environmental impacts. But for their baseline assessment and future projections, Phase I fixed displacements and thereby obscured a key uncertainty.

2.3.6 Considering a wider range of displacements

In this Phase II work, we have tried to illustrate the effects of allowing a wider range of displacements. UCSB in Phase I examined the effect of different fuel displacements for RFO use, but did not consider alternative displacements for other products such as base oil and MDO.

2.3.7 Updating composition data

In addition to addressing the issue of water balance errors noted previously, in Phase II we also updated composition data where possible.

CalRecycle sponsored a program of detailed chemical analysis of a large number of samples relevant to used oil management including used oil (automotive lubes, industrial oils, mixed oils), used-oil derived products (MDO, RFO) and by-products (VTAE). These data were not fully available or used by UCSB in Phase I.

The most significant changes with respect to the original model were in assumed average used oil composition. In Phase I, UCSB had used commercial vehicle lubricant with apparently high additive/metals content to characterize the total used oil stream. Thus, we believe that CalReycle's more recent, broader-based data set (Summit labs) provides a more representative snapshot and gives a better data set for typical used oil in California in 2010 – and in other jurisdictions.

Of course, it is important to note that average composition data used for the model does not imply that this is the composition of any specific batch of used oil, nor that it remains consistent over time and certainly not between places. It is important to review composition data and to use the most appropriate data for the study in question.

It is unfortunate that we still do not have comparably detailed composition data on by-product streams (eg other fuel streams from used oil distillation) or on virgin fuels.

2.3.8 *Combustion Model*

The emissions from the combustion of virgin and recovered fuel petroleum products are identified in Phase I and in previous LCAs to be a significant driver of impact. The combustion model developed in Phase I is based on combustion data derived from different data sources. These references include the MACT (Maximum achievable control technology) database, which reports combustion of a variety of fuels from a large number of facilities in the US, as well as a study of the combustion of used oil in a small vaporizing space heater by Lubrizol (referenced in Phase I as P. Dyke, 2007).

The changes made in this Phase II study are essentially to remove unintended bias that may be introduced between similar fuels as a result of inconsistent data sets (eg using combustion emissions data from a variety of combustion sources equipped with unknown levels of pollution control and operated on a fuel of unknown composition). This Phase II study has addressed the issue by differentiating between combustion emissions that are directly related to process and pollution control (eg carbon monoxide) and those that will vary dependent on a combination of composition of the fuel and pollution control.

In addition, as noted earlier, we have addressed a perceived shortcoming of Phase I, i.e., failure to address the fate of those contaminants not released to air via combustion. In this Phase II work, we have tracked contaminants (as far as reasonably possible) through to final fate. So for contaminants captured by pollution controls, their fate in landfill has been included.

2.3.9 *Calorific Values*

The calorific value (CV) applied to each fuel (virgin and those derived from used oil) is an important parameter in the assessment (affecting the amounts of fuels required to satisfy the overall demand and in turn affecting calculated emissions). In this Phase II work, the main difference from Phase I was updating the lower heating value used for dry RFO to 43 MJ/kg from the 41 MJ/kg used by UCSB. This is justified based on posing the question why a CV lower than distillate fuel oil would be appropriate for a dry processed fuel oil and, when considering, heating values for used engine oils of 44.6-45.6 MJ/kg (Yahaya and Diso, 2012) are reported and the properties stated by producers such as OSS Group, which report a typical NCV of 43.5 for its Gen3 PFO, and OSL which reports NET CV greater than 42MJ/kg for its PFO products.

2.3.10 *Uncollected oil model*

The inclusion by UCSB of the impacts of uncollected used oil in the LCA, where the magnitude of the uncollected used oil flows are assessed to equal the difference between estimated collectable used oil and the quantity of oil reported on manifests, marked a positive and major step forward in considering impacts from used oil management. However, the model developed was very complex and, in trying to focus on the specific situation in

California, it missed key aspects of impacts of illegal or 'informal' management of used oil.

It is impossible to get a fully accurate picture of how used oil is managed illegally in any jurisdiction. However, we know enough to make reasonable assumptions and estimates of how used oil may be illegally disposed.

UCSB attempted to differentiate between releases to freshwater and coastal water in its model using complex analysis. In examining the Phase I model, we noticed errors where flows disappeared and where there was inconsistent treatment of some elements of the model. The net result of trying to make the model too exact was that it missed useful information and gave a false impression of exactness.

We simplified the model, kept the used oil amounts going to landfill, combustion, and improper disposal at the percentages used by UCSB, ensured that all flows were included, and removed the benefit given by UCSB for used oil combusted informally. We believe that the value of this Phase II model is to show reasonable illustrations of potential impacts and to establish a range through looking at the differences from assuming the used oil is handled in different ways (eg disposal to freshwater rather than to sea water).

Although it is arguable that illegal burning of used oil for, say, space-heating will obviate the need to produce an equivalent amount of fuel product, we believe that assuming that a displacement credit should be applied to all used oil burned illegally a) is unlikely in practice; and b) potentially gives a misleading impression of the value of such illegal disposal. We know that, in some jurisdictions, on-site use of used oil for space heating in workshops is common (and legal). However, it was repeatedly stated by CalRecycle that in California this use is uncommon or absent. It is also probable that used oil will be added to wastes and burned as a method of disposal.

We believe that this modified uncollected used oil model provides useful information on the relative potential impacts of illegal disposal of used oil, illustrates how those impacts may vary depending on the exact means of disposal, and can be regarded as more generally applicable compared to the previous Phase I model, that was, in and of itself, a notable step forward relative to prior LCAs in the used oil domain.

2.3.11 Export

In Phase I, the used oil "exported" from California was calculated at 13.2%, based on a material flow analysis (MFA) of used oil generated in the state, using hazardous waste haulage data over the MFA period. The amount of oil contained in each shipment of waste was estimated based on the waste code. To simplify the model, we have not separately distinguished used oil exported from California. Instead, we assign the assumed fate of exported used oil to the corresponding treatment processes within California. It is important to be

aware that treatment processes outside of California could differ from those included in this study. This is therefore a limitation of the model.

2.3.12 Abiotic depletion

The impact category, resource depletion, was excluded from the Phase I study. Since a good deal of the discussion about Sustainability in general, and specifically treatment of used oil centers on possible effects on resource use and conservation, we added consideration of abiotic depletion to the impact categories assessed.

A reader should be aware that assessing abiotic resource depletion is challenging and there is no universally accepted way of characterizing the results appropriately. The indicators of abiotic depletion should be read with an understanding of what they do.

A reader should also note the work in Phase I that clearly shows that there is no inherent advantage for closed loop (material) recycling (e.g., automotive or industrial lubricant use) as compared to open loop (e.g., energy product use) when there is adequate demand for all of those products.

Three impact methods produced by third parties and commonly applied have been used in Phase II to account for abiotic depletion:

- Fossil fuel depletion (TRACI);
- Abiotic depletion, elements (CML); and
- Abiotic depletion, fossil fuels (CML).

Method 1 estimates the increased effort (surplus energy expressed in MJ of fossil fuel depletion) likely to be required to extract future resources. Method 1 only appraises fossil fuels e.g., coal, natural gas and oil reserves.

Method 2 uses relative scarcity of mineral reserves (expressed in antimony equivalent depletion) based on estimates of ultimate reserves and annual extraction. Method 2 appraises metal and non-metal element resources that are extracted through mining operations (excludes fossil fuels e.g. coal, natural gas and oil reserves).

Method 3 estimates energy of resources extracted from the ground (expressed in MJ of fossil fuel depletion), and does not take account of scarcity (available reserves). Method 3 only appraises fossil fuels e.g. coal, natural gas and oil reserves.

Further detail is provided in the impact assessment section.

2.3.13 VTAE

A major product from the re-refining of used oil to lubricant base oils, from distillation to VGO, and from reprocessing to fuel petroleum products (such

as MDO) is the heavy residue from distillation, known as vacuum tower asphalt extender (VTAE), sometimes referred to as asphalt or asphalt extender.

VTAE is not the same as asphalt that is produced by primary crude oil refineries. It tends to be a heavy, dark-colored oil stream, in some respects to be more akin to a heavy fuel oil fraction than to asphalt. That said, VTAE in the US may be used in road asphalt or in roof shingle production. We understand that the product can modify the physical properties of virgin asphalt.

In Phase I, UCSB treated VTAE as substituting on a straight mass basis for virgin asphalt from primary crude oil refineries. It might be argued that alternative substitutions should be considered – for example as a substitute for a property modifying additive.

VTAE may be expected to contain the bulk of contaminants (certainly the metals) in processed used oil. The fate of this stream then will affect the overall environmental impacts of the process.

UCSB assumed no releases to the environment. This is both conservative (there will be some release) and inconsistent with other model elements (eg the landfill model). Data on the long term fate of metals in VTAE used in road construction or roof shingles both in use and as a result of disposal at end of life are not available.

In some instances, VTAE or similar streams from used oil regeneration or reprocessing may be burned for energy recovery. Clearly, the impacts of this will depend on the process and pollution controls (as for other combustion processes). We examine this to illustrate the effect on the overall analysis.

2.3.14 Model development

Model development by ERM can be summarized as follows:

- removal of displacement and use of system expansion to ensure functional equivalence;
- replacement of proprietary regeneration/re-refining and reprocessing data; and
- updating used oil composition.

As a result of the software updates, data changes, model changes and correcting the water balance, results from the Phase I and Phase II studies cannot be compared directly. However, the interpretation and analyses provided can be combined to provide greater insight and understanding.

The goal of this study is:

To generate a quantitative environmental profile of the used oil management system for all used oil generated in California in 2010 and to analyze the effects of changes in collection rate and disposition on the profile.

This is consistent with the goal of the Phase I study "The goal of this LCA was to generate a quantitative environmental profile of the management system for all of the used oil generated in CA".

CA Senate Bill 546 required the used oil LCA to provide a basis for statutory recommendations to *"promote increased collection and responsible management of used oil"*. Therefore, this LCA should help to address the following questions:

- what are the environmental impacts if policy changes resulted in different used oil collection rates; and

- what are the environmental impacts if policy changes resulted in differing disposition mixes and 'responsible management of UO' through recovery as re-refined base oil (RRBO), fuel oil (RFO), vacuum gas oil (VGO) and/or marine distillate oil (MDO)?

Although the Phase II goal is aligned with that of Phase I, the modelling approach and execution of this Phase II LCA allows the questions above to be addressed more directly.

The target audiences for this study are a number of external stakeholders directly or indirectly affected by SB546 and used oil management. These include: legislators; CalRecycle and other regulators worldwide; interested Non-Governmental Organizations; as well as companies or others involved in Petroleum Product markets and/or used oil management in CA or elsewhere as represented by API, the National Oil Recyclers Association (NORA); and the Western States Petroleum Association (WSPA).

Phase II does not include an economic appraisal of the options, or consider capacity shortfalls and potential infrastructure needs.

It is anticipated that this Phase II study will be made available to third parties. As a result, this report has been prepared in accordance with ISO 14040 and ISO 14044 guidelines.

A critical review by a panel of independent experts has been undertaken consistent with these ISO guidelines.

4.1 PRODUCT SYSTEM

Consistent with the Phase I UCSB work, the product system under investigation in this Phase II study is the formal and informal management of all used automotive lubricating oils and industrial lubricating oils (used oil, or UO) generated in CA during a single calendar year. The informal management includes dumping, landfilling and on-site combustion. The formal management includes the main routes of formal disposal (hazardous waste incineration and hazardous waste landfill of used oil unsuitable for recovery) as well re-refining of used oil as a feedstock to RRBO and various types of re-use or reprocessing of used oil as a raw material to fuel products: RFO, MDO, and VGO.

In Phase II, we have not specifically addressed recovery of used oil from oily waters, although in Phase I, UCSB included a process which we understand may be an attempt to reflect the preprocessing of higher water content streams at the MDO production facility. The preprocessing component of the model was left unchanged in the baseline scenario. Rejuvenation of used industrial oils and handling, treatment and any reuse of transformer oil were ignored, as was the option of employing used oil as a raw material feed stock in a primary crude oil refinery.

Fuel products generated are consumed and, through system expansion, virgin production to ensure constant product supply to the commercial market and, thus, comparable system function is included.

4.1.1 *Used oil generated in CA in 2010*

In Phase I, ICF estimated the total volume of used oil generated in CA during each single calendar year from 2005 to 2030. At the time that the work(1) was carried out, sales data for lubricants were available for 2005 to 2011. From 2011 to 2030, projections were made. ICF used work by Kline to assign the different uses of automotive lubricants, to estimate volumes and assume uses of industrial oils as well as estimate the generation of used oil in each segment. These estimates were used to 'calibrate' estimates for used oil collected.

California has comparatively good information on the collection and hauling of used oil. However, the information is not of sufficient quality reliably to analyze the split between used oil derived from automotive lubricant versus from industrial oils (the distinction between automotive and industrial oils/lubricants as defined by the California legal code is not fully consistent with more typical Petroleum Products industry nomenclature).

(1) Final Report on Direct Impacts Model (DIM). Analysis of the California Used Oil Market. CalRecycle. July 26, 2013.

UCSB considered three waste streams – defined by CA Waste Codes 221, 222 and 223 (described in *Table 4.1*) and assigned an assumed water content to each. As described earlier, the handling of water within the Phase I LCA model was flawed and the assumptions made influenced the model and the results reported.

In addition to the assumed water content of the different waste codes (see *Table 4.1*) the work of ICF/UCSB also assumed water contents for used oil derived from automotive lubricants (5%) and industrial oils (30%).

Table 4.1 CA Waste Codes related to Used Oil

Code	Description	Mass in 2011	Assumed Oil Content
221	Waste oil and mixed oil	480,000 metric tons	95%
222	Oil/water separation sludge	21,000 metric tons	50%
223	Unspecified oil-containing waste	75,000 metric tons	15% / 65%

Source: Phase I LCA report. 2010 values were used for the baseline scenario.

This study uses the Phase I 2010 baseline scenario of 434.9 thousand metric tonnes of dry (collectable used oil) generated in 2010 as a starting point for used oil arising.

For reference, *Table 4.2* presents the dispositions in the Phase I report's 2010 baseline scenario used oil.

Table 4.2 Used oil arisings (Phase I)

Phase I used oil arisings and baseline disposition	Used oil Mass (Dry million kg)	Used oil Mass (Wet million kg)
Collectable dry used oil	435	521*
Collected UO water content		64
Recycled oil reprocessed	296*	354
UO to informal management	112	134*
UO dumped to soil	49	59*
UO dumped to water	49	59*
UO landfilled	4	5*
UO to incineration	0.5	1*
UO to onsite combustion	11	13*
Waste to disposal	27	32*

Note – data are sourced from Table 26 and Table 17 in Phase I report. The 354 million kg of used oil described as 'Recycled oil Reprocessed' in the Phase I report is assumed to be a wet oil.
**ERM estimates based on back-calculated Phase I moisture content of 16.5%*

For a complete description of the method applied to the materials flow analysis, refer to Appendix A in the Phase I LCA Report.

In this Phase II work, we have simply used the ICF/UCSB Phase I data for volumes of dry used oil that are generated and ensured that water is tracked carefully through the system. No allowance is made for the effect of processing or handling more or less water (i.e. no differences can be derived here for the effect of taking used oil with more or less water).

In practice, processors will have to manage the water content and ensure that it is properly managed – they are likely to want to minimize water in used oil that is accepted for processing. Where high water content is encountered, this is likely to affect whether a consignment (or source) of used oil can be accepted and how it will be treated.

4.1.2 Functional unit

The function of the used oil product system is the management of all used oil generated in CA during a single calendar year. This function is the same as that defined in Phase I and includes formal and informal management routes for used oil.

The functional unit defined in Phase I remains the same in this Phase II LCA:

The formal and informal management of all used oil generated in CA during one calendar year

As with Phase I, the calendar year 2010 has been established as the baseline scenario for comparison with future scenarios.

However, in order to overcome the problems noted in Section 2, Phase II used system expansion rather than avoided burden.

To ensure functional equivalence among scenarios, it is necessary to accommodate the possible functions delivered by the modelled used oil management system in fixed amounts of each of the products. In this case these include:

- provision of fuel energy (liquid petroleum product fuels in the baseline, with others considered individually);
- provision of vacuum tower asphalt extender (asphalt flux = VTAE);
- provision of vacuum gas oil (VGO); and
- provision of lubricant base oils.

The functions are quantified on the basis of managing 4.35 E+08 kg (435,000 metric tons) of dry used oil and delivering:

- Fuel energy MJ 1.87E+10 MJ
- Lube base oils 3.48E+08 kg
- VTAE 1.47E+08 kg
- VGO feedstock 3.83E+08 kg

All scenarios will deliver this functionality through a combination of virgin petroleum products from primary crude oil refinery production and used oil management which utilizes used oil as a raw material to make petroleum products. This concept is referred to hereafter as the constant commercial market output approach.

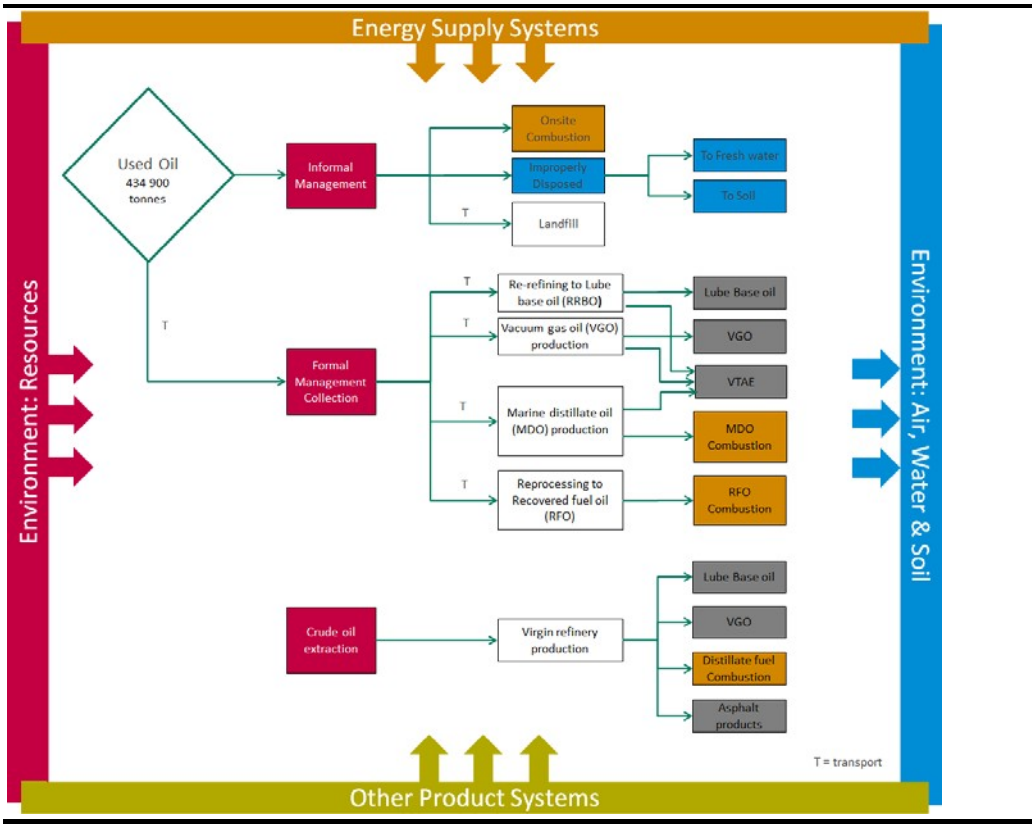
These scenarios reflect the functionality that can potentially be delivered by the used oil management routes. *The quantity of each product is set at the maximum amount of product that can be generated by the direct used oil management system (e.g. re-refining or reprocessing) when considering the most extreme scenarios and range of yields*. The fuel energy quantity is defined by the lower heating value of the total amount of dry used oil at 43 MJ/kg. In every scenario the maximum of any product cannot be exceeded by product made directly from used oil alone. In this way, a full appreciation of the entire portion of the product system that could be affected in the commercial market by direct used oil processing can be captured. Very importantly, this approach avoids the misleading results arising from comparing small changes and negative numbers.

4.1.3 System Boundary

The system boundaries are represented in *Figure 4.1*. For simplicity, only the main life cycle stages and outputs of the re-refining processes are shown here -- and the co-products are not listed.

The Phase II constant commercial market output approach applies the same system boundaries as Phase I, but avoids displacement of products by accommodating product functionality within the system.

Figure 4.1 Used Oil Management - System Boundaries



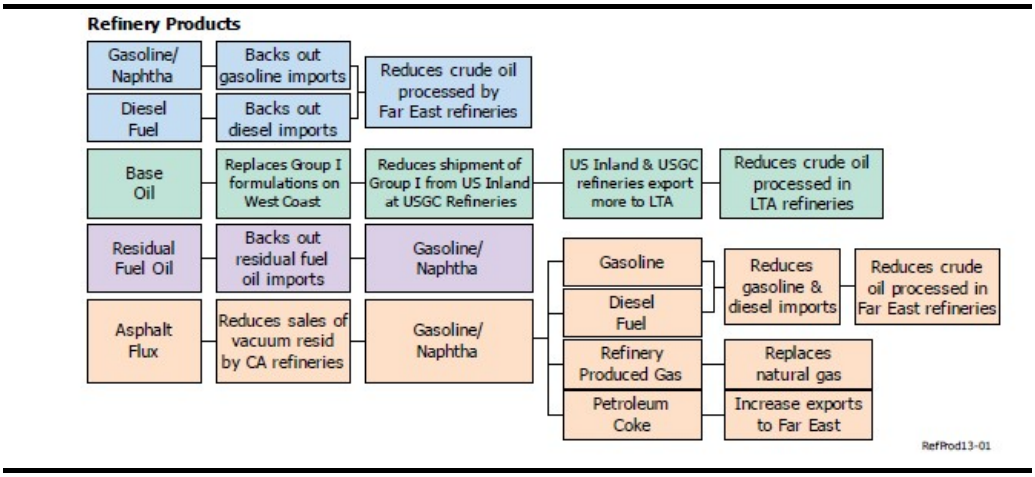
As with Phase I, an attributional LCA has been undertaken, but some aspects of this Phase II LCA can be said to follow a consequential approach, i.e. that as the volume of a secondary petroleum product derived from used oil raw material increases, a reduction in the volume of the virgin product supplied to the commercial market will occur.

The premise of this study, and that of the Phase I study, is the same in that an increase in secondary (used oil management system) production will be matched by a direct and equal decrease in the equivalent virgin production – or vice versa – with the net output of the total system being a constant output to the commercial marketplace. This means that demand in the commercial marketplace is assumed to be unaffected by the specific production mechanism (used oil management or virgin refinery) to supply that commercial demand.

It is important to recognize the potential effect on results of alternative displacement rates. As part of the Phase I study, Solomon Associates studied the likely products and refineries that would be affected (as of 2010) through changes in quantities of product generated through processing California used oil (see *Figure 4.2*). Their work showed that in a sophisticated internationally traded market such as petroleum products, the virgin refineries adapting their outputs could be situated in many different parts of the world and that the products displaced might not be those assumed in Phase I.

In particular, they note that re-refined base oil would likely displace group I base oil produced in Latin America, while fuel products ultimately were assumed to displace both Far East and Latin American, production. A reader should note that since these analyses were undertaken, the crude oil price has undergone very significant fluctuations – the effects of which were not predicted or analyzed in the Phase I work.

Figure 4.2 ***Likely product displacement scenario (HSB Solomon Associates, 2013)***



Used Oil

The system starts with the generation of used automotive lubricants (also called, more simply, "lubricants" or "lubes," consistent with the CA Code) and industrial lubricating oils in the state of CA that could be collected and processed. As noted, the Legal code in CA distinguishes between automotive lubricants (eg passenger car motor oils that are called 'lubricants' in CA) and industrial lubricants (eg hydraulic oils or paper machine oils). Many other jurisdictions and the petroleum industry tend to consider them together as 'finished lubricants.' The impacts associated with the first manufacture, blending and the use of lubes and industrial oils that give rise to the used oil are not considered in the Phase I and Phase II study.

Informal Management

A percentage of the used oil generated in CA is informally managed despite the applicable legislation. This Phase II LCA considers informal/illegal disposal. Compared to Phase I, the informal management model was simplified and limitations addressed. The routes considered were designed to capture a reasonable range of possible informal management options and to provide information on the likely range of impacts that might be expected:

- improper disposal - draining and disposal of used oil directly onto soil or into waterways;

- landfill - disposal of used oil into the municipal solid waste stream; and;

- on-site combustion – use (if with energy recovery) or disposal (if without energy recovery) of used oil onsite by the generator of the UO.

The quantity of used oil that is illegally/informally disposed is unknown. For this work, we used the estimates made in Phase I which were based on the difference between the estimated amount of used oil generated (from sales and assumed loss in use) and estimates of the amount of used oil collected.

The volume of used oil and its fate are subject to considerable uncertainty. For the purposes of this work, we do not need exact numbers, but rather a reasonable model and the ability to examine the effect of changing the amount of illegally disposed used oil.

Formal Management

Most of the used oil in CA is formally managed through a number of available routes either for final disposal, re-use, regeneration or reprocessing into a marketable and valuable product. In addition to the management routes considered in Phase I, this LCA includes the VGO route, a pathway that is becoming increasingly important according to NORA.

The following formal management handling steps are included in this LCA.

Used oil collection and storage: this includes the collection of used oil by haulers and its' storage in collection centers or waste handling facilities.

Waste disposal: this includes the direct disposal of used oil not suitable for processing because it is off-specification or is deemed in local regulation to contain hazardous components with prescribed (limited) disposition options. The formal disposal routes include hazardous waste incineration and hazardous waste landfilling.

Regeneration and reprocessing of used oil: this includes the operations on used oil raw material to produce commercially marketable petroleum products (valuable substances): RRBO by re-refining, and RFO, MDO or VGO by reprocessing (reclaiming or distillation processes). These pathways produce a number of recovered petroleum products.

Table 4.3 Selected volume of used oil and used oil product for California 2007-2011 (from UCSB final report and DIM model spreadsheet(1))

	2007	2008	2009	2010	2011
Total UO generated (m gall – dry)	139	134	129	132	132
Total collected (dry)	111	108	100	102	99.7
% uncollected	20%	19%	22%	23%	25%
California products (m gall)					
Re-refined base oil	10.0	9.00	9.70	10.2	3.6
MDO/light fuel	31.6	35.6	38.6	36.6	42.1

(1)DIM model July 2013 – available from CalRecycle

	2007	2008	2009	2010	2011
Asphalt flux	15.5	17.1	19.3	22.0	17.8
RFO	22.4	20.9	15.7	11.9	14.5
Export products (m gall)					
Re-refined base oil	6.30	5.50	4.50	5.20	7.10
Light fuel	0.80	0.60	0.50	0.60	0.70
Asphalt flux	1.30	1.20	0.90	1.00	1.40
RFO	14.0	10.4	6.90	5.10	4.20

As *Table 4.3* shows, there are considerable variations in the volume of used oil generated, collected and the disposition over the years 2007-2011. 2010 was selected as a base year in part because the re-refined base oil production was significantly reduced in 2011 and was expected to recover in later years.

Over the period, it is estimated that volumes of used oil generated have decreased by about 5%, the volume collected decreased by just over 10% and the percentage uncollected is estimated to have increased from 20% of the total generated to 25%.

Over the period, there has been a substantial reduction in total exports from CA to other US states or countries (~40%) and in total RFO production (~50%). It would be interesting (but beyond the scope of this work) to study how the market has responded to changes in capacity or the oil price, and to understand the apparent reductions in collection rate over the period.

Crude oil and refinery system

Depending on the management route, the petroleum products market (both lube and fuel components of that market) is satisfied either through the reprocessing / regeneration of UO, or through production by conventional (primary oil / virgin) refineries. As a result of this approach, the system boundaries include the production of petroleum products manufactured using either used oil as the primary feedstock / raw material, or using crude oil as the primary feedstock / raw material.

Lubricant manufacturing assumptions

The total lube output to commercial market is held constant throughout the baseline and each of the comparison scenarios in this Phase II study. However, a key assumption (arguably limitation) of this study is an assumption that the lube base oil performance and toxicological qualities of virgin and re-refined production routes is always equivalent. The quantity and quality of virgin lube base oil necessary to produce a quantity of finished lubricant product meeting certain performance and toxicological specifications (safely providing a given duration of lubrication to a designated piece of equipment) is not necessarily equivalent to the quantity and quality of re-refined lube base oil needed to produce the same lubrication performance with the same levels of product handling safety.

Any differences in virgin base oil versus re-refined base oil qualities can, at least partly, be compensated by differing quantity and quality of the chemical additives that need to be blended with an oil base stock to make an on-specification finished lubricant. However, this potential difference in functionality is not accommodated within this Phase II LCA study. To do so would require formulation and performance differences by application to be considered.

Combustion of fuels

Assessing and modelling the environmental impacts associated with combustion of used-oil derived fuel products (and of virgin fuels) is complex. Emissions will depend heavily on the combustion process used, the pollution controls applied and the operation of the process, as well as the composition and properties of the fuels.

The various fuel products can be burned in a number of appliances and will have a wide range of pollution controls applied.

In addition to petroleum products from primary crude oil refineries, natural gas and coal combustion were also included within the system boundary, as they all represent potential substitutes for fuels derived from reprocessed UO.

The issue of selecting appliances, levels of pollution control and potential displaced fuels is not straightforward, but it is very significant in estimating overall impacts and in comparing impacts among options.

For a given fuel, emissions of individual pollutants to air can vary over orders of magnitude, depending on the combustion appliance and pollution control. In some processes, several emissions are effectively independent of the fuel used (eg CO in cement kilns) further complicating the analysis. For this work, we wanted to capture the main features that affect emissions. To be conservative, we linked emissions to composition of used-oil derived fuels.

It is important to account for the possibility that fuel substitution will include changes in applied levels of pollution controls (it is common for different regulations to apply to use of used-oil derived fuels and use of virgin fuels). Over time, the long-term effects of fuel substitution mean that there may be investments in plant to allow fuel switching – such as we have seen over time from solid fuels to liquids and then gases. In order to reflect the possible range of substitutions, we examined a number of scenarios designed to reflect the possible range.

Electricity modelling assumptions

The Phase I, electricity modelling was employed for the study. *Table 4.4* details the electricity mix used in this Phase II study and in Phase I for 2010. The grid mix is based on the reference case developed by the Energy Information Agency (EIA) and reported in their Annual Energy Outlook (US

Energy Information Administration, 2012). The reader should note that in different places the fuel mix may well be different, and that the mix will change over time. This will of course affect the results of this study. However, for the purposes of investigating the collection and processing of used oil, we believe that the effects can be safely ignored. Future work should review this in the light of individual circumstances and the objectives of the study.

Table 4.4 Phase I Electricity Mix (%)

WECC Grid Mix	**2010**
Transmission loss	0.07471
Biomass	0.01285
Coal	0.28771
Geothermal	0.02035
Heavy Fuel Oil	0.0054
Hydro	0.22801
Lignite	0
Natural Gas	0.32098
Nuclear	0.09468
Solar	0.00117
Wind	0.02769
Unspecified fossil	0.00115
US average grid mix	**2010**
Transmission loss	0.08969
Biomass	0.00738
Coal	0.42257
Geothermal	0.00412
Heavy fuel oil	0.00896
Hydro	0.06716
Lignite	0.02604
Natural gas	0.23799
Nuclear	0.19556
Solar	0.00024
Wind	0.02485
Unspecified fossil	0.00512

4.1.4 Exclusions and Cut-off Criteria

The processes included in the system boundaries of this study are presented in *Figure 4.1*. Exclusions to this system boundary were as follows.

- All processes upstream of used oil generation (i.e., extraction of crude oil used during the first use of virgin lubricants; production, distribution and sale of lubricants; and use and losses in use of automotive lubricants and industrial oils before the end-of-life stage).

- Processes associated with blending lubricants from virgin or re-refined base oil with chemical additive packages to produce finished lubricants (engine or industrial oils).

- Use phase and other downstream processes associated with petroleum products of re-refined base oil and other non-fuel co-products generated

during used oil re-refining or reprocessing (eg re-refined base oil, VGO and minor co-products such as ethylene glycol). The exception to this exclusion is the use phase of fuels (i.e., combustion) produced from used oil or crude oil raw materials.

- Transportation and distribution processes associated with virgin and reprocessed fuels.

- Manufacture of additives to be blended with RRBO or virgin base oils to produce finished lubricants.

- Human energy inputs to processes.

- Infrastructure and capital goods.

- Transport of employees to and from their normal place of work.

Of these, a reader should note that infrastructure and capital goods may be significant when a policy is designed to change disposition or might change the market structure – such as increasing numbers of collection vehicles or journeys. When impacts are finely balanced among different used oil re-processing options, the impacts of significant capital development of processing plants, if required, should be considered.

Exclusion of activities or flows associated with processes within the system boundary was avoided whenever possible. No arbitrary cut-off criteria have been applied.

However, when exclusions were made, they have been documented.

The following were excluded from this Phase II LCA, consistent with the Phase I LCA.

- Dielectric oil rejuvenation, which was approximately 0.93% of total used oil collected in the base year.

- Transfer losses during collection and transportation of used oil due to leaks and spillage, incidental dewatering, and accounting inconsistencies in hauler data reporting, which was estimated to be 1.35% of total used oil collected in the base year of 2010. Further investigation of losses in collection and transport may be required as the estimate makes up a significant flow of used oil if it is lost directly to the environment. However, it was not included in this analysis.

4.1.5 Modelled Scenarios

The scenarios considered were as follows.

- **'Baseline' –** the proportion of used oil sent to each formal and informal waste management option is fixed as per 2010 values in CA.

- **'Extreme RFO' –** all used oil produced in CA is reprocessed into RFO. All used oil produced is collected, and no used oil is managed informally.

- **'Extreme MDO' –** all used oil produced in CA is reprocessed into MDO. All used oil produced is collected, and no used oil is managed informally.

- **'Extreme VGO' –** all used oil produced in CA is reprocessed into VGO. All used oil produced is collected, and no used oil is managed informally.

- **'Extreme RRBO' –** all used oil produced in CA is re-refined into RRBO. All used oil produced is collected, and no used oil is managed informally.

The proportion of total used oil sent to each management option in each of these different scenarios is presented in *Table 4.5* and *Table 4.6*. The baseline follows that used in the Phase I LCA (Table 17).

A stepwise approach was taken to analysis and the development of the scenarios.

The first stage was to model the baseline for 2010.

Step two involved considering the effect of changes in the rate of collection. To do this, we developed scenarios with increased and decreased collection (i.e., no collection at all, with all of the used oil being informally or illegally disposed) compared to the baseline.

In the next step, we look at some other uncertainties, choices and sensitivities relevant to policy making. These include the effect that improved pollution control for used oil derived fuels might have as it is a potential policy option to require specific standards of pollution control for used oil derived fuels that do not apply to virgin fuels.

As previously discussed, there are important areas of uncertainty in modelling the used oil management system. Some uncertainties can be addressed through improved information. Several parameters are fixed in this Phase II analysis to remove additional uncertainty (eg the used oil generation rate, the baseline mix of processing). Others are considered separately to the main model – such as uncertainty in the fate of uncollected oil.

Some key uncertainties can be fixed for modelling, but not usually in practice, in particular, the fuels which might be displaced by used oil derived products. To a degree, these might be fixed through rules on which processes and which

fuels might be used in a given situation. However, in a freely operating market where fuels are blended and exported, very limited governmental control can be exerted on either the use of or the substitution that takes place.

The model responses to changes in the following parameters were assessed. Each was varied independently of the others, although of course in practice they may vary together. The following analyses were selected to cover key areas of uncertainty and test model sensitivity.

Effect of levels of pollution control on combustion:

- High level of pollution control (HPC) during combustion (see Section 5.1.11).
- Low level of pollution control (LPC) during combustion (see Section 5.1.11).

Assumed substituted fuel:

- Virgin fuel market supplied by coal only.
- Virgin fuel market supplied by natural gas only.
- Virgin fuel market supplied by No 2 fuel oil only.
- Virgin fuel market supplied by No 6 fuel oil only.

Table 4.5 The proportion of total used oil sent to each waste management option in each scenario

Management Disposition	Phase I 87/9/4***	Scenario Baseline	Extreme RFO	Extreme MDO	Extreme VGO	Extreme RRBO	0% Collection	85% Collection	100% Collection
Informal management disposition quantity (kg)	**113,074,000**	**113,074,000**	**0**	**0**	**0**	**0**	**434,900,000**	**65,235,000**	**0**
Used oil to improper disposal	87%	87%	-	-	-	-	87%	87.0%	-
Used oil to onsite combustion	9.0%	9.0%	-	-	-	-	9.0%	9.0%	-
Used oil to MSW disposal	4.0%	4.0%	-	-	-	-	4.0%	4.0%	-
Formal management disposition quantity (kg)	**321,826,000**	**321,826,000**	**434,900,000**	**434,900,000**	**434,900,000**	**434,900,000**	**-**	**369,665,000**	**434,900,000**
*Used oil pre-processing***	8.4%	8.4%	0.0%	0.0%	0.0%	0.0%	-	8.4%	8.4%
*Used oil to export **	10.2%	0.0%	0.0%	0.0%	0.0%	0.0%	-	0.0%	0.0%
Used oil to hazardous waste formal disposal	0.7%	0.7%	0.0%	0.0%	0.0%	0.0%	-	0.7%	0.7%
Used oil distillation to MDO	55.1%	55.1%	0.0%	100%	0.0%	0.0%	-	55.1%	55.1%
Used oil to rejuvenation	0.9%	0.9%	0.0%	0.0%	0.0%	0.0%	-	0.9%	0.9%
Used oil recycling to RFO	7.2%	11.4%	100%	0.0%	0.0%	0.0%	-	11.4%	11.4%
Used oil re-refining to RRBO	18.8%	24.9%	0.0%	0.0%	0.0%	100%	-	24.9%	24.9%
Used oil to VGO	0.0%	0.0%	0.0%	0.0%	100%	0.0%	-	0.0%	0.0%
Used oil to waste water treatment	5.6%	5.6%	0.0%	0.0%	0.0%	0.0%	-	5.6%	5.6%
Used oil transfer losses	1.4%	1.4%	0.0%	0.0%	0.0%	0.0%	-	1.4%	1.4%

**Using a similar approach to that of the Phase I LCA, all exported used oil is assumed managed in-state (where 59.4% RRBO re-refining and 40.6% RFO reprocessing is assumed) by the same management routes defined in ERM scenarios.*

***Proportion that incurs an intermediate step*

**** see section 5.1 and 4.2 of Phase I Report*

Table 4.6 The amount of total used oil in kg sent to each waste management option in each scenario in Phase II

Management Disposition (kg)	Baseline	Scenario Extreme RFO	Extreme MDO	Extreme VGO	Extreme RRBO	0%Collection	85% Collection	100% Collection
Informal management *disposition quantity (kg)*	**113,074,000**	**-**	**-**	**-**	**-**	**434,900,000**	**65,235,000**	**-**
Used oil to improper disposal	98,374,000	-	-	-	-	378,363,000	56,754,000	-
Used oil to onsite combustion	10,177,000	-	-	-	-	39,141,000	5,871,000	-
Used oil to MSW disposal	4,523,000	-	-	-	-	17,396,000	2,609,000	-
Formal management disposition quantity (kg)	**321,826,000**	**434,900,000**	**434,900,000**	**434,900,000**	**434,900,000**	**0**	**369,665,000**	**434,900,000**
Used oil pre-processing**	27,123,000	-	-	-	-		0	36,653,000
Used oil to export *	-	-	-	-	-	-	-	-
Used oil to hazardous waste formal disposal	2,326,000	-	-	-	-	-	2,672,000	3,144,000
Used oil distillation to MDO	177,353,000	-	434,900,000	-	-	-	203,716,000	239,666,000
Used oil to rejuvenation	3,027,000	-	-	-	-	-	3,477,000	4,091,000
Used oil recycling to RFO	36,584,000	434,900,000	-	-	-	-	42,022,000	49,438,000
Used oil re-refining to RRBO	79,994,000	-	-	-	434,900,000	-	91,885,000	108,100,000
Used oil to VGO	-	-	-	434,900,000	-	-	-	-
Used oil to waste water treatment	18,135,000	-	-	-	-	-	20,831,000	24,507,000
Used oil transfer losses	4,406,000	-	-	-	-	-	5,061,000	5,954,000

**Using a similar approach to that of the Phase I LCA, all exported used oil is assumed managed in-state (59.4% RRBO and 40.6% RFO) by the same management routes defined in ERM scenarios.*

***Proportion that incurs an intermediate step.*

4.1.6 The Data Requirements and Data Quality

Data were collected for all processes described within the system boundary (*Figure 4.1*). Formal and informal management data were gathered during Phase I using a combination of primary and secondary sources. In the Phase II study reported here, the main changes made to the Phase I data were as follows:

- Re-refining and reprocessing of used oil were modeled using publicly available data.

- Used oil management and recovery of used oil were modelled on a dry basis.

- The RFO calorific value was modelled as 43MJ/kg, compared to 41.4 MJ/kg in Phase I. (see section 2.3.9)

- A VGO pathway from both used oil and virgin sources was added using a combination of primary and secondary sources.

- Used oil and virgin oil lubricant/industrial oil composition has been updated from the Phase I study based on data from Summit Industrial Products (provided by CalRecycle).

- A 'constant maximum output to commercial market' approach was used to achieve functional equivalence among used oil management options.

- In the baseline, the virgin fuel liquid market was set to be 91% No 2 fuel oil and 9% No 6 fuel oil, based on data from the US Energy Information Administration.

- The imposition of a metals mass balance.

- Combustion data were updated and differing levels of pollution control were appraised.

- Informal management was simplified through the following:
  - The exclusion of on-site combustion from the commercial energy market (i.e., removal of Phase I displacement benefit) assuming that not all informally combusted used oil directly displaces virgin fuel products in the commercial marketplace -- we assume that at least some illegal burning of used oil is primarily for the purposes of disposal, not for beneficial heating.
    Therefore, the proportion of energy recovery during onsite combustion cannot be accurately determined.

  - Changing improper disposal to reflect illegal dumping and, in the absence of survey data, to assume 50% disposal to land and 50%

disposal to freshwater - so as to understand the potential for impact from illegal dumping activities.

A list of differences between Phase I and Phase II LCA studies is presented in Annex A.

In order to be consistent with Phase I and, thus, to be able to build on the LCA model, in Phase II the data quality requirements were maintained (Table 4.7).

Table 4.7 Data quality requirements

Data quality category	Requirement
Reliability	Where possible, primary data based on measurements have been used. When these are unavailable, or secondary data were considered to be more representative, secondary data or engineering models were used. The source of the data was indicated for every process inventory. Data were extracted from transparent and well-documented sources. When computations or assumptions have been made, they were explicitly documented.
Completeness	The study used as many data sources as necessary to ensure completeness of data.
Temporal Correlation	Data were from a time period that was relevant to current production rates and technologies. In order to account for fluctuations in production over time, data from the years 2003-2013 were solicited.
Geographic Correlation	Data were sourced to represent the management of used oil generated in California
Technological Correlation	Data were sought that reflected currently used technologies, as well as technologies that might be used in the future.

Source: Phase I LCA report (Table 5).

As discussed above, there remain difficulties associated with ensuring complete and comparable data in every element of the study. Overall, the objective has been to develop datasets that are suitable and fit for the purpose of making the analysis. Datasets drawn from multiple sources are inevitably inconsistent with each other (eg lists of pollutants included) and do not necessarily reflect the range of processes needed (i.e., for displaced processes, a range from low to high to reflect the uncertainty).

4.1.7 Life Cycle Impact Assessment Method

In order to assess the environmental impact of used oil management, characterization models and factors of the impact assessment method 'TRACI v2.1' were used. In addition, the CML 2001 impact assessment method was used for abiotic depletion, which includes both fossil and other non-fossil resources. The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) was developed by the US Environment Protection Agency (EPA), specifically for the assessment of products in the United States. Therefore, it was considered the most representative impact assessment method for used oil management in CA and was also used in the Phase I LCA.

The impact categories used in this study comprised the following:

- CML 2001 (April 2015), Abiotic Depletion (ADP elements) in kg Sb eq;
- CML 2001 (April 2015), Abiotic Depletion (ADP fossil) in MJ;
- TRACI 2.1, Acidification Potential in kg SO_2 eq;
- TRACI 2.1, Ecotoxicity Potential in Comparative Toxicity Units (CTUeco);
- TRACI 2.1, Eutrophication Potential in kg N eq;
- TRACI 2.1, Global Warming Air, excl. biogenic carbon (kg CO_2 eq);
- TRACI 2.1, Human Health Particulate Air in in kg PM2.5 eq;
- TRACI 2.1, Human Health (Cancer) Comparative Toxicity Units (CTUh);
- TRACI 2.1, Human Health (Non-Cancer) Comparative Toxicity Units (CTUh);
- TRACI 2.1, Ozone Depletion Air in kg CFC 11 eq;
- TRACI 2.1, Resources, Fossil Fuels in MJ surplus energy; and
- TRACI 2.1, Smog Air in kg of ground-level ozone equivalent (kg O_3 eq);

Please refer to Section 6.1 for a description of each impact category.

Results presented in this LCA were not normalized, grouped or weighted in any way.

4.1.8 Allocation Procedures

In accordance with ISO 14040/44, allocation was avoided when possible by dividing unit processes or expanding the product system. However, in some cases allocation of burdens and benefits between multi-product processes was required and economic or mass allocation, or other suitable allocation methods were used. In each case, the allocation approach is described alongside inventory data.

4.1.9 Reporting

In anticipation of communication to third parties, this report has been prepared in accordance with the requirements of ISO 14040/44 for third-party reporting and consequently is presented to include the following:

- background;
- goal and scope;
- inventory;
- impact assessment
- interpretation;
- conclusions;
- references; and
- annexes.

4.1.10 Critical Review

As it is anticipated that this study will be disclosed to third parties by the API, a critical review by a panel of interested parties will be undertaken as described in ISO 14040/44. The panel will be chaired by an external

independent expert and comprise three other independent qualified reviewers (see *Table 4.8*).

Table 4.8 Critical review panel

Name and organization of reviewer	Organization and job title	Role in critical review process
François Charron Doucet	Groupe Ageco, Scientific Director	Chair of panel, lead reviewer
Christopher Loreti	The Loreti Group, Principal	Panel member
Keith A. Weitz	RTI International, Environmental Scientist	Panel member
Richard P. Zink	Process Engineering Associates, LLC, Chief Process Engineer	Panel member

Source: Phase I LCA report (Table 5).

The critical review process will ensure that:

- the methods used to carry out the LCA are consistent with ISO 14040/44;
- 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 interpretations reflect the limitations identified and the goal of the study; and
- the study report is transparent and consistent.

5.1.1 Used Oil Generation, Treatment and Composition

The product system under investigation begins with the generation of UO. In CA, the total quantity of used oil generated annually was estimated as 435,000 metric tons (4.35x108 kg) by ICF Incorporated, LLC in the Phase I LCA (Table 17) and this figure is also used here. Of this total, approximately 75% was used lubricating (automotive/engine) oil and 25% used industrial oils in the 2010 baseline scenario in Phase I.

Summit Laboratory LLC determined the chemical composition of 20 used industrial oil samples and 125 used automotive lubricating oil samples, which were collected from a number of used oil re-processing or re-refining facilities in CA. The concentrations of various analytes in these samples were determined using a range of analytical techniques (see *Table 10.3 Annex A*) and averaged and corrected for water content to provide a mean composition of dry used lubricating (automotive/engine) and industrial oil (see *Annex A*).

The composition of used oil was then calculated (*Table 10.2* in the *Annex A*), by weighting the concentration of each analyte in lubricating and industrial oils according to the proportions of these that make up the total generated UO. For reference, the chemical composition of recovered petroleum products from used oil was also determined by Summit Laboratory LLC and is provided in *Table 10.6* in *Annex A*.

For some analytes, the determined concentration was below the Practical Quantification Limit (PQL), which was established for each analytical method by multiplying the standard deviation of replicate measurements of each analyte by ten (PQLs for each analyte for each method are provided in *Table 10.4 Annex A*). There is no single ideal approach to dealing with a data set with non-detected data. In this case we used the approach of setting non-detects to half the PQL. This will likely overestimate concentrations of some components. Further analysis of the laboratory data would be valuable, and we recommend that CalRecycle publish the full results of their work.

Of the total amount of used oil estimated to be generated in CA, the majority is collected and managed formally -- although a considerable amount is not accounted for and is assumed to be informally or illegally disposed. Details of UCSB's materials flow analysis and the assumptions made are contained in the Phase I report. Details of the approach taken to estimate generation of used oil are included in the Phase I Kline reports. As noted previously these estimates are subject to uncertainty and there is a particular issue with ensuring that water content of used oil is properly accounted for in the estimates and then through the model. The total amount of used oil collected

for formal management was estimated as 322,000 (dry) metric tons in the 2010 baseline scenario (Table 17 of the Phase I report).

Management of used oil by all formal and informal routes is based on dry weight. Therefore, where data on wet used oil were collected, they were first adjusted based on water content before being used in LCA modeling. It should be noted that dry used oil has not been modeled in this LCA. Rather, process inputs and outputs have been adjusted to respond to used oil flows on a dry basis.

Table 5.1 Californian waste codes for used oil

Code	Description	Oil Content
221	Waste Oil and Mixed Oil	95%
222	Oil/Water Separation Sludge	50%
223	Unspecified Oil-containing Waste	15% / 65%

Source: Phase I LCA report (Table 135).

UCSB assumed the water contents shown in *Table 5.1*– a reader should be aware that these are assumed and not based on statistical analysis of the wastes listed. The actual water content of any batch of each waste and representative averages could be very different.

The amount of used oil informally managed was determined as the difference between the estimated used oil generated in CA (as determined using materials flow analysis in Phase I) and the used oil collected for formal management. This difference was estimated as 113,000 metric tons in the 2010 baseline scenario (Table 17 of the Phase I report).

Table 4.5 details the flows of used oil by each informal disposal route and each formal management route in the Phase I baseline and in the scenarios appraised in this study.

5.1.2 Used Oil Collection and Storage

For this Phase II work we used UCSB's analysis of collection and storage. No changes were made in any scenario to reflect different possible logistics and no analysis was made of any measures that would change the collection – such as allowing increased storage on site before collection (reducing transport demands and collection costs). We believe that in life cycle terms the environmental impacts from possible changes in logistics would be small (although the effect on costs and value of used oil might be significant). We recognize that this is a simplification – there would be logistical advantages (shorter average distances) for distributed production of RFO as compared to centralized production of RRBO, VGO or MDO.

Following its generation, used oil must be collected from generating facilities, consolidated, and delivered to facilities where it is either stored before onward transport to reprocessing or re-refining facilitates, or is disposed.

The average total distance that used oil is transported between generator facilities and a Transfer, Storage or Disposal Facility (TSDF) was calculated in Phase I to be 361 km based on manifest records of used oil transportation in CA.

Modes of transportation between generator facilities and TSDF were assumed to be 32% medium trucks (class 6), 67% large trucks (class 8b) and 1% rail, following the Phase I LCA (Page 26). Inputs and outputs for this transportation stage were modeled using GaBi data for 'Truck - Medium Heavy- duty Diesel Truck / 9,333 lb payload – 3' and 'Truck - Tank, liquid or gas / 50,000 lb payload - 8b' for medium and heavy trucks, respectively, and 'Rail transport cargo – Diesel' for rail. Upstream flows associated with diesel fuel production were modeled using 'Diesel mix at refinery' from GaBi. Life cycle inventory data from databases used in this study is given in *Table 10.9* in Annex A.

Transportation from TSDF to re-refining or re-processing facilities was assumed to be 3,500 km by rail, which matched the Phase I study (Page 26). Inputs and outputs for this transportation stage were modeled using GaBi data for 'Rail transport cargo – Diesel', with upstream flows associated with diesel production modeled using 'Diesel mix at refinery' from GaBi.

During collection and storage, a small proportion (1.35% in the 2010 baseline scenario) of used oil was lost due to leaks and spillages, incidental dewatering and accounting discrepancies. These used oil losses were excluded, due to uncertainty over the loss rate and its immateriality to the study. Also, since there are potentially in CA (and actually in other jurisdictions) fewer, larger re-refining and major used oil reprocessing facilities, compared to a much larger number of facilities where used oil could be (is) burned for energy recovery – then the distances to transport the used oil to Re-refineries would be substantially longer than for transport to combustion facilities. The impact of this difference was not considered in either Phase I or Phase II of this LCA.

5.1.3 Management routes

Hazardous Waste Landfill

Transportation from TSDF to hazardous waste landfill was assumed to be 224 km by a combination of light and heavy diesel trucks. Inputs and outputs for this transportation stage were modeled using GaBi data for 'Truck - Light Heavy-duty Diesel Truck / 6,667 lb payload - 2b' and 'Truck - Medium Heavy-duty Diesel Truck / 9,333 lb payload – 3' for light and medium trucks, respectively.
Upstream flows associated with diesel fuel production were modeled using 'Diesel mix at refinery' from GaBi.

Once at the hazardous waste landfill site, 100% of the used oil sent to this disposal route was assumed to be landfilled and modeled as such using ecoinvent v2.2 data for 'disposal, hazardous waste, 0% water, to underground

deposit', following the approach used in the Phase I LCA. The generation of hazardous waste accounted for in Phase I was based on manifest records of used oil haulage within the state of California. In the Phase I LCA, a small proportion of the used oil sent to hazardous landfill was assumed to be incinerated. However, for simplicity this was not modelled here and landfilling was assumed in the absence of better data.

Hazardous Waste Incineration

Transportation from TSDF to hazardous waste incineration was assumed to be 224 km by a combination of light and heavy diesel trucks. Inputs and outputs for this transportation stage were modeled using GaBi data for 'Truck - Light Heavy-duty Diesel Truck / 6,667 lb payload - 2b' and 'Truck - Medium Heavy-duty Diesel Truck / 9,333 lb payload – 3' for light and medium trucks, respectively.

Upstream flows associated with diesel fuel production were modeled using 'Diesel mix at refinery' from GaBi.

Once at the hazardous incinerator site, 100% of the used oil sent to this disposal route was assumed to be incinerated without energy recovery (no displacement impact in the commercial fuel market) and modeled as such using ecoinvent v2.2 data for 'disposal, used mineral oil, 10% water, to hazardous waste incineration'. The non-combustible component of used oil was modeled as being collected as bottom ash and landfilled using data for 'disposal, hazardous waste, 0% water, to underground deposit', which considers recovery of useful materials (eg metals) and the associated displacement of virgin products.

Wastewater treatment

Transportation from TSDF to wastewater treatment was assumed to be 224 km by a combination of light and heavy diesel trucks. Inputs and outputs for this transportation stage were modeled using GaBi data for 'Truck - Light Heavy-duty Diesel Truck / 6,667 lb payload - 2b' and 'Truck - Medium Heavy-duty Diesel Truck / 9,333 lb payload – 3' for light and medium trucks, respectively.

Upstream flows associated with diesel fuel production were modeled using 'Diesel mix at refinery' from GaBi.

Once at the wastewater treatment facility, 100% of the used oil sent to this disposal route was modeled using GaBi data for 'Waste water treatment (contains organic load)'. This process is a generic process for treatment of waste water stream from the chemical sector and not specific to used oil (4% of used oil is disposed by this route in the baseline scenario). The process accounts for mechanical, biological and chemical treatment for incoming waste water, and treatment steps for the sludge produced. The lack of specificity to used oil is a limitation. However, when considering the amount

of used oil that is disposed this way, the uncertainties around composition and the lack of specific data, the approach is considered reasonable.

5.1.4 Re-refining of used oil to lube base oil (RRBO)

The process of re-refining used oil to RRBO was modeled in this LCA using publicly available inventory data from IFEU (2005)[(1)] . This approach is different from that used in Phase I, where primary data collected from refinery facilities, which was protected by non-disclosure agreements, were used. The phase I model shared by UCSB aggregated the facility data with upstream burdens for energy and chemicals used and they could not be analyzed to test the effect of different process configurations, different yields or varying levels of pollution control.

The IFEU data provides a range of performance and burden data across five processes reflecting some of the range of process performance available.

Five re-refining techniques to RRBO from the IFEU report were considered in this study, as follows.

- **Cyclon –** a re-refining technique based on hydro-treatment technology. This process involves heating used oil with hydrogen to a temperature of ~ 300 °C in the presence of a catalyst to produce gas and liquid phases. The latter is then treated with stream to remove the most volatile components and produce a low sulfur base oil.

- **Evergreen –** a re-refining technique that includes both vacuum distillation and hydro-treatment (see above) processes. The former process involves lowering the pressure above used oil contained in a distillation column, which allows volatile liquids to be removed, leaving behind base oil for further refining with hydro-treatment.

- **HyLube –** a re-refining technique based on hydro-treatment technology (see above).

- **MRD –** a re-refining technique for used oil and oily water feedstocks, which involves initial separation steps to remove water. Flash distillation then follows, which produces a number of oil fractions, including base oil.

- **Viscolube –** a re-refining technique for used oil where water and light ends are first separated by vacuum distillation. Asphaltic and bituminous products are then removed via thermal de-asphalting (TDA). Hydro-treatment (see above) is finally used to produce base oil.

The IFEU study was used to generate a combined data set that reflects an average of the re-refining process presented in *Table 5.2*. All the input and

(1) IFEU (2005) Ecological and energetic assessment of re-refining used oils to base oils: Substitution of primarily produced base oils including semi-synthetic and synthetic compounds.

output data presented were adjusted (uplifted) to account for the 6% water content of used oil modeled by IFEU and provide inventory data for re-refining of used oil (dry basis) to RRBO.

In addition to used oil (dry basis) and energy, a number of other auxiliary feedstocks are required in these processes, including caustic soda, hydrogen and potassium hydroxide. Multiple usable co-products are produced alongside RRBO, which include gas oil, heavy oil and bitumen additive (VTAE). Allocation of impacts associated with re-refining processes to RRBO and all other co-products was avoided through system expansion and inclusion of liquid fuels products within the system. In this approach, all of the total associated burdens of the re-refinery were considered (rather than being allocated to RRBO) in addition to the benefits associated with co-products produced, which reduced the quantity of virgin products required to achieve functional equivalence.

It should be noted that, for reasons of confidentiality, data presented for each technique in *Table 5.2* are not in the same order as the technique descriptions provided above. In addition, process heat and steam is assumed to be generated from the combustion of natural gas in the IFEU study. However, it may be the case that at least some of this process heat and steam may have been generated from the combustion of UO. This is a limitation of this study. All outputs are assumed to be useable.

Table 5.2 IFEU Inputs and outputs associated with re-refining of used oil to RRBO

Input/Output	**Unit**	**Re-refining Technique**				
		1	**2**	**3**	**4**	**5**
INPUTS						
Used oil (Dry)	kg	1000	1000	1000	1000	1000
Auxiliaries						
Caustic soda	kg	4.97	10.6		0.76	2.86
Potassium hydroxide	kg			0.06		
Hydrogen	kg	5.49	4.6		2.15	0.32
Nitrogen	kg					1.51
Soda	kg	8.95				
Propane	kg				2.39	
n-Methylpyrrolidon	kg			0.06		
Energy demand						
Electricity	MJ	931	240	130	301	237
Process heat	MJ			662	2574	
Process heata	MJ	1447				
Process heat (gross	MJ		2149			3606
demand)b						
Process heat (net	MJ		281			960
demand)b						
Process steam	MJ	672		1734	656	
Process steama	MJ					230
Process steamc	MJ		2511			
Process water	kg	398				383
Natural gas	MJ					
OUPUTS						

Input/Output	Unit	Re-refining Technique				
Petroleum products						
Base oil kg		820	739	579	771	740
Naphtha kg		40				
Light endsd kg			50			
Light endse kg				26.6	15.1	
Light endsh kg						150
Extractse kg				83		
Flux oilh kg				31.2	87.4	
Light fuel oile kg					106	
Light fuel oilf kg		80				
Gas oilf kg			73			
Gas oilg kg						40
Heavy oile kg				146.1		
Heavy oili kg		60				
Heavy oilj kg						70
Bitumen additivek kg			143			
Residuei kg				131.5		
Used process water	kg	##	63.8	63.5	84	447
Net energy deliverance						
Process heat	MJ			7979		
Process heatl	MJ				752	

Source: IFEU (2005)

a Process heat and steam is produced by a natural gas fired furnace resp. boiler.

b After combustion of light ends (a) and covering partly the 'gross' demand on process heat there results a 'net demand'. This is normally covered by by-products of other refining sites of the company. For this balancing, natural gas firing is applied to avoid additional complications due to allocation.

c Steam is also produced by by-products. Here, natural gas firing is also presumed to be employed.

d Light ends (naphtha quality) are applied as fuel on the regeneration site and cover partly the process heat demand (input: 'gross demand' minus 'net demand').

e Light ends, extracts and fuel oil (DIN quality) are applied as fuel on the regeneration site. These cover the process heat and process steam demand (input) and leave a 'net energy deliverance' (Output).

f Gas oil (Diesel quality) applied as fuel away from the regeneration site but within the system boundary; equivalency process is a light fuel oil combustion with pre chain.

g Diesel quality; equivalency process is production of hydro-finished diesel

h'Flux oil', residues and light ends are applied as additives to bitumen; the equivalency process is an application of vacuum distillate (flux oil) with pre chain.

i Heavy oil and residues are applied as reduction material within a blast furnace; the equivalency process is an application of heavy fuel oil with pre chain.

j Heavy oil is applied on-site as fuel and covers partly the process heat demand (input: 'gross demand' minus 'net demand').

k Residues are applied in the manufacture of bitumen layers; the equivalency process is an application of bitumen distillate with pre chain and partly of polypropylene fibers (1 kg of residue substitutes 1 kg of bitumen and allows in addition to reduce the polypropylene demand about 420 g.

l After combustion of light ends and light oil (a) and covering the process demand on heat, this amount is another benefit of the process; equivalency process is a fuel oil combustion with pre chain.

Table 5.3 compares the impact profile of processing 1 kg of used oil using the data presented in *Table 5.2* and the Phase I model. The impact results, with the exception of acidification and ozone depletion are comparable and well within the uncertainty associated with issues concerning treatment of moisture content in Phase I. The acidification impact difference is a consequence of: (a) the use of natural gas combustion data for process energy, and (b) the fact that the source and completeness of data for combustion emissions in Phase I are unknown. Re- refineries may have the option to use some of the by-product fuel streams for energy on the plant which potentially affects yields as well as consumption of natural gas and electricity. Further work would be needed to fully investigate the effects of this on the life cycle results.

Table 5.3 Re-Refining Process Comparison

Impact	Unit	RRBO	Phase I	Comparison (Phase II result as % of phase I)
Acidification	kg SO_2-Equiv.	3.55E-03	2.44E-03	145%
Ecotoxicity (recommended)	CTUe	3.62E-01	3.39E-01	107%
Eutrophication	kg N-Equiv.	2.94E-05	4.44E-05	66%
Global Warming Air, excl. biogenic carbon	kg CO_2-Equiv.	3.54E-01	3.25E-01	109%
Human Health Particulate Air	kg $PM_{2.5}$-Equiv.	1.78E-04	1.51E-04	117%
Human toxicity, cancer (recommended)	CTUh	2.04E-10	1.74E-10	117%
Human toxicity, non-canc. (recommended)	CTUh	1.77E-08	1.70E-08	104%
Ozone Depletion Air	kg CFC 11-Equiv.	2.62E-12	2.44E-11	11%
Smog Air	kg O_3-Equiv.	7.71E-03	6.22E-03	124%
Resources, Fossil fuels	MJ surplus energy	7.33E-01	6.58E-01	111%
Abiotic Depletion (ADP elements)	kg Sb-Equiv.	1.24E-07	1.31E-07	95%
Abiotic Depletion (ADP fossil)	MJ	5.56E+00	4.87E+00	114%

Inputs and outputs of upstream processes associated with the production of caustic soda, potassium hydroxide, hydrogen, nitrogen, soda, propane and n-methylpyrrolidon were modeled using GaBi data. These secondary data sets comprised '*Sodium hydroxide (caustic soda) mix (100%)*', '*Potassium hydroxide (KOH)*', '*Hydrogen (cracker)*', '*Nitrogen (liquid)*', '*Soda (Na_2CO_3)*', '*Propane at refinery*' and '*n-Methylpyrrolidone (NMP, Butyrolactone via Maleic anhydride)*', respectively. Secondary data for energy demand were taken from a variety of LCI databases, which are described in *Table 5.4*.

Table 5.4 Secondary data used for energy demand associated with re-refining of used oil to RRBO

Process	Secondary data used	Source
Electricity	Electricity Mixer	US LCI
Process heat	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	Phase II
Process heat a	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	Phase II
Process heat b (gross demand)	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	Phase II
Process heat b (net demand)	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	Phase II
Process steam	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	Phase II
Process steam a	Natural Gas Supply Mixer	US LCI
Process steam c	Combustion - Natural Gas HHV	Phase II

Process	Secondary data used	Source
	Natural Gas Supply Mixer	US LCI
Process water	Water deionized	PE
Natural gas	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	Phase II

5.1.5 Reprocessing of used oil to VGO

Used oil can also be reprocessed via vacuum distillation to produce the intermediate product/feedstock VGO, which has a further use (a) as a precursor through chiefly catalytic cracking to diesel fuel, motor gasoline, and (b) in other products (eg asphalt or heavy fuel oil blending component). Of the used oil collected in CA, none was reprocessed into VGO in the 2010 baseline scenario. However, this emerging used oil management route was modeled in the 'extreme VGO' scenario.

Primary inventory data for this process was collected from a number of NORA members who produce VGO from used oil and inputs and outputs averaged across producers. The only inputs to this process are used oil (dry basis) and natural gas. Multiple usable co-products are produced alongside VGO, which include asphalt extender (VTAE) and light fuel. These averaged inputs and outputs associated with reprocessing used oil (dry basis) to VGO are shown in *Table 5.5*. We do not have comprehensive information on the composition or fate of each of the product and by-product streams or emissions from combustion of these. We make the assumption that contaminants are generally concentrated in the VTAE fraction.

As with the RRBO re-refinery, allocation of impacts associated with reprocessing to VGO and all other co-products was avoided through system expansion, whereby the total associated burden of reprocessing and total benefits associated with co-products produced was considered. It is assumed that production impacts for virgin VGO are equivalent to those attributed to the heavy fuel oil fraction in Phase I and summarized in *Table 5.8*. The result is a production cost attributed to virgin VGO that is approximately 10% lower than that of diesel.

Table 5.5 Inputs and outputs associated with reprocessing of used oil to VGO

Input/Output	Averaged inventory data	
	Value	Unit
INPUTS		
Used oil (dry basis)	1	kg
Natural gas	0.0329	m3
OUTPUTS		
VGO	0.8	kg
Asphalt extender	0.16	kg
Light fuel	0.04	kg
Wastewater	0.056	l
Sox	0.000116	kg
NOx	0.000194	kg
CO	7.73E-05	kg

5.1.6 *Reprocessing of used oil to MDO*

Of the options for the formal management of UO, the majority (55%) in the 2010 baseline scenario was reprocessed by vacuum distillation to be used as a fuel for marine engines (i.e., reprocessed to MDO). Inventory data associated with producing MDO from used oil (dry basis) were taken from Boughton and Horvath (2004) [1)] . Inputs to this process comprise electricity, natural gas and sodium hydroxide, in addition to used oil (dry basis). Outputs comprise MDO, asphalt flux (VTAE) and light ends and allocation of associated impacts was avoided through system expansion. These inputs and outputs are provided in *Table 5.6.*

Table 5.6 Inputs and outputs associated with reprocessing of used oil to MDO

Input/Output	Inventory data	
	Value	Unit
INPUTS		
Used oil (dry basis)	1	kg
Electricity	0.32	MJ
Natural gas	6.7	MJ
Sodium hydroxide	3.1	g
OUTPUTS		
MDO	0.4	kg
Asphalt flux	0.52	kg
Light ends	0.04	kg

Source: Boughton and Horvath (2004).

5.1.7 *Reprocessing of used oil to RFO*

A sizable proportion (11.4% including exports) of used oil collected for formal management was reprocessed into RFO. Typically this involves heating used oil to remove water, following an initial stage of natural settling to remove any sediment. Inputs comprise UO, natural gas and electricity and the only output is RFO (no account is taken of any sediment collected). All constituents of used oil, excluding water, are assumed to be carried over into the RFO. The consequence of this assumption will be an underestimate of the impact from disposal of the sediment and filtered water, and an overestimate of the contaminants present in the RFO.

The quantities of natural gas and electricity inputs were extracted from the Phase I model. Inputs and outputs associated with this process are provided in *Table 5.7*.

Table 5.7 Inputs and outputs associated with reprocessing of used oil to RFO

Input/Output	Averaged Inventory data	
	Value	Unit
INPUTS		
Used oil (dry basis)	1	kg

(1) Boughton, B. and Horvath, A. (2004) 'Environmental Assessment of Used Oil Management Methods', Environmental Science & Technology, 38(2), pp. 353–358.

Input/Output	Averaged Inventory data	
Natural gas	0.00139	kg
Electricity	0.0135	MJ
OUTPUTS		
RFO	1	kg

Source: Phase I LCA.

5.1.8 Informal Management

The proportion of used oil that is not collected for formal management is informally managed. In the 2010 baseline scenario, this was estimated to be 113,000 metric tons (26% of all used oil generated). Of this total, 87% was assumed to be improperly disposed (i.e., dumped illegally), 9% was assumed to be combusted onsite and 4% was assumed to be sent to a municipal landfill. These assumptions were based on the Phase I LCA report (Table 17).

Used oil improperly disposed was modeled by considering four disposal routes: 'used oil to fresh water', 'used oil to salt water', 'used oil to agricultural soil' and 'used oil to industrial soil'. Used oil sent to the fresh water and salt water routes is intentionally dumped or accidentally drips into storm drains or the sewerage system and is subsequently discharged to fresh, estuarine or salt water. Used oil sent to the agricultural soil or industrial soil pathways was assumed to be directly deposited on these soils with associated transfers to the air and watercourses.

Emissions from used oil assumed combusted onsite were modeled using the same approach as that of the Phase I LCA (Appendix B), where combustion burdens and benefits were assumed to be identical to those of RFO combustion (note - the calorific value of RFO differs between the Phase I and Phase II LCAs). In this Phase II LCA, all benefits associated with onsite combustion (eg displaced fuel products) were assuming that not all informally combusted used oil directly displaces virgin fuel products in the commercial marketplace. We assume that at least some illegal burning of used oil is primarily for the purposes of disposal, not for beneficial heating. Therefore, the proportion of energy recovery during onsite combustion cannot be accurately determined.

Informally managed oil that is sent to a municipal landfill was modeled using GaBi data for 'Used oil, in landfill'. Transportation from used oil generator to landfill was assumed to be 10 km by 22 metric ton trucks, following the Phase I LCA. Inputs and outputs for this transportation stage were modeled using ELCD data for 'Lorry (22t) incl. fuel', which includes upstream processes associated with the manufacture of diesel fuel.

5.1.9 Production of Virgin Products

The 'constant maximum output to commercial market' concept used in this study requires that the amount of Lube Base Oil (LBO), VGO, VTAE and energy from combustion remains fixed at the maximum possible output (set

by estimated available volume of used oil generated) to the California commercial market for each product system under investigation.

For each waste management scenario modeled, the quantity of these products remained exactly the same, and where there was a shortfall in production of any individual product from used oil reprocessing or re-refining, 'top-up' from a virgin refinery was added to bring the total to the required value. The production of these virgin products was modeled using the Gabi life cycle inventory data from the Phase I LCA (Table 13). Summary data reflecting refinery inputs and outputs for each are presented in *Table 5.8*.

In the default scenario, production of virgin product is modeled as taking place at virgin refineries in California ('CA' in *Table 5.8*). Inputs comprised crude oil, electricity, natural gas and water. Outputs comprised a number of lubricating base oils and combustion fuels. All inputs to each virgin refinery process step were allocated to each virgin product based on the energy content of each product flow and are summarized in *Table 5.8* on a 'per kilo of virgin product' basis. It should be noted that not all lubricant base oils are Group II and that other base oils such as Group I will also be substituted. This is a limitation of the study.

Further, displaced virgin products of natural gas and coal were modeled using secondary data from US LCI ('Natural Gas Supply Mixer') and GaBi ('US: Bituminous coal, at mine'), respectively.

Table 5.8 Inputs and outputs associated with production of 1 kg of virgin product

Virgin Product	Crude Oil (kg)	Electricity (MJ)	Natural gas (kg)	Water (kg)
Group II Base Oil (CA)	1.08	0.286	0.113	0.323
Group II Base Oil (US)	1.04	0.57	0.0869	0.313
Diesel (CA)	1.11	0.144	0.0477	0.332
Diesel (US)	1.12	0.198	0.0199	0.336
Heavy Fuel Oil > 0.3% sulfur (CA)	0.979	0.132	0.0507	0.294
Heavy Fuel Oil > 0.3% sulfur (US)	0.972	0.212	0.0234	0.292
Bunker fuel 3.5% sulfur (CA)	0.979	0.132	0.0507	0.294
Bunker fuel 3.5% sulfur (US)	0.972	0.212	0.0234	0.292

Source: Phase I LCA (Table 13).

Inputs and outputs of upstream processes associated with the production of crude oil, electricity, natural gas and water were modeled using data sets from GaBi ('*US crude oil mix' and 'Water deionized') and US LCI ('Electricity Mixer' and 'Natural Gas Supply Mixer*').

For reference, the chemical fuels was determined from data collected by Summit Laboratory LLC using 26 samples of off-road (high- sulfur) diesel, 7 samples of low-sulfur diesel, 6 samples of kerosene, and 24 samples of heavy (No.6) fuel oil. The concentrations of various analytes in these samples were

averaged to provide a mean composition of each of these virgin fuels (*Table 10.5* in the Annex).

5.1.10 Combustion of fuels

The product system includes the combustion of both reprocessed and virgin fuels. It was necessary to include these processes within the system boundary, as calorific values and compositions are not equivalent and because they may be burned in a variety of appliances with differing levels of pollution control. Further previous work has established clearly that the combustion of fuels and the ability of combustion processes to control emissions has a major impact on the relative environmental impacts of the different treatment options. Calorific values (Lower Heating Value - LHV) for these virgin and reprocessed fuels are provided in *Table 5.9*.

Table 5.9 Calorific values (LHV) of virgin and used oil petroleum products

Fuel	Average Calorific value (MJ kg^{-1}) dry	Reference	Assumptions
RFO	43		Based on reported dry CV for PFO. No basis for differentiation. Same calorific value as fuel oil (No.2)
VGO	43		No basis for differentiation. Same calorific value as fuel oil (No.2)
RRBO	43		No basis for differentiation. Same calorific value as fuel oil (No.2)
Asphalt (VTAE)	40.4	Phase I LCA report (Table 11)	Same calorific value as heavy fuel oil (No.6)
Light distillates	43	Phase I LCA report (Table 11)	
Light ends	44	Phase I LCA report (Table 11)	
Middle distillates	43	Phase I LCA report (Table 11)	
Heavy fuel oil (No.6)	40.4	Phase I LCA report (Table 11)	
Fuel oil (No.2)	43	Phase I LCA report (Table 11)	
Off-road diesel (low sulfur)	43	Phase I LCA report (Table 11)	
Natural gas	50.9	EPA AP 42	
Coal	22.6	EPA AP 42	

The proportion of total liquid fuel sold in the United States in the base year of 2010 is provided in *Table 5.10*, which was taken from the US Energy Information Administration1. In the baseline data for Phase I, the virgin displacement as a result of used oil fuel products was equally split between No.2, No.6 and natural gas. The 2010 sales data show that the ratio of

distillate fuels to residual oils was 91:9, and on this basis we used a 91:9 split between No.2: residual fuels in the baseline. We also examined the effects of a 100% No.2, 100% No.6 as well as 100% natural gas and 100% coal displacement.

Table 5.10 The proportion of total liquid fuel sales by volume, in 2010 in the United States

Fuel	Proportion of total sales of liquid fuels by volume, in US from Jan to Dec 2010 (%)
Gasoline	59%
Aviation Gasoline	0.09%
Kerosene-Type Jet Fuel	8.8%
Propane	5.1%
Kerosene	0.16%
No 1 Distillate	0.19%
No 2 Distillate	25%
No 4 Fuel Oil	0.08%
Residual Fuel Oil	2.4%

Source: US Energy Information Administration.(1)

5.1.11 Fuel composition and combustion emissions

The significance of combustion emissions when assessing fuels of different composition has been well documented in previous LCA studies. The variation of emissions per unit of energy output among solid, liquid and gaseous fuels has been a key driver of outcome for comparative LCAs. The outcomes have been driven by differences in electricity generation between geographies, differences in consumption amounts and in the assumptions regarding which marginal fuels are displaced when secondary fuels are made available.

LCA results can be highly sensitive to the choice of displaced fuels and the performance of industrial combustion processes. Choices can drive results of LCA studies. This is especially true where it is not known how virgin or secondary fuels will be used and how the combustion processes will perform. The combination of a variation in fuel quality and composition, and differences in combustion processes in terms of their purpose (stationary, heat, electricity, mobile etc), location (regulatory control) and performance (efficiency) can result in variations in emissions. The table below provides an indication of the variation that can be encountered across a single fuel in one type of application. This table does not capture the bounds of performance, only some of the documented variation within this one source. Multiply this variation up over a range of fuels and combustion devices and this presents a significant source of uncertainty.

(1) US Energy Information Administration (2016), available at: http://www.eia.gov/dnav/pet/pet_sum_mkt_dcu_nus_m.htm

Table 5.11 EMEP/EEA Emission factors for process furnaces using refinery fuel oil

Pollutant	Value	Unit	Lower 95% confidence interval	Upper 95% confidence interval
NOx	142	g/GJ	71	284
CO	15	g/GJ	9.05	21.1
NMVOC	2.3	g/GJ	0.676	4.09
SOx	485	g/GJ	146	1700
TSP	20	g/GJ	12	28
PM10	15	g/GJ	9	21
PM2.5	9	g/GJ	5.4	12.6
Pb	4.6	mg/GJ	0.9	23
Cd	1.2	mg/GJ	0.24	6
Hg	0.3	mg/GJ	0.03	0.6
As	3.98	mg/GJ	0.796	19.9
Cr	14.8	mg/GJ	2.96	74
Cu	11.9	mg/GJ	2.38	59.5
Ni	1030	mg/GJ	206	5150
Se	2.1	mg/GJ	0.40	10.5
Zn	49.3	mg/GJ	9.86	247
PCDD/F	2.5	ng I-TEQ/GJ	1.25	3.75

Source EMEP/EEA air pollutant emission inventory guidebook - 2013

There is a long track record of comprehensive emissions accounting and monitoring of the efficiency of large-scale combustion operations, such as power plants and refineries. This is in part due to their potential significance for national inventories and local environmental loading. Such data are captured in life cycle inventories for national and regional electricity generation grids and for large industrial processes, including refineries. It is generally accepted that these life cycle inventories are consistent in the breadth of environmental flows considered and in capturing the most important environmental contributors. Significantly, these data show a considerable range from worst to best performing units. This is often overlooked in LCA where average values are frequently used. This serves to disguise an important source of uncertainty in potential displacement benefits through use of secondary fuels.

For the study presented here, an approach was needed to address the significant issue of uncertainty around the use of virgin and secondary fuels in the market and smaller industrial processes. This approach needed to capture this variation without imposing a bias in the choice of combustion route and combustion technology performance through selecting a particular process (which has often been the case in previous work). To this end, a bespoke (customized) combustion model was developed that attempted to accommodate this variation. This model generated fuel-specific emission factor ranges, under default, low and high pollution control conditions.

The combustion model included estimates of high, low and default concentrations of selected pollutants, which are more dependent on the type of combustion device than on the variation in fuel composition (eg CO, CH_4). For other emissions that are more related to fuel composition (eg metals) and/or pollution control, emission factors are derived from fuel composition

and assumed pollutant capture rates. In this approach, the application of retention rates was used to calculate the amount of a given constituent substance retained within the combustion equipment or otherwise mitigated prior to release to the environment. The retention rates developed in Phase I have been used (see *Table 5.12*).

Table 5.12 Summary of retention rates used in the study

	Sulfur	Metals	Halogens	Phosphorus
High pollution control (HPC)	0.6	0.998	0.2	0.99
Low pollution control (LPC)	0.02	0.4	0.1	0
Default	0.31	0.699	0.15	0.495

Elemental flows, including sulfur and metals, were modeled on a mass balance basis, in which a portion of the constituent element is retained within the equipment and the rest is released into the environment. All metals are assumed to have the same retention rate. Constituents that are retained within the combustion equipment as bottom and/or fly ash are assumed to be landfilled in residual material landfills. In an extension compared to Phase I, the subsequent leaching to the environment due to infiltration water is modelled and described in Section 4.1.3.

Data sources

The following references are used to determine fuel compositions and emission factors:

- Summit: composition data (a program carried out for CalRecycle – data provided for this work by personal communication from Robert Carlson of CalRecycle. Full data to be published on CalRecycle website.)

- Life Cycle Assessment of Used Oil Management in California carried out by University of California, Santa Barbara (UCSB) in 2013. The combustion model developed by the UCSB is based on combustion data coming from different data sources. These references include the MACT (Maximum achievable control technology) database, which reports combustion of a variety of fuels from a large number of facilities in the US, as well as a study of the combustion of used oil in a small vaporizing space heater by Lubrizol (P. Dyke, 2007). To meet the objectives of this work, no additional data were required. We recommend that further work be done to characterize the emissions from use of used-oil derived fuels in a number of processes so that additional site and process-specific data can be generated. This will be valuable in quantifying absolute emissions, changes with short term fuel substitutions and appropriate factors for a range of processes.

- US EPA AP 42 compilation of air pollutant emission factors. This includes emission factors from stationary point and area sources such as boilers. The current revision dates from the late 1990s.

- Life Cycle Inventories of Waste Treatment Services, ecoinvent report No.13 by Doka G. (2009), reporting short and long-term transfer coefficients for residual material landfills.

Product composition

A metals balance was imposed on the used oil processing routes. The differences between used oil composition and product composition analysis data resulted in fuel product composition being amended and any surplus contaminant differences being attributed to the asphaltic residue and/or to be captured and disposed to landfill.

Due to a lack of composition data for by-products such as light ends, and given the fact that these lighter fractions account for less than 10% for one given route, it was assumed that metals that are not carried over in the main distillation product were contained in the asphaltic residue. We understand that lighter components including chlorine containing organic chemicals can be concentrated in the light ends, but we do not have sufficient information to quantify this effect or emissions that result from combustion. As a result, asphaltic residues have a different composition depending on the route. For the used oil recycling to RFO route, it was assumed that any metal content of used oil that is greater than the RFO composition analysis were removed from the used oil and sent to landfill. For metal content of used oil that is lower than the RFO analysis data, it was assumed 100% was carried over from used oil to the fuel product and therefore metal concentration is presented in the used oil baseline rather than RFO column of *Table 5.13*.

Starting compositions used in this study are summed up in the following table:

Table 5.13 Compositions - Summary

Element	Unit	UO baseline	UO fuel products			Heavy Fuel Oil (No.6)	Diesel (No.2)
			RFO	MDO	VGO		
Aluminum	kg/kg	1.50E-05	9.26E-06	7.89E-07	5.00E-07	3.73E-06	5.00E-07
Antimony	kg/kg	4.81E-06	1.50E-06	3.03E-07	2.50E-07	2.50E-07	2.50E-07
Arsenic	kg/kg	5.17E-07	5.17E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07
Barium	kg/kg	8.22E-06	3.57E-06	2.50E-07	2.50E-07	2.50E-07	2.50E-07
Beryllium	kg/kg	5.17E-08	5.11E-08	5.00E-08	5.00E-08	5.00E-08	5.00E-08
Boron	kg/kg	1.25E-04	1.15E-04	4.32E-06	2.15E-05	3.67E-06	2.50E-06
Cadmium	kg/kg	6.63E-08	5.11E-08	5.00E-08	8.29E-08	5.00E-08	5.00E-08
Calcium	kg/kg	1.49E-03	1.49E-03	4.72E-06	5.96E-06	1.09E-05	5.00E-07
Chloride	kg/kg	1.31E-04	1.31E-04	7.78E-05	1.51E-04	1.42E-04	
Chromium	kg/kg	2.20E-06	2.04E-06	2.00E-06	2.00E-06	2.20E-06	2.00E-06
Cobalt	kg/kg	2.58E-06	2.55E-06	2.50E-06	2.50E-06	2.50E-06	2.50E-06
Copper	kg/kg	2.00E-05	2.00E-05	2.50E-06	2.50E-06	2.50E-06	2.50E-06
Fluoride	kg/kg	3.30E-05	3.30E-05	2.50E-05	2.50E-05	2.50E-05	2.50E-05
Iron	kg/kg	5.01E-05	4.85E-05	2.50E-06	2.50E-06	1.43E-05	2.50E-06
Lead	kg/kg	1.09E-05	1.09E-05	5.00E-07	5.00E-07	5.00E-07	5.00E-07
Lithium	kg/kg	2.58E-06	2.55E-06	2.50E-06	2.50E-06	2.50E-06	2.50E-06
Magnesium	kg/kg	1.04E-04	9.51E-05	2.50E-06	2.50E-06	2.25E-06	2.50E-06

Element	Unit	UO baseline	UO fuel products			Heavy Fuel Oil (No.6)	Diesel (No.2)
Manganese	kg/kg	1.62E-06	1.62E-06	5.00E-07	5.00E-07	5.00E-07	5.00E-07
Mercury	kg/kg	4.28E-08	1.02E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
Molybdenum	kg/kg	4.35E-05	4.35E-05	2.50E-06	2.50E-06	2.50E-06	2.50E-06
Nickel	kg/kg	1.69E-06	8.52E-07	5.00E-07	5.00E-07	8.11E-06	5.00E-07
Phosphorus	kg/kg	5.70E-04	5.70E-04	1.49E-05	2.75E-05	1.09E-05	2.50E-06
Potassium	kg/kg	1.07E-04	8.10E-05	1.02E-04	1.32E-05	3.07E-05	5.34E-06
Selenium	kg/kg	1.03E-06	1.02E-06	1.00E-06	1.17E-06	1.00E-06	1.00E-06
Silicon	kg/kg	9.45E-05	9.45E-05	1.93E-05	2.52E-05	6.07E-06	1.00E-06
Silver	kg/kg	5.01E-07	2.55E-07	2.50E-07	2.50E-07	2.50E-07	2.50E-07
Sodium	kg/kg	7.90E-05	7.90E-05	2.50E-06	2.55E-06	5.99E-06	9.33E-06
Sulfur	kg/kg	2.09E-03	1.63E-03	5.00E-04	5.00E-04	1.60E-02	5.00E-04
Thallium	kg/kg	1.03E-07	1.02E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07
Tin	kg/kg	1.46E-05	1.35E-05	2.50E-06	2.50E-06	2.50E-06	2.50E-06
Titanium	kg/kg	3.12E-06	2.62E-06	2.50E-06	2.50E-06	2.50E-06	2.50E-06
Vanadium	kg/kg	2.32E-06	2.55E-07	2.50E-07	2.50E-07	1.74E-05	2.50E-07
Zinc	kg/kg	4.98E-04	4.98E-04	1.24E-06	1.33E-06	1.60E-06	5.00E-07

Natural gas

Natural gas consists mainly of methane (generally above 85%) and varying amounts of ethane, propane, butane and has a typical carbon content of 76%(w/w) (EPA AP 42).

The high, low and default emission factors used for natural gas combustion were taken from the Phase I LCA with the exception of CO_2, which was calculated on a stoichiometric mass balance basis and SOx, which was calculated on a retention rate and stoichiometric basis.

Table 5.14 EF summary – Natural gas

Pollutant	Unit	Default	HPC	LPC	Source
CH_4	kg/kg	5.5E-05	2.0E-06	1.0E-03	PHASE I
CO_2	kg/kg	2.8E+00	2.8E+00	2.8E+00	EPA AP42
N_2O	kg/kg	5.5E-06	5.5E-06	5.5E-06	PHASE I
CO	kg/kg	1.4E-04	1.2E-05	5.0E-04	PHASE I
NOx	kg/kg	8.0E-04	1.9E-04	2.3E-03	PHASE I
SOx	kg/kg	1.4E-05	8.3E-06	2.0E-05	EPA AP 42
PM total	kg/kg	4.0E-05	1.0E-05	2.0E-04	PHASE I
PM10	kg/kg	4.0E-05	1.0E-05	2.0E-04	PHASE I
PM2.5	kg/kg	4.0E-05	1.0E-05	2.0E-04	PHASE I
NMVOC	kg/kg	2.2E-04	3.0E-05	4.0E-02	PHASE I
PAH	kg/kg	1.4E-08	1.4E-09	1.4E-06	PHASE I

Inorganics and organics default emission factors were taken from US EPA AP42. Retention rates were then applied to determine emissions associated with high and low pollution control.

Coal

Coal used in the electric power industry in the US had a LHV of 22.6 MJ/kg and a sulfur content of 1.32% (w/w) in 2014. Carbon content was determined

considering US coal production data by coal type for 2013 (47.8% bituminous, 44.1% sub-bituminous, lignite 7.8%) and was estimated at around 75%. Combustion factors used were drawn from the AP42 document.

Table 5.15 EF summary – Coal

Pollutant	Unit	Default	HPC	LPC	Source
CH_4	kg/kg	2.30E-04	4.50E-06	2.30E-03	EPA AP 42
CO_2	kg/kg	2.70E+00	2.70E+00	2.70E+00	mass balance
N_2O	kg/kg	5.50E-06	5.50E-06	5.50E-06	EPA AP 42
CO	kg/kg	6.50E-03	2.30E-04	1.20E-01	EPA AP 42
NOx	kg/kg	6.50E-03	2.30E-03	1.50E-02	EPA AP 42
SOx	kg/kg	2.20E-02	1.90E-02	2.30E-02	EPA AP 42
PM total	kg/kg	7.70E-03	5.40E-05	3.00E-02	EPA AP 42
PM10	kg/kg	5.40E-03	3.30E-05	6.00E-03	EPA AP 42
PM2.5	kg/kg	6.40E-04	1.50E-05	2.10E-03	EPA AP 42
NMVOC	kg/kg	2.20E-04	3.00E-05	4.00E-02	EPA AP 42

As in the case of natural gas, for inorganics and organics pollutants associated with coal combustion, default emission factors were calculated using EPA AP42 default values, which were adjusted by the retention rates indicated in *Table 5.12* for the high and low pollution control situations.

Liquid fuels

In the study presented here, the following liquid fuels are considered: No.6 residual oil: No.2 distillate oil; and fuels derived from used oil and associated by-products.

Distillate oils are more volatile and less viscous than residual oils and have negligible nitrogen and ash content. Used oil RFO fuel product is close to virgin distillate fuel oil in terms of viscosity, but has higher ash content due to impurities and metal-containing chemical additives present in used oil.

A common approach has been used to determine the emission factors used in this study. Summaries of the emission factors determined for the different liquid fuels are given in the following tables (*Table 5.16, Table 5.17* and *Table 5.18*).

Table 5.16 EF summary – No.2 distillate oil

Pollutant	Unit	Default	HPC	LPC	Source
CH_4	kg/kg	1.3E-04	2.0E-06	4.0E-04	Phase I for liquid
CO_2	kg/kg	3.2E+00	3.2E+00	3.2E+00	mass balance
N_2O	kg/kg	2.6E-05	2.5E-05	4.0E-04	Phase I for liquid
CO	kg/kg	1.4E-04	7.0E-06	1.3E-03	Phase I for liquid
NOx	kg/kg	1.7E-03	1.8E-04	5.8E-03	Phase I for No.2 and UO
SOx	kg/kg	6.9E-04	4.0E-04	9.8E-04	mass balance + retention rates
PM total	kg/kg	9.6E-05	7.9E-06	2.9E-03	Phase I for No.2
PM_{10}	kg/kg	4.8E-05	4.0E-06	1.5E-03	EPA size distribution
$PM_{2.5}$	kg/kg	1.2E-05	9.5E-07	3.5E-04	EPA size distribution
NMVOC	kg/kg	3.7E-04	1.0E-05	3.2E-03	Phase I for liquid

Pollutant	Unit	Default	HPC	LPC	Source
PAH	kg/kg	1.0E-05	2.0E-08	3.0E-03	Phase I for liquid

Table 5.17 EF summary – No.6 residual oil

Pollutant	Unit	Default	HPC	LPC	Source
CH_4	kg/kg	1.3E-04	2.0E-06	4.0E-04	Phase I for liquid
CO_2	kg/kg	3.1E+00	3.1E+00	3.1E+00	mass balance
N_2O	kg/kg	2.6E-05	2.5E-05	4.0E-04	Phase I for liquid
CO	kg/kg	1.4E-04	7.0E-06	1.3E-03	Phase I for liquid
NOx	kg/kg	7.2E-03	3.2E-03	1.2E-02	Phase I for No.6
SOx	kg/kg	2.2E-02	1.3E-02	3.1E-02	mass balance + retention rates
PM total	kg/kg	9.1E-04	6.0E-05	2.2E-02	Phase I for No.6
PM_{10}	kg/kg	7.8E-04	5.1E-05	1.9E-02	EPA size distribution
$PM_{2.5}$	kg/kg	5.1E-04	3.4E-05	1.2E-02	EPA size distribution
NMVOC	kg/kg	3.7E-04	1.0E-05	3.2E-03	Phase I for liquid
PAH	kg/kg	1.0E-05	2.0E-08	3.0E-03	Phase I for liquid

Table 5.18 EF summary –RFO

Pollutant	Unit	Default	HPC	LPC	Source
CH_4	kg/kg	1.3E-04	2.0E-06	4.0E-04	Phase I for liquid
CO_2	kg/kg	3.1E+00	3.1E+00	3.1E+00	mass balance
N_2O	kg/kg	2.6E-05	2.5E-05	4.0E-04	Phase I for liquid
CO	kg/kg	1.4E-04	7.0E-06	1.3E-03	Phase I for liquid
NOx	kg/kg	1.7E-03	1.8E-04	5.8E-03	Phase I for No.2 and UO
SOx	kg/kg	2.2E-03	1.3E-03	3.2E-03	mass balance + retention rates
PM total	kg/kg	1.6E-03	1.6E-05	5.3E-03	Phase I for Used Oil
PM_{10}	kg/kg	1.3E-03	1.3E-05	4.2E-03	EPA size distribution
$PM_{2.5}$	kg/kg	7.9E-04	8.1E-06	2.6E-03	PHASE I size distribution
NMVOC	kg/kg	3.7E-04	1.0E-05	3.2E-03	Phase I for liquid
PAH	kg/kg	1.0E-05	2.0E-08	3.0E-03	Phase I for liquid

The derivation of emission factors for liquid fuels is described in more detail in the following paragraphs.

The derivation of emission factors for liquid fuels is described in more detail in the following paragraphs.

Carbon dioxide (CO^2)

Carbon dioxide emission factors were calculated based on fuel carbon content, assuming 99% conversion of carbon.

The carbon content of virgin fuels was based on data from AP 42: 87.3% for No.2 distillate oil; and 86.2% for No.6 residual oil. The carbon content assumed for used oil in this study is 86%.

Sulfur oxides (SOx)

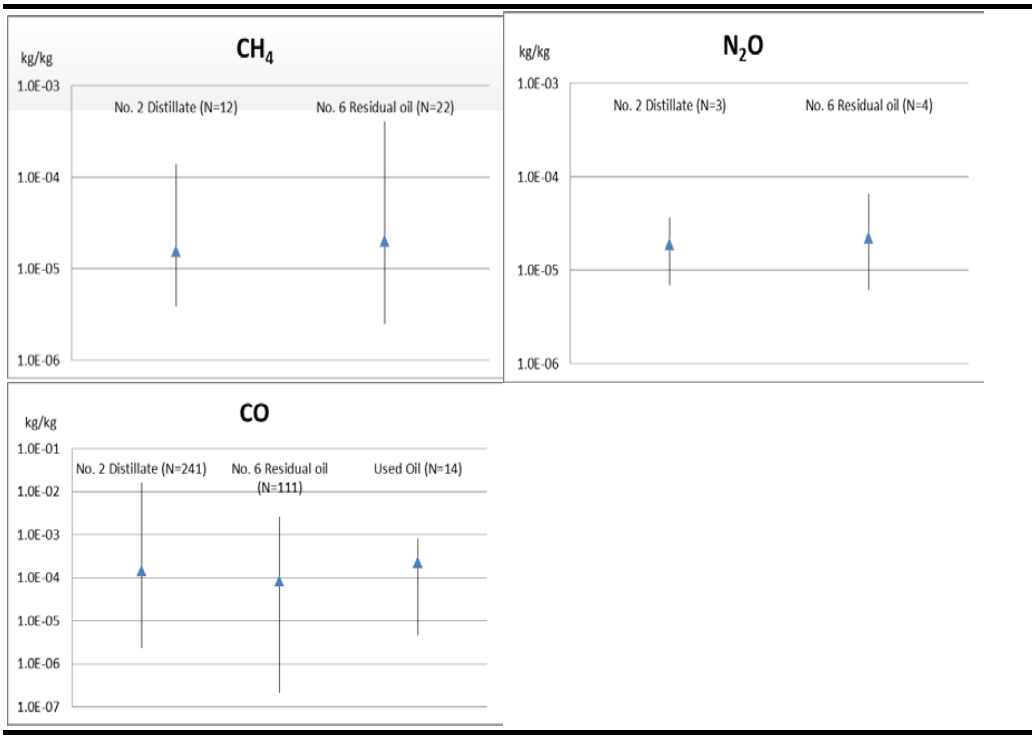
Sulfur oxide emission factors were also determined on a mass balance basis by considering that all the sulfur present in the fuel is converted to sulfur dioxide. Retention rates for sulfur were then applied to this maximum emission figure in order to calculate default, HPC and LPC values (see *Table 5.12*). Sulfur content applied to of the different fuels is shown in *Table 5.13*.

Other greenhouse gases (CH_4, N_2O) and carbon monoxide (CO)

Methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO) emissions are produced during fuel oil combustion and vary with the type of fuel and firing configuration.

We have no basis to suggest a significant difference in these emissions among the liquid fuels, so they are assumed to be equal for all liquid fuels (see *Figure 5.1*). Default values were determined by calculating the geometric mean of emission factors for all liquid fuels. Maximum and minimum values were assumed to represent high and low pollution control, respectively.

Figure 5.1 Analysis of available emission data for CH_4, N_2O and CO

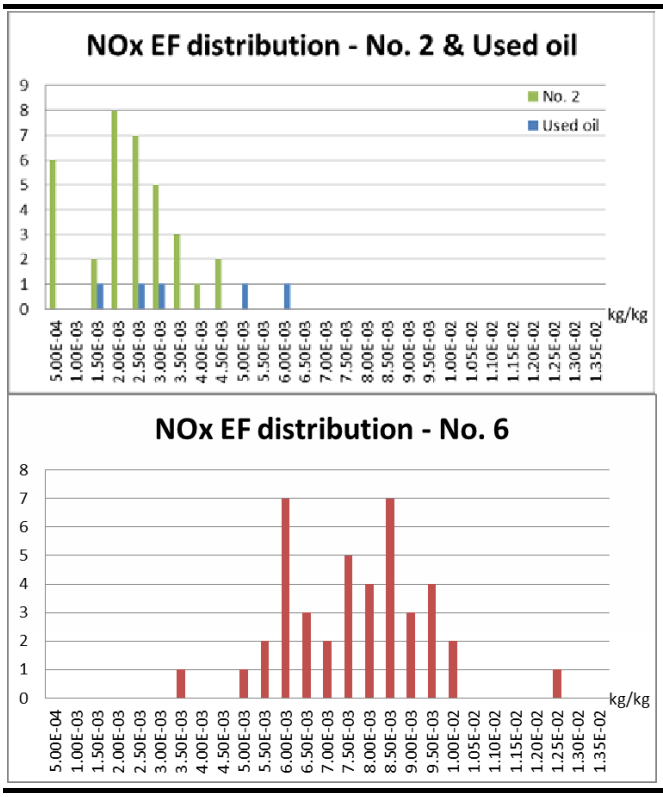


Nitrogen oxides (NOx)

While fuel nitrogen conversion is an important NOx-formation mechanism in residual oil boilers, thermal fixation is the dominant mechanism in units firing distillate oils, primarily because of the negligible nitrogen content in these lighter oils. As distillate oil-fired boilers are usually smaller and have lower heat release rates, the quantity of thermal NOx formed in them is less than that of larger units that typically burn residual oil. Used oil has similar

properties to No.2 in terms of composition and viscosity and it is assumed that thermal NOx account for the majority of NOx emissions from used oil combustion as is the case for No.2 distillate fuel oil.

Figure 5.2 *Analysis of available emission data for NOx*

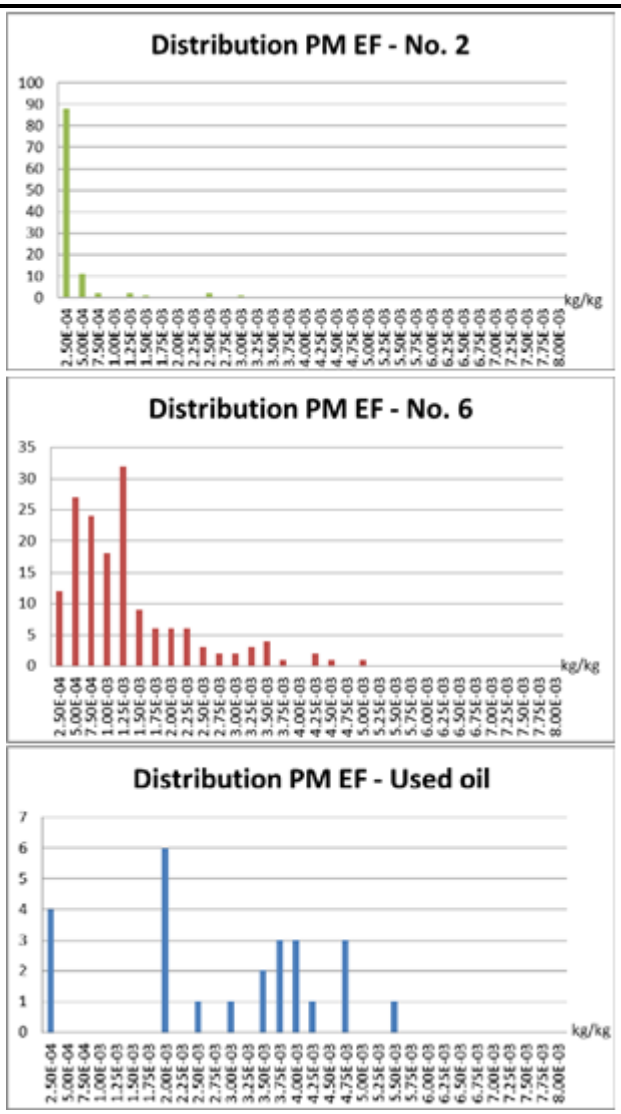


For the study presented here, it was assumed that used oil and No.2 distillate oil had the same NOx emission factors. Therefore, combustion factors were calculated from the data used in the Phase I study considering the average, minimum and maximum values for these fuels. No.6 residual oil emission data have been considered separately to determine default, HPC and LPC combustion factors specific to heavy fuel oil.

Particulate matter (PM)

Ash levels in used oil are normally much higher than ash levels in either distillate oils or residual oils, as used oil has substantially higher concentrations of most trace elements. Therefore, specific PM emissions factor for each fuel are derived from the Phase I study.

Figure 5.3 Analysis of available emission data for total PM



Default values for each fuel are determined by calculating the geometric mean of the corresponding dataset from the Phase I study, HPC values as the minimum and LPC as the maximum.

To determine corresponding PM10 and PM2.5 emission factors, the size distribution given in the Phase I study was used, as presented in *Table 5.19*.

Table 5.19 PM size distribution

Fuel	PM10/ PM total	PM2.5/ PM total	Source
RFO	0.8	0.5	EPA AP 42, PHASE I
No.2	0.5	0.12	EPA AP 42
No.6	0.86	0.56	EPA AP 42

Organic compounds (NMVOC and PAH)

The flue gases from fuel oil and used oil combustion often contain organic compounds, including volatile organic compounds (VOC) and condensable organic compounds.

For the purposes of this study there was no basis to distinguish between emissions of VOC or PAH on the basis of fuel type so all were set to be equal as per Phase I. Total NMVOC and PAH emissions factors were drawn from the Phase I study and then split into specific emission factors using the speciation profiles indicated in Phase I report and shown in *Table 10.7* (see *Annex A)* and in *Table 10.8* (see *Annex A*)

Metals

Quantities of metals emitted to air were determined for each configuration (default, high pollution control (HPC) and low pollution control (LPC)) by applying corresponding retention rates (see *Table 5.12*) to the fuel derived metal quantity (based on compositions determined in *Table 5.13*). Metals not emitted to air were assumed to be retained in bottom ash or residues, which are subsequently sent to landfill. This assumption extends the phase I model where these contaminant fates were ignored.

5.1.12 Emissions to water

Residues resulting from burning fuels were treated as being disposed in controlled landfills.

It has then been assumed that landfilled substances may be leached as a result of water infiltration and leachate management and loss. The rate of leaching is highly uncertain and will differ depending on landfill location, construction and management. The quantities of substances leached to the environment are estimated using short-term transfer coefficients (*Table 5.20*) developed for landfills (emissions occurring over the first 100 years), drawn from Doka G. (2009).

Table 5.20 Short-term transfer coefficients for residual material landfills

Element	Short-term coefficient (kg/kg element)	Element	Short-term coefficient (kg/kg element)
Ag	6.43E-05	Mn	1.38E-05
Al	4.96E-04	Mo	9.95E-01
As	1.00E+00	N	1.89E-01
B	7.84E-03	Na	3.75E-01
Ba	1.38E-05	Ni	6.04E-04
Be	6.04E-04	O	1.51E-04
Br	8.03E-01	P	3.73E-04
C	1.08E-03	Pb	8.66E-06
Ca	1.51E-04	S	1.07E-01
Cd	1.13E-05	Sb	3.53E-01
Cl	2.86E-01	Sc	1.41E-01
Co	2.85E-04	Se	3.53E-01

Element	Short-term coefficient (kg/kg element)	Element	Short-term coefficient (kg/kg element)
Cr	6.01E-02	Si	2.25E-03
Cu	6.43E-05	Sn	3.16E-05
F	5.42E-02	Sr	6.04E-04
Fe	8.36E-06	Ti	4.96E-04
H	1.51E-04	Tl	6.04E-04
Hg	7.88E-05	V	2.45E-03
I	1.00E+00	W	3.53E-01
K	2.82E-01	Zn	2.05E-05
Mg	1.90E-04		

5.1.13 Data Quality Assessment

The reliability, completeness, geographical correlation, temporal correlation and technological correlation of all data used in this study were assessed against the data quality requirements described in *Table 10.10* in *Annex A.*

6.1 IMPACT ASSESSMENT CATEGORIES

The impact indicators chosen for this study have been sourced primarily from the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI 2.1), which was developed by the US Environmental Protection Agency (EPA).

The TRACI impact assessment method transforms data gathered in the inventory phase to a number of indicator scores. These indicator scores express the relative severity of a contribution to an environmental impact category and can either be represented at the 'midpoint' or 'endpoint' stage. At the 'midpoint' stage, individual impact categories are shown, with a score given for each impact in the appropriate unit. 'Midpoint' indicators can be grouped and weighted to produce an aggregated score, known as an 'endpoint'. In this study, results are represented at the midpoint stage, which allows for easier evaluation of individual impact categories.

With respect to resource depletion, in addition to TRACI, the CML 2001 impact assessment method was also used in this study. This method was developed by the Institute of Environmental Science at Leiden University in The Netherlands. Impact categories for both 'elements' and 'fossil fuels' from CML 2001 were chosen and results presented at the 'midpoint' stage. The impact of fossil depletion was calculated using both TRACI 2.1 and CML 2001 to allow two alternative metric scores for interpretation. TRACI 2.1 represents fossil depletion in terms of the extra energy required to extract a fuel in the future (due to depletion) compared with the same fuel today, whereas CML 2001 simply represents the MJ of energy associated with the extracted fossil fuel.

The environmental indicators and impact categories used in this study are presented below:

- Acidification (TRACI 2.1);
- Ecotoxicity (TRACI 2.1);
- Eutrophication (TRACI 2.1);
- Global warming (TRACI 2.1);
- Human health, particulates in air (TRACI 2.1);
- Human toxicity, cancer (TRACI 2.1);
- Human toxicity, non-cancer (TRACI 2.1);
- Ozone depletion (TRACI 2.1);
- Smog (TRACI 2.1);
- Fossil fuel depletion (TRACI 2.1);
- Abiotic depletion, elements (CML 2001); and
- Abiotic depletion, fossil fuels (CML 2001).

For some impact categories, particularly human toxicity and freshwater ecotoxicity, there is a high level of uncertainty associated with the impact assessment methods. As a result, their completeness, suitability and adequacy in representing and comparing impacts is still the subject of some scientific discussion.

The impact assessment reflects potential, rather than actual, impacts and takes no account of the local receiving environment. As a result, the actual impacts could be very different from the values presented and there remains significant uncertainty associated with these. LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

In the Phase I LCA, UCSB performed sensitivity analyses on the choice of LCIA method, comparing toxicity results generated using TRACI 2.0 (baseline) with those generated using ReCiPe 1.07 and CML (2010). This investigation found that, in some cases, toxicity and ecotoxicity impacts differ, depending on the LCIA method chosen, which is likely to be due to differences in the characterization factors used in each method for certain substances (see Section 6.2.3 of the Phase I report for more details).

6.1.1 Acidification

Acidification refers to processes that increase the hydrogen ion concentration ([H+]) of water and soil systems, such as atmospheric deposition of sulfur, nitrogen and phosphorous compounds. Any change from the natural pH can have detrimental effects on plant and aquatic life.

Some common emissions that contribute to acidification include nitrogen oxides (NOx), sulfur dioxide (SO_2) and ammonia (NH_3). The TRACI 2.1 method calculates characterization factors for acidification, based upon moles of hydrogen equivalents (mol H+ eq) for each acidifying gas, and then averages these H+ formation potentials based on average atmospheric composition of these gases in the US. The resulting characterization factor unit for acidification is presented in relation to 1 kilogram of SO_2 (kg SO_2 eq).

6.1.2 Ecotoxicity

Ecotoxicity is a measure of the toxic impact that chemicals emitted by human activities have on natural ecosystems and the organisms that live in them.

In TRACI 2.1, the USETox(1) model is used to assess the ecotoxicological effects of substances, and was developed by the United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC). This model contains ecotoxicity potentials for over 3,000 organic and inorganic substances.

(1) UNEP/SETAC (2010) Available online: http://www.usetox.org/sites/default/files/support-tutorials/user_manual_usetox.pdf.

USETox characterization factors consider a fate factor, an exposure factor, and an effect factor. The fate factor considers transportation and transformations of chemicals within urban air, rural air, freshwater, sea, natural soil and agricultural soil compartments on a 'continental' scale and transportation and transformations of chemicals within air, freshwater, ocean, natural soil and agricultural soil compartments on a 'global' scale.

The exposure factor considers partition coefficients between different phases (eg dissolved organic carbon and freshwater). The effect factor is based on the concentration at which 50% of the species population displays a negative effect during ecotoxicological tests.

These three parameters are calculated for each substance and the resulting characterization factor is given in units of comparative toxicity units (CTUe). As such, it gives a relative indication of ecotoxicity potential, but not a measure of actual impacts, which will depend strongly on the concentration of releases, their location and the receiving environment.

6.1.3 Eutrophication

Eutrophication is defined as nutrient enrichment (which can result in algal growth) in an aquatic environment, resulting in increased consumption, and hence depletion, of oxygen from the environment. This nutrient pollution is typically generated in aquatic environments from phosphorous or nitrogen compounds through discharges from sewage treatment works, decaying plant life in pulp and paper mills, and storm water run-off of fertilizers or manure.

In TRACI 2.1, eutrophication is expressed in equivalents of kilograms of nitrogen (kg N eq) for freshwater ecosystems. Only phosphorous and nitrogen compounds are characterized in this impact category.

6.1.4 Global warming

Global warming potential is a metric representing the adverse environmental effect caused by man-made emissions of greenhouse gases which cause heat to be trapped in the atmosphere and so result in a temperature rise of the Earth's surface. The Intergovernmental Panel on Climate Change (IPCC) has developed a characterization model to quantify the climate change impact of emissions released to the atmosphere. Emissions of different gases are given characterization factors, expressing the release of a gas in terms of its carbon dioxide equivalent (CO_2 eq), depending upon its radiating force in relation to that of CO_2.

On calculating CO_2 equivalents, the residence time of the gases in the troposphere is taken into account and models for time periods of 20, 50 and 100 years have been developed. Commonly, a time horizon of 100 years is used, as this better reflects the long-term impacts of climate change. A 100-year time horizon is used in TRACI 2.1 and is therefore employed in this project.

In TRACI 2.1, and for the purposes of this study, the substances contributing to climate change and their corresponding characterization factors (also known as global warming potential, GWP) were based on IPCC 2007 data[1] . The contribution to climate change was calculated by summing the products of the amount of each emitted harmful material (mi) and the corresponding characterization factor (GWPi) as expressed in the following equation:

Climate change = Σ(mi x GWPi)

Climate change and biogenic carbon

Although bio-based lubricants are not considered in this LCA study and, therefore, there are no anticipated biogenic carbon emissions from the direct processing of used oil, there is the potential in other parts of the life cycle system upstream and downstream of these stages to use biogenic sources for energy generation etc. Therefore, it is necessary to state how this biogenic carbon is handled. There are different approaches to calculating climate change impacts related to biogenic carbon. The approaches can be described as follows.

a) *Accounting for carbon uptake.* Biogenic CO_2 uptake is included in the calculations. During the growth phase of renewable materials (eg trees, crops), CO_2 from the atmosphere is absorbed and converted through photosynthesis. This is accounted for in the calculation through a negative characterization value. At the end of the material's life, the carbon stored in the material is released again. This is accounted for in the calculation through a positive characterization value.

b) *Assuming carbon neutrality.* Uptake of CO_2 during the growth phase and the emission of CO_2 at end of life are assumed to counterbalance one another. As such, the uptake and emission of CO_2 are disregarded in the calculations.

In this study, approach b) was applied.

Emissions of methane from biogenic materials (eg during landfill) are always accounted for.

6.1.5 Human health, particulates in air

Particulate matter refers to minute pieces of solid or liquid matter suspended in the atmosphere. Particulate matter can be anthropogenic or natural, and can adversely affect human health (eg causing respiratory illnesses such as asthma) and have impacts on climate and precipitation. Particle pollution is made up of a number of components, including ammonia, NOx, SOx, organic chemicals, metals, ash, and dust particles.

(1) IPCC 2007, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avery KB, Tignor M, Miller HL (ed

The size of particles is directly linked to their potential for causing health problems. Once inhaled, the smallest particles can affect the heart and lungs and cause serious health effects. Respirable particles with a diameter of less than 10 µm are referred to as PM10. Fine particles with a diameter of less than 2.5 µm are referred to as PM2.5.

Particle impacts are reported as an expression of the potential impact atmospheric particulates have on human health. In TRACI 2.1, this is reported in kilograms of $PM_{2.5}$ equivalents (kg PM2.5 eq), as the smallest particles are those of most concern to human health, following the approach used in Humbert (2009) [(1)].

6.1.6 Human toxicity, cancer

The carcinogenic toxicity of substances to humans is assessed in TRACI 2.1 using the USETox model[(2)]. This model contains human health cancer and non- cancer toxicity potentials for over 3,000 organic and inorganic substances.

USETox characterization factors consider a fate factor, an exposure factor and an effect factor. The fate factor is identical to that used in the ecotoxicity impact category and considers transportation and transformations of chemicals at continental (urban air, rural air, freshwater, sea, natural soil and agricultural soil) and global (air, freshwater, ocean, natural soil and agricultural soil) scales. The following exposure pathways are models for the exposure factor: air; drinking water; exposed produce (above-ground crops); unexposed produce; meat; dairy; and fish. Finally, the effect factor considers the change in lifetime disease probability due to the change in lifetime intake of a given substance.

These three parameters are calculated for each substance and the resulting characterization factor is given in units of comparative toxicity units (CTUh). As with the other toxicity indicators, this is therefore a potential impact, and not a measure of actual impact, which will depend on many site-specific factors.

6.1.7 Human toxicity, non-cancer

Similarly, non-carcinogenic toxicity of substances to humans is also assessed in TRACI 2.1 using the USETox model. Characterization factors for non-carcinogenic toxic substances are provided in units of comparative toxicity units (CTUh).

(1) Humbert, S. (2009) Geographically Differentiated Life-cycle Impact Assessment of Human Health - A Dissertation. University of California, Berkeley.
(2) UNEP/SETAC (2010) Available online: http://www.usetox.org/sites/default/files/support-tutorials/user_manual_usetox.pdf.

6.1.8 Ozone depletion

Ozone depletion refers to the destruction of stratospheric ozone. This layer of ozone is crucial to life, as it absorbs harmful solar ultraviolet radiation that can cause increased human health risk and have negative impacts on plant life and aquatic ecosystems if it reaches the troposphere. Ozone depleting substances, such as chlorine from chlorofluorocarbons (CFCs) and bromine from halons, can decrease the concentration of ozone in the stratosphere resulting in the potential for less ultraviolet radiation to be absorbed.

In TRACI 2.1, ozone depletion is measured in terms of the capacity for an emission to reduce ozone in the stratosphere relative to the ozone reduction potential of trichlorofluoromethane (CFC-11) as a baseline. This is commonly expressed in terms of kilograms of CFC-11 per kilogram of emission of a substance. The significance of ozone layer depletion has reduced with the effectiveness of the Montreal protocol in reducing emissions of ozone depleting substances.

6.1.9 Smog

Photochemical smog (or photochemical ozone formation, or simply smog) is an indicator of the potential adverse effects from the formation of low-level ozone and other photo-oxidants formed through a complex reaction pattern involving sunlight and nitrogen oxides (NOx) with certain air pollutants, such as volatile organic compounds (VOCs), nitrogen oxides (NOx) and carbon monoxide (CO). Smog can adversely affect human health by causing respiratory illnesses such as asthma and emphysema.

Models are used to calculate photochemical oxidation are based on the mass of each released substance and the photochemical ozone creation potential (POCP) of the substance. POCP is a measure of the likelihood of the substance to contribute towards smog formation. POCPs are calculated from the change in ozone concentration in a set volume of air with the introduction of the emission of a substance relative to the change in emission of ethylene. TRACI 2.1 considers the POCP of nearly 1,200 substances, which are based on data from Carter (2010) [(1)] . The reference unit used for photochemical oxidation is kilograms of ozone equivalents (kg O_3 eq).

6.1.10 Fossil fuel depletion

Fossil fuel depletion is a measure of the impact from consuming non-renewable natural fossil resources. The consumption of resources that cannot be regenerated, or may take thousands of years to regenerate, limits the options of future generations and can result in more expensive and damaging exploration and extraction of poorer quality or less-available reserves. This impact category was not considered in the Phase I LCA.

(1) Carter, W. (2010b) SAPRC Atmospheric Chemical Mechanisms and VOC Reactivity Scales.

The term fossil fuel refers to a group of resources that contain hydrocarbons. The group ranges from volatile materials like methane, to liquid petrol/gasoline, to non-volatile materials like anthracite coal.

In TRACI 2.1, based on a method used in Eco-indicator '99 (1) , it is assumed that continued extraction of fossil fuels would consume the most economically recoverable reserves before attempting to consume less accessible reserves. Using this approach, the increase in unit energy requirement for the extraction and production of each fuel type in a number of future scenarios was calculated and represented in terms of MJ of surplus energy. As such, the result does not indicate how much fossil fuel is used in a given scenario, but rather provides a projection of the increasing effort to extract resources in future.

6.1.11 Abiotic depletion, elements

Abiotic depletion is a measure of the impact from consuming non-living, non-renewable natural resources such as iron ore, crude oil and coal. The consumption of 'elements', specifically, considers metal and non-metal element resources that are extracted through mining operations. This impact category was not considered in the Phase I LCA.

In the CML approach, based on a method by Guinee (1996) (2) , the quantity of resource extracted is compared to the ultimate reserve of the resource. In addition, the depletion of antimony (Sb) is used as a reference resource and the unit of the resulting characterization factor is kilograms of Sb equivalents (kg Sb eq). Therefore, the result is not an absolute measure of depletion of any element or group of elements but rather an estimate drawn from comparing use to reserves (as per the model).

6.1.12 Abiotic depletion, fossil fuels

'Abiotic depletion, fossil fuels' is an aggregated measure of the energy extracted from the ground through consuming fossil fuels, such as crude oil and coal. The CML method is based on work by Guinee (1996), and directly reflects the energy associated with the fossil resource extracted. The resulting characterization factor is presented in terms of MJ of fossil depletion. Again, the indicator is not the absolute value of fossil fuels used in a scenario, but an estimate of energy associated with extraction of the fossil fuel used. This impact category was not considered in the Phase I LCA.

(1) Pre (2000) Available online: https://www.pre- sustainability.com/download/EI99_Manual.pdf
(2)Guinee, J., R. Heijungs, L. van Oers, D. van de Meent, T. Vermeire, and M. Rikken. 1996. LCA impact assessment of toxic releases: Generic modelling of fate, exposure, and effect for ecosystems and human beings with data for about 100 chemicals. No. 1996/ 21. The Hague, The Netherlands: VROM, Ministry of Housing, Spatial Planning, and the Environment.

6.2 *LIMITATION OF LCIA*

For some impact categories, particularly human toxicity and freshwater ecotoxicity, there is a high level of uncertainty associated with the impact assessment methods. The characterization factors for metals are all considered 'interim', i.e. these factors can be used, but should be interpreted with care, since they have a high level of uncertainty. As a result, their adequacy in representing impacts is still the subject of some scientific discussion.

The impact assessment reflects potential, not actual, impacts and takes no account of the local receiving environment.

6.3 *PROVIDING CONTEXT*

To provide some context with regard to the scale of the impact contribution for the used oil management systems appraised, we have developed some comparisons with the impact contribution from a selection of pollutant releases for the entire state of California in 2010. This is not a full normalization step as defined within ISO14040, as it is incomplete (not all pollutants or resource consumptions are captured). It is presented purely for illustrative purposes to provide the reader with a useful reference and sense of scale of the contribution from used oil management.

These 2010 context factors were determined using emissions inventory data and energy balance for the state of California, sourced from the following references:

- California Greenhouse Gas Emission Inventory: 2000-2012, 2014 edition;
- Almanac Emission Projection Data (published in 2013), 2010 Estimated Annual Average Emissions (NOx, SOx, PM, CO and organic gases emissions);
- 2010 California Toxic Inventory (including CFC-11 emissions); and
- California Energy Balance Database, January 2012 (data from 2008).

The context factors calculated for California in 2010 are shown in *Table 6.1* below. These context factors are used in subsequent evaluative displays, e.g., *Table 6.2*.

With the exception of GWP, the impact contribution for California is an underestimate, as it is based on a limited set of pollutants released in 2010.

Table 6.1 California Context Factors (2010)

Impact	Value	Comment
Acidification [kg SO_2-Equiv.]	6.6E+08	NOx, SOx and NH_3 emissions considered
Global warming air, excl. biogenic carbon [kg CO_2-Equiv.]	4.53E+11	CO_2, CH_4, N_2O, SF_6 and other halogenated gases
Human health particulate air [kg $PM_{2.5}$-Equiv.]	1.62E+10	$PM_{2.5}$, NOx, CO and NH_3 emissions considered
Ozone depletion air [kg CFC 11-Equiv.]	7.20E+03	CFC-11 emissions considered
Smog air [kg O_3-Equiv.]	2.12E+10	NOx and CO emissions considered
Abiotic depletion (ADP fossil) [MJ]	9.67E+12	based on data from 2008

6.4 LCIA RESULTS

6.4.1 Baseline (2010)

Figure 6.1 is the summary system diagram for the baseline scenario. The diagram identifies the major flows associated with the used oil management system and the contribution from the virgin system to meet any shortfall in the defined constant commercial market.

Table 6.2 provides Life Cycle Impact Assessment (LCIA) results for the environmental impact of the baseline scenario (scenario 1) for used oil management in California over one calendar year (2010). This scenario is designed to reflect a reasonable model of the generation and management of used oil in California in 2010 along with the 'top up' of virgin products necessary to meet the constant commercial market demand for all products as set for each basic product by assuming that all of the used oil generated in CA were to be collected and managed through a single process, e.g., re-refining to RRBO, or reclaiming/laundering to produce RFO.

Absolute values are presented for the total system for each impact category investigated in this study, and the units for each are also displayed in the table. For example, in this baseline scenario, the carbon footprint associated with management of 435,000 metric tonnes of generated used oil (and virgin fuel top up to meet the constant commercial market) in California in 2010 was ~ 2.8 million metric tonnes CO_2e (1) and the associated fossil fuel depletion was ~ 57 million MJ.

In addition, the contributions of formal management, informal management and virgin top-up (per impact category) are also provided in *Table 6.2* and *Figure 6.2*. It can be seen that for most impact categories (acidification, global warming, human health particulate, human health cancer, smog and resource depletion), virgin top-up contributed the majority of the environmental impact, with the remaining burden being shared between formal and informal management.

(1) e = equivalents

However, for other impact categories (ecotoxicity, eutrophication, human health non-cancer), informal management contributed the majority of the environmental impact. Although collection was estimated to be 74% of available used oil in California, the remaining 26% is shown to present a significant potential for environmental impact: highlighted by the high contribution to ecotoxicity (77%), human toxicity, non-cancer (82%) and eutrophication (53%) impact categories. Informal management also contributes 340 000 metric tonnes of carbon dioxide equivalents.

Formal management did not contribute substantially (< 26%) to the total environmental impact of any impact category, with one exception: ozone depletion, for which it is the major contributor (61%). The ozone depletion contribution is extremely low and is associated with secondary life cycle data used.

For global warming, acidification, particulate formation, ozone depletion, smog formation and abiotic depletion categories, results are compared against the California context factors, as described above.

Annex C identifies the main substances which contribute to each impact.

Figure 6.1 System summary diagram for the Baseline scenario

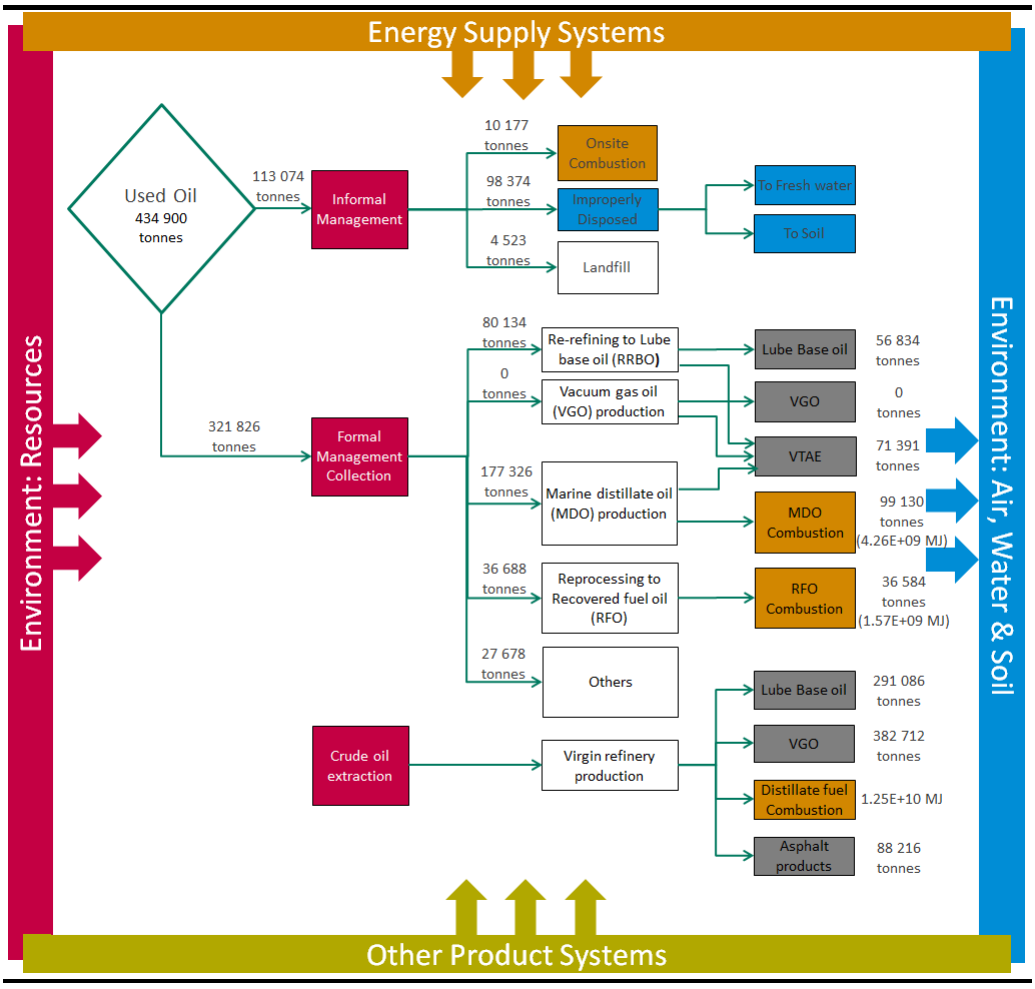
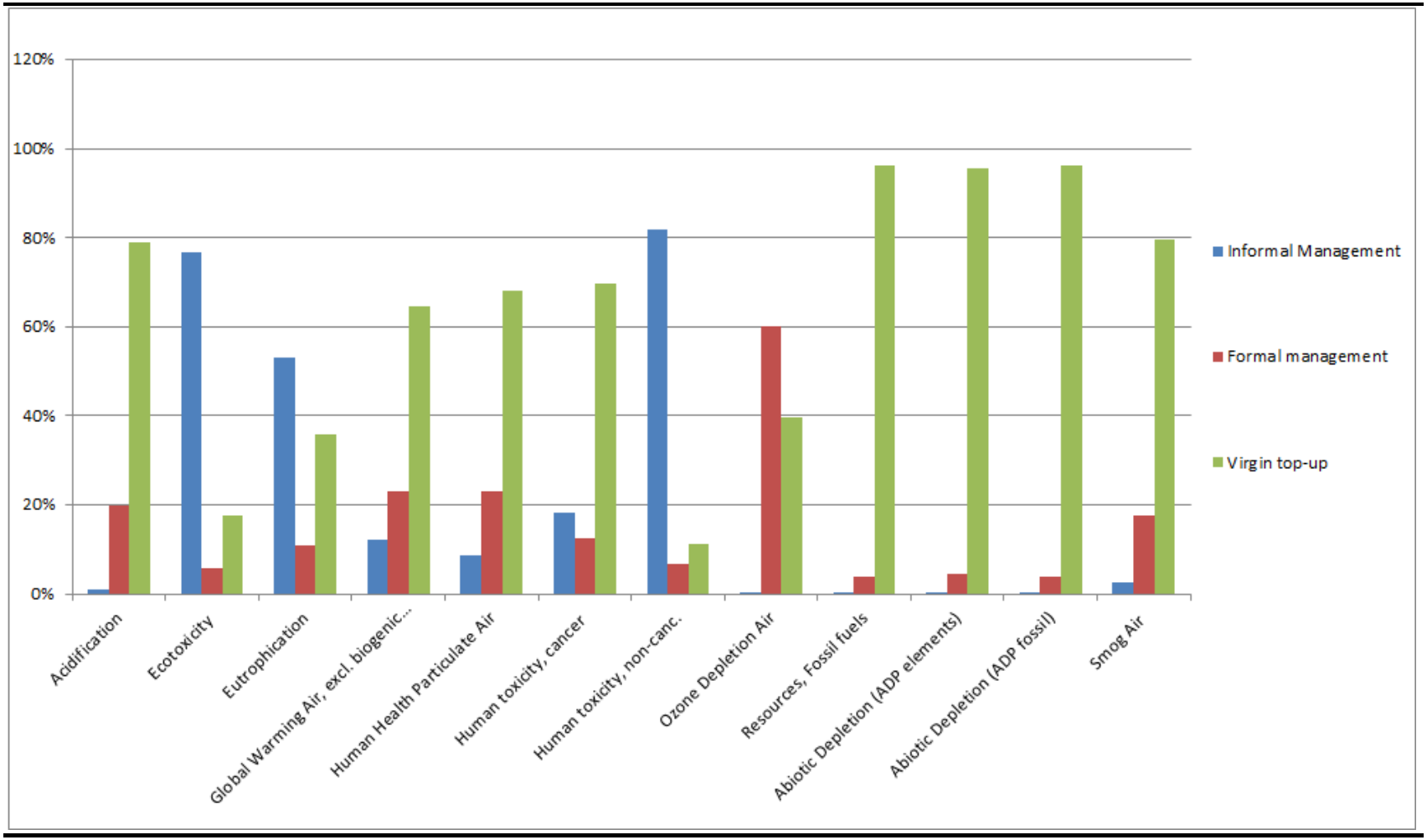


Table 6.2 Life Cycle Impact Assessment (LCIA) results for the baseline scenario (74% collection)

Impact	Unit	Baseline Total	Informal	Formal	Virgin top-up	Informal & formal contribution to California[1]	Total contribution to California[1]
Acidification	kg SO_2-Equiv.	7,574,619	73,783	1,505,788	5,988,112	0.24%	1.15%
Ecotoxicity	CTUe	4,358,638,296	3,336,365,378	256,035,518	765,967,701		
Eutrophication	kg N-Equiv.	449,301	238,573	49,373	160,593		
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,792,735,162	343,656,836	644,499,856	1,802,354,096	0.22%	0.62%
Human health particulate air	kg $PM_{2.5}$-Equiv.	567,665	49,181	130,824	387,138	0.001%	0.004%
Human toxicity, cancer	CTUh	2.8	0.5	0.3	1.9		
Human toxicity, non-canc.	CTUh	1,440	1,180	99	161		
Ozone depletion air	kg CFC 11-Equiv.	0.04	0	0.02	0.01	0.000%	0.001%
Resources, fossil fuels	MJ surplus energy	7,792,924,733	489,458	305,756,076	7,482,451,709		
Abiotic depletion (ADP elements)	kg Sb-Equiv.	520	0	23	497		
Abiotic depletion (ADP fossil)	MJ	57,404,070,661	3,781,525	2,243,674,926	55,125,367,980	0.02%	0.59%
Smog air	kg O_3-Equiv.	65,900,949	1,679,444	11,672,462	52,345,495	0.06%	0.31%

Figure 6.2 *Baseline scenario impact contribution*



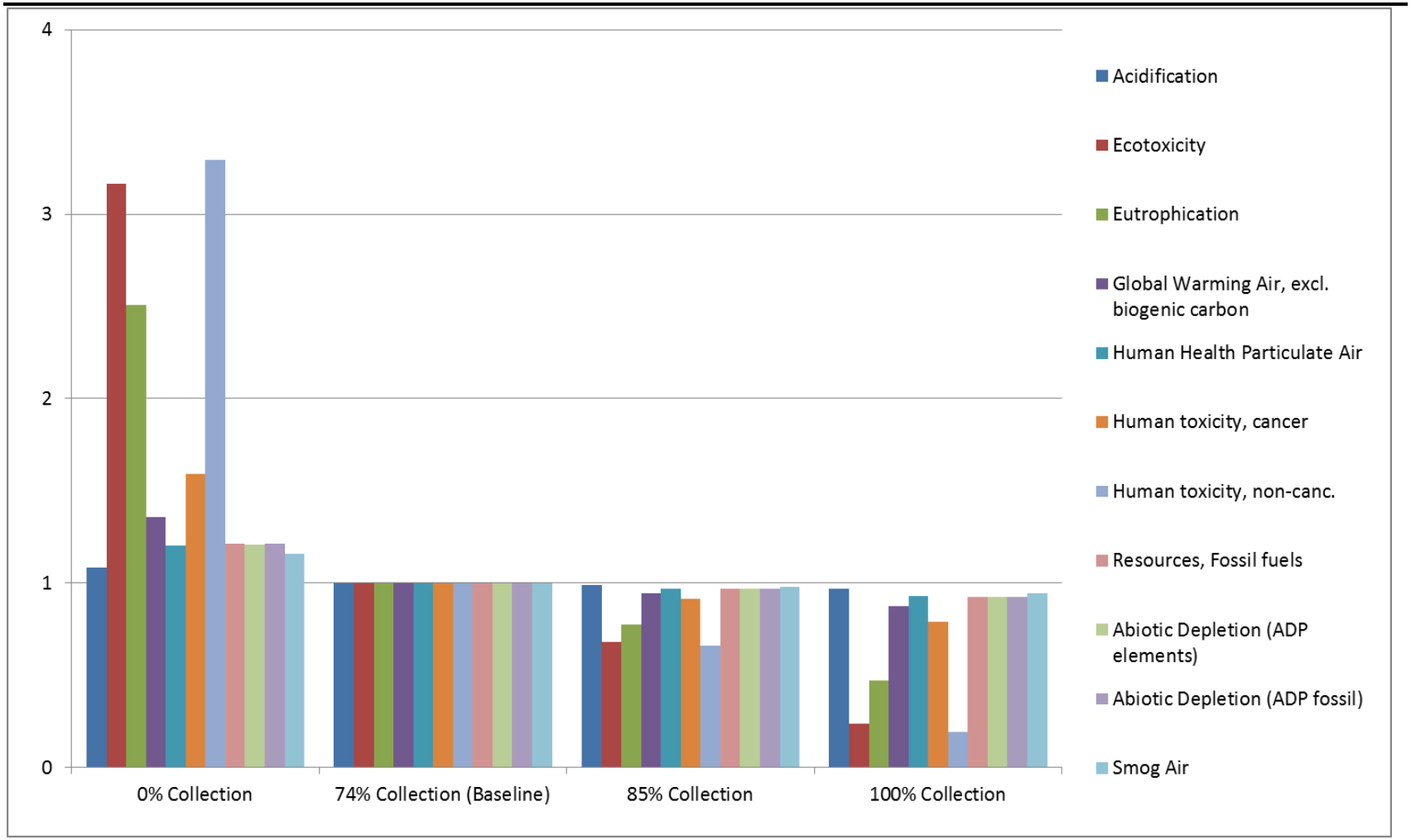
Examining the effects of changing the collection rate

CA Senate Bill 546 required assessment of steps that could be taken to improve the collection rate of used oil. *Figure 6.3* shows the consequence for the baseline scenario of altering the collection rate to 0%, 85% and 100%. Reducing collection would result in a significant increase in environmental impact, while increasing collection would reduce the environmental impact.

Human toxicity, ecotoxicity and eutrophication impact categories are shown to improve significantly when increasing the collection rate and thus reducing the share of collected oil being improperly disposed (dumped and combusted). Increasing collection from 74% to 85% and maintaining the same disposition for collected oil as the baseline will deliver a saving of 149 000 metric tonnes CO_2e and 1800 TJ of fossil reserves. The most significant benefits are seen for eco-toxicity, eutrophication and human toxicity impact categories.

The analysis suggests that the existing baseline system of 74% collection delivers savings of one million metric tonnes of CO_2 equivalents and 12 000 TJ of fossil energy when compared with a zero collection rate. The most significant benefits are associated with ecotoxicity, where 79% reduction is delivered and 1x1010 comparative ecotoxicity units are avoided. On reviewing Annex C, which identifies the main contributors to each impact for each scenario, this reduction is primarily associated with avoiding the release of zinc and organic compounds to water and soil from the informal management of used oil.

Figure 6.3 *Alternate Collection Rates (relative performance where 1=Baseline)*



Baseline uncertainty

As discussed previously, when considering policy options for used oil management, and using LCA as one tool in the assessment process, it is important to understand the uncertainty associated with the results, and to be aware of those aspects that can be influenced by the policy maker and those where influence is more challenging.

In this LCA, we have fixed various parameters that give rise to uncertainty in order to facilitate analysis and to make a study practicable. For example, we know that the estimates of used oil generation, composition, collection rate are uncertain, but we can assume reasonable fixed values in the first instance.

The key uncertainties that have been discussed previously and require analysis include:

- the processes used to combust fuels and the degree of pollution control employed; and

- the virgin products that are assumed to be substituted through the production of secondary products from used oil management.

While in some instances it may be feasible to control which processes are permitted to substitute fuels, this is not typically the case. So we have to allow for different substitutions. This is also true for non-fuel products, such as lubricant base oils, where re-refined base oils of varying properties will substitute for a range of base oils produced in different markets. In Phase I, re-refined group II base oil was expected to displace group I base oil in the market.

The results of the sensitivity analyses that explored different levels of pollution control (high - HPC and low - LPC), alternate fuel substitutions and a variation in virgin product manufacturing, impacts are shown in *Figure 6.4* and *Figure 6.5*. The results are normalized against the baseline to illustrate the scale of the influence of the choices and the uncertainty.

The pollution control variation is only applied to the combustion of secondary fuels and not virgin fuels. As one would expect, these sensitivity scenarios produced a wide variation in results. For example, applying high levels of pollution control delivers decreased environmental impact across impact categories influenced by airborne emissions, whereas environmental impact is generally increased in the 'low pollution control' sensitivity analysis, especially in terms of human health (particulate), human toxicity and smog air.

The importance of pollution control and environmental legislation to ensure good and clean combustion as a priority is reinforced through this analysis. This sensitivity analysis demonstrates that the environmental outcome and the conclusions of an LCA looking at used oil management are highly dependent

on the level of process and pollution control associated with combustion of each fuel appraised. For some impact categories, poor levels of pollution control can result in the loss of the benefit delivered through collection. The ability to appraise uncertainty and to ground conclusions with performance requirements is a strength of LCA.

Figure 6.5 clearly reinforces the work of previous LCAs in demonstrating that, for fuel based systems, the pollution-related environmental impacts are highly dependent on the virgin market that is affected by production of secondary products. A doubling of the acidification impact is seen if the defined energy market is satisfied by coal. In the baseline scenario, direct used oil management (re-refining and reprocessing) meets 33% of the defined market requirement for energy, 16% of the lubricant base oil requirement and 45% of the VTAE requirement.

The use of only No 2 fuel oil causes minimum variation in comparison with the baseline, as it already assumes the market fuel requirement is met 90% by No 2 fuel oil. The replacement of No 2 with only coal, natural gas or No 6 has an adverse effect on acidification, particulate formation and smog air (except for natural gas for this category). The replacement of No 2 with coal or natural gas has beneficial impacts on a number of category impacts (eg human toxicity, abiotic depletion).

The use of alternative data for the production of virgin refinery fuels and base oil (i.e., using the US profiles in place of the California profiles) does not have a significant influence on the baseline results. This is not surprising, given that the impacts reflect both production and combustion of fuels and typically the 'well to tank' impact contributes less than 15% of 'well to wheel' impact, with the exception of resource depletion. Therefore, as a general rule, differences in virgin refinery production efficiency across different markets will only lead to variation within that limited 15% of the total impact on a life cycle basis. However, this can be of importance when results are closely balanced.

The variation seen in virgin production burdens when looking beyond just the US (in this case average US refineries versus average California refineries) may be expected to be greater, but that potential effect was not assessed.

Figure 6.4 Effect of pollution control – Baseline (relative performance, where 1=Baseline)

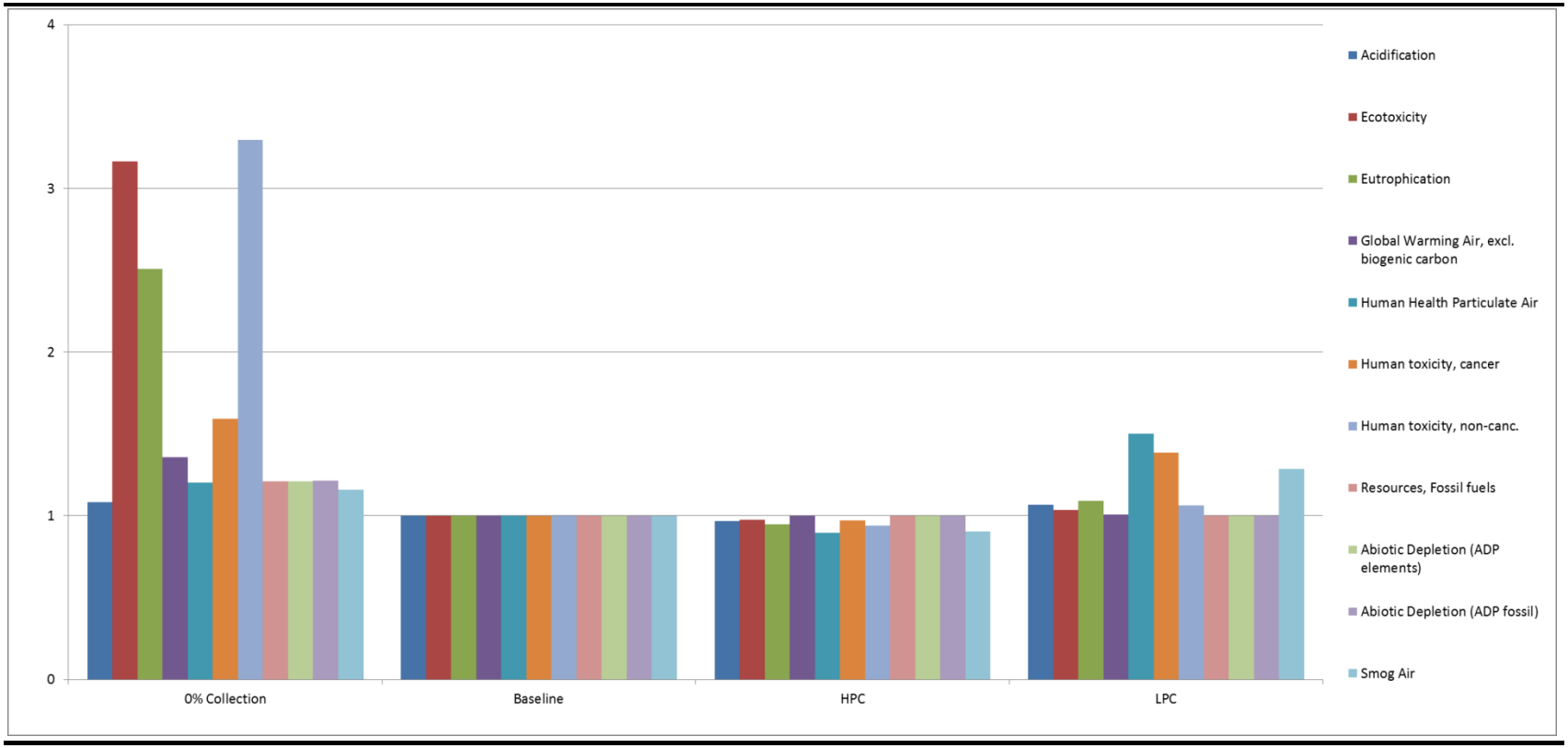
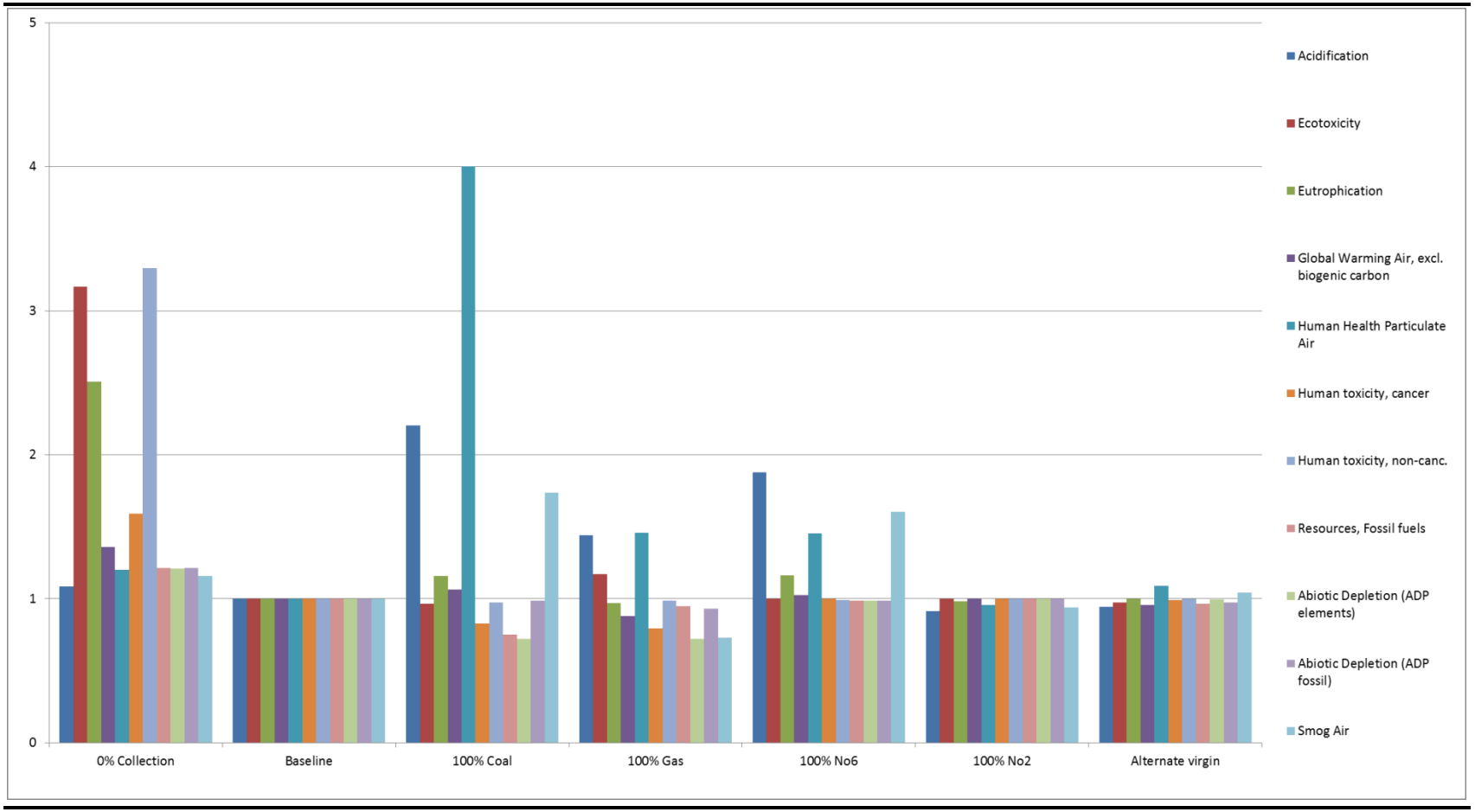


Figure 6.5 Effect of the choice of substituted fuels – Baseline (relative performance, where 1=Baseline)



6.4.2 *Extreme RFO scenario*

Figure 6.6 is the summary system diagram for the extreme RFO scenario. The diagram identifies the major flows associated with the used oil management system and the contribution from the virgin system to meet any shortfall in the defined constant commercial market. The diagram illustrates that, consistent with the intent to define the system by the maximum amount of each commercial product that could be supplied using all the generated UO in CA as the raw material, the RFO produced in this scenario meets all of the market demand for fuel energy and no virgin fuel product is required. Consequently there is no virgin fuel production or combustion in this scenario. However, virgin production provides all other product requirements defined by the constant commercial market, e.g. lubricant base oil and VGO.

In all of these "extreme disposition options" collection is set to 100%. So there is no improperly disposed oil.

Figure 6.6 System summary diagram for the extreme RFO scenario

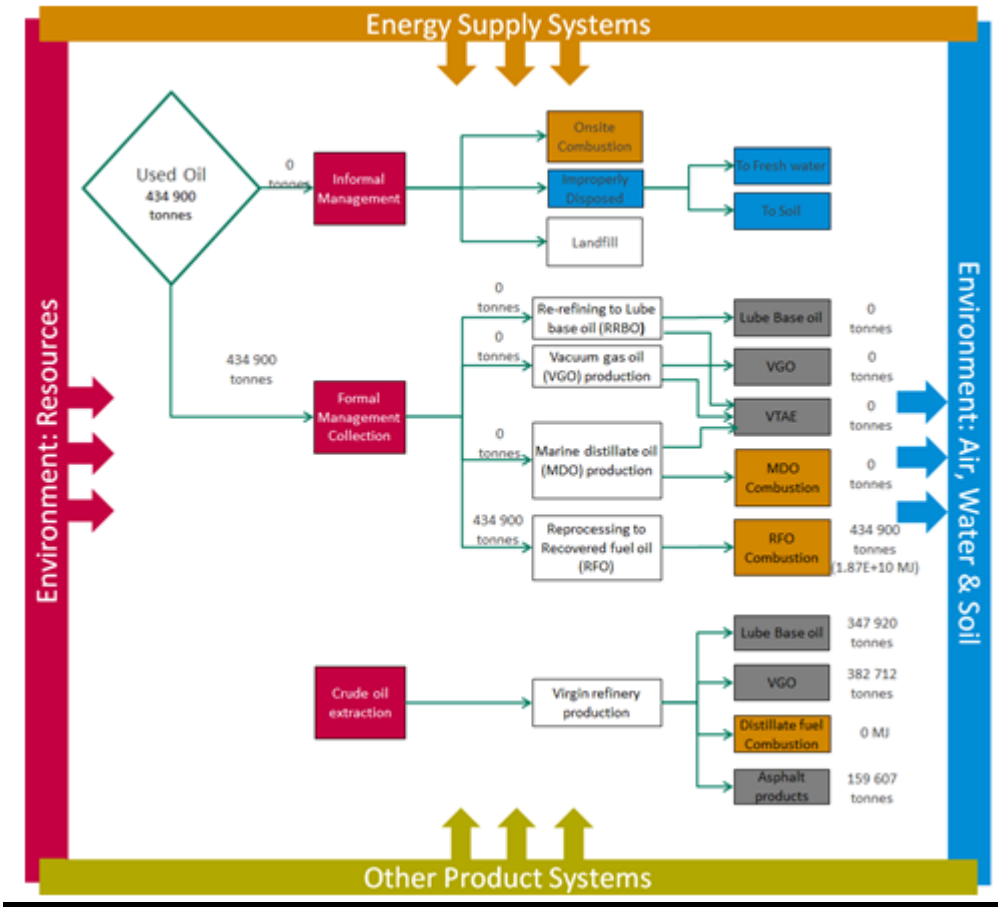


Table 6.4 presents LCIA results for the environmental impact of the extreme RFO scenario (scenario 2) for used oil management in California over one calendar year (2010). The extreme scenarios are designed to build on the baseline assessment and the appraisal of 100% collection described above.

They investigate how each management technology performs by assuming that all used oil is collected and managed according to a single technology.

Absolute values are presented in *Table 6.4* for the total system for each impact category investigated in this study. The units for each are also displayed in the table. In this extreme RFO scenario, the carbon footprint associated with annual used oil management in California was ~ 2.2 million metric tonnes CO_2e and the associated fossil fuel depletion was ~ 46 million MJ.

The contributions of formal management, informal management and virgin top-up (per impact category) are also provided in *Table 6.4* and illustrated in *Figure 6.7*.

Formal management (i.e., the processing and combustion of RFO) is the major contributor to the ecotoxicity, eutrophication, global warming air excl. biogenic carbon, human health particulate air, human toxicity: cancer, and human toxicity: non-cancer impact categories. Virgin top-up is the major contributor to the acidification, ozone depletion air, resources: fossil fuels, abiotic depletion (ADP elements), abiotic depletion (ADP fossil), and smog air impact categories.

Informal management makes no contribution, as all used oil is collected and processed into RFO in this scenario.

As modelled, extreme RFO has the potential to result in the greatest direct release of contaminants through combustion (assuming no VTAE is combusted by the other routes). The emissions to the environment with the greatest contribution to each impact category are presented in Annex B (actual emission contained in the life cycle inventory) and Annex C in terms of their contribution to each impact.

The impact contributions for used oil management processes are influenced mainly by sulfur content, NOx and particulate emissions factors, zinc, arsenic and lead content of used oil.

As described earlier, there is significant uncertainty over the toxicity contribution of metals. It is generally accepted that toxicity models are not characterizing metal releases such as zinc correctly. This is especially the case when we consider the use of zinc in a diverse range of consumer products and its direct release to the environment as sacrificial anodes.

There is also significant uncertainty associated with used oil composition and the treatment of contaminates that are below detection limits.

Table 6.3 below details the substances within used oil that are significant drivers for impact and whether their presence is estimated because they were below detection limit or their presence was quantified. As can be seen from the list, a significant proportion were below detection limits and their contribution should be treated with caution. The substances that are above

detection limit suggest themselves for particular control and monitoring on the basis of their potential contribution.

Table 6.3 Used oil substance contribution (refer to Annex C)

Main contributors	Impacts affected	Below detection limits
Anthracene	Ecotocicity	Yes
Arsenic	Human Toxicity Non-Cancer, Human Toxicity Cancer	Yes
Benzo{a}anthracene	Ecotoxicity	Yes
Cadmium	Human Toxicity Cancer	Yes
Copper	Ecotocicity	No
Lead	Human Toxicity Non-Cancer, Human Toxicity Cancer	No
Molybdenum	Human Toxicity Non-Cancer,	No
Nickel	Human Toxicity Cancer	No
Phosphorous	Eutrophication	No
Zinc	Ecotocicity, Human Toxicity Non-Cancer	No

Arsenic was found to be below detection limit in 100% of the used oil samples. For zinc, the Phase I used oil composition, which relies on old and varied data, contained zinc at 1030 ppm. This study using the more recent analysis of used oil samples appraised 498 ppm zinc. Ignoring the high level of uncertainty around the appraisal of metals by the impact assessment methods, the differences in composition will result in a potential 100% variation in ecotoxicity and human health (non-cancer) impact values.

This uncertainty around used oil composition makes any previous comparative conclusions of disposition preference for ecotoxicity and human toxicity impacts unsafe. This is especially the case when this is then combined with other uncertainties associated with pollution control and combustion device performance.

The contribution from virgin top up are a result of sulfur oxide, NOx, arsenic, barium, copper, silver and R 114 (dichlorotetrafluoroethane) emissions from refinery and upstream extraction activities. It is important to note that R 114 is subject to bans as a result of the Montreal Protocol. However, database inventories are from an extended period of time and they are not updated to include industry adaptation to the Montreal Protocol in all cases. As it is not possible to gather specific data on the substitution substances, these refrigerants cannot be eliminated from the database. Virgin product production dominates for the acidification, human toxicity (cancer), ozone depletion and smog impacts.

Table 6.4 Life Cycle Impact Assessment (LCIA) results for extreme RFO scenario

Impact	Unit	Extreme RFO Total	Formal	Virgin top-up	Informal & formal contribution to California[1]	Total contribution to California[1]
Acidification	kg SO_2-Equiv.	5,396,832	1,617,406	3,772,489	0.25%	0.82%
Ecotoxicity (recommended)	CTUe	1,836,222,530	1,182,153,557	653,799,275		
Eutrophication	kg N-Equiv.	301,112	184,828	115,521		
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,199,131,951	1,391,644,515	805,263,061	0.31%	0.49%
Human health particulate air	kg $PM_{2.5}$-Equiv.	950,447	636,307	313,619	0.004%	0.006%
Human toxicity, cancer (recommended)	CTUh	2	0	1		
Human toxicity, non-canc. (recommended)	CTUh	1,169	1,051	118		
Ozone depletion air	kg CFC 11-Equiv.	0	0	0	0.097%	0.000%
Resources, fossil fuels	MJ surplus energy	6,312,161,390	55,764,221	6,252,169,680		
Abiotic depletion (ADP elements)	kg Sb-Equiv.	415	4	411		
Abiotic depletion (ADP fossil)	MJ	46,495,876,888	420,837,587	46,043,793,071	0.00%	0.48%
Smog air	kg O_3-Equiv.	53,731,053	22,587,408	30,940,097	0.11%	0.25%

Figure 6.7 Extreme RFO scenario impact contribution

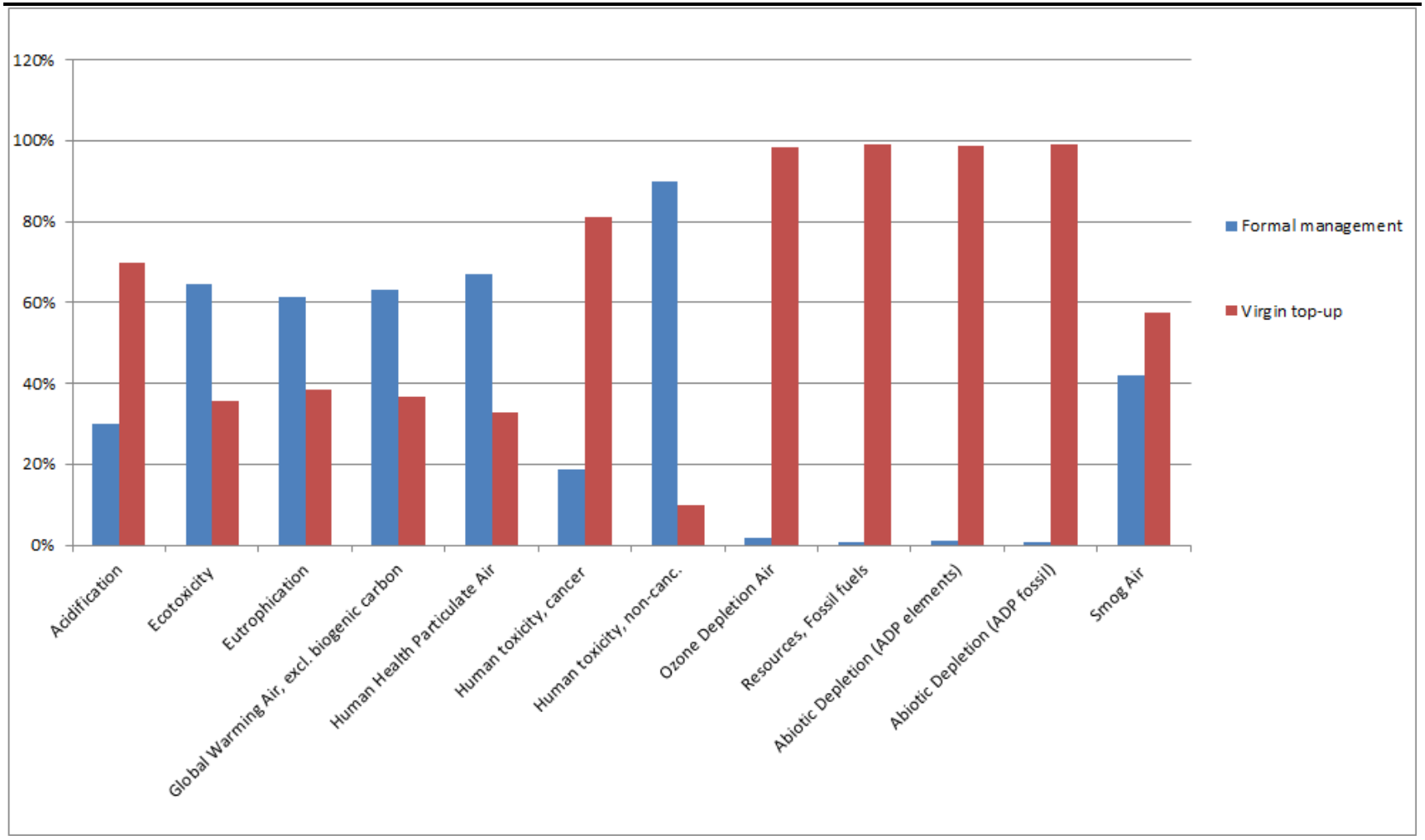
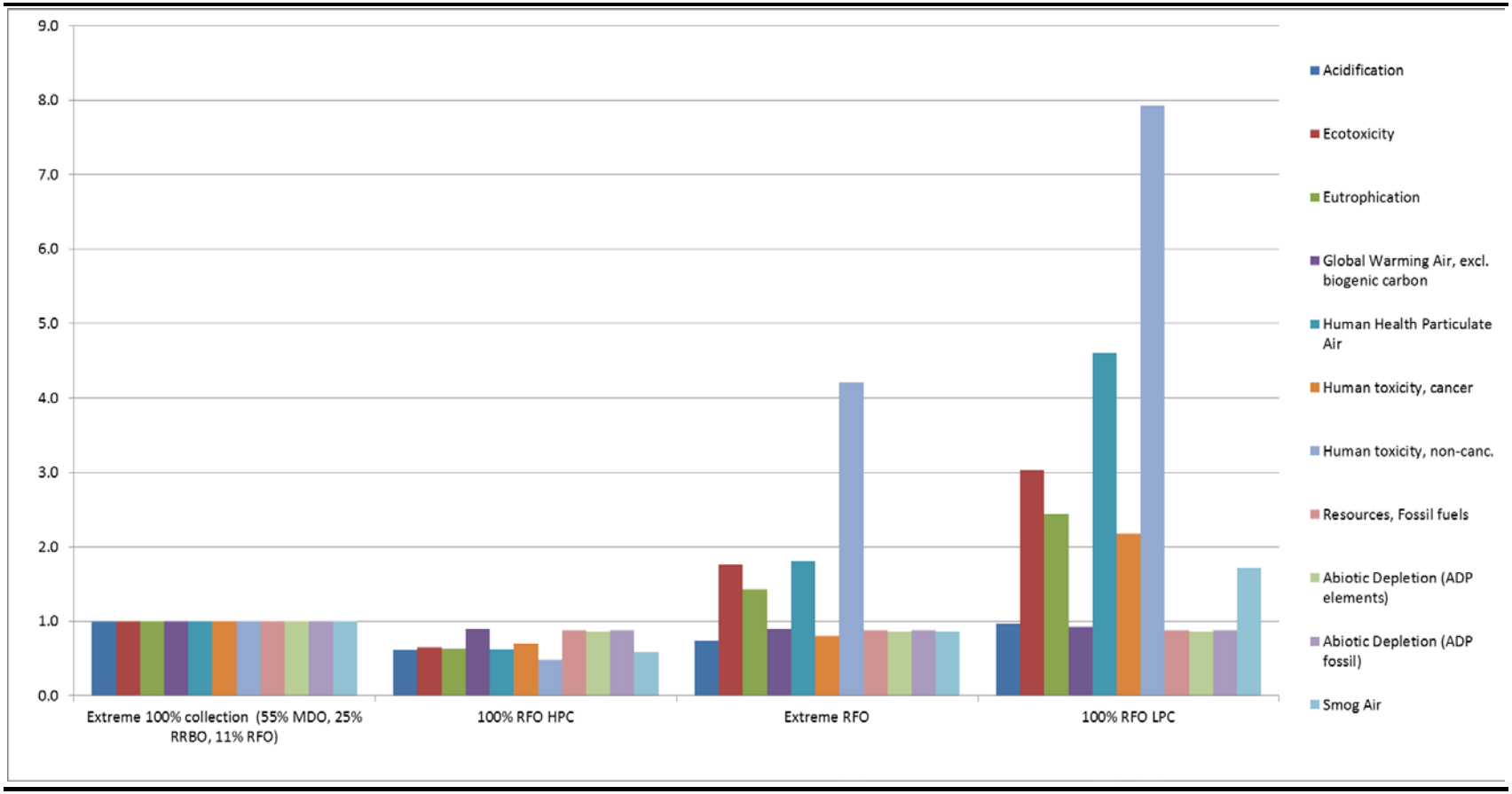


Figure 6.8 Pollution control sensitivity for extreme RFO scenario (relative performance, where 1=Extreme collection)



HPC – High Pollution Control, LPC – Low Pollution Control

Alongside results for the 'pure' extreme RFO scenario, data for a number of sensitivity scenarios are also presented. In the first instance, we test the significance of pollution control and compare the results against the 100% collection and baseline scenario disposition. *Figure 6.8* presents the outcome of this sensitivity analysis and demonstrates that combusting RFO with high pollution control will result in RFO performing better than the baseline disposition of collected used oil.

Table 6.5 presents the impact values for each sensitivity analysis and the percentage change compared with the extreme RFO scenario. The results highlight the sensitivity of the impact profile for the RFO management route to assumptions about pollution control and the retention rate for metals in particular zinc (see contributions in Annex C).

Regardless of pollution control, the extreme RFO scenario shows significant benefit for the following impacts:

- acidification;
- global warming air, excl. biogenic carbon;
- resources, fossil fuels;
- abiotic depletion (ADP elements);
- abiotic depletion (ADP fossil); and
- smog air.

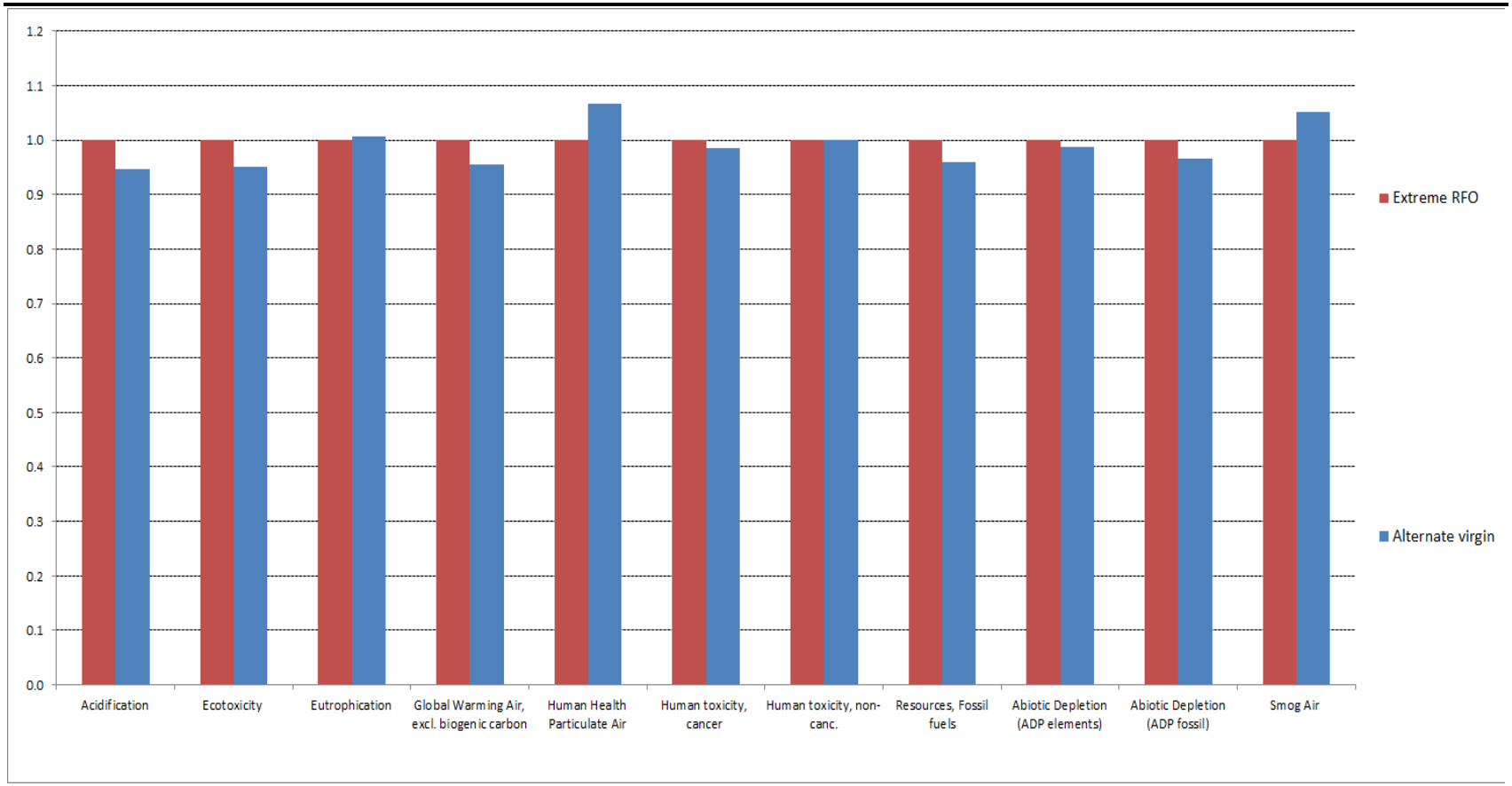
Unlike the baseline, and other extreme scenarios, the extreme RFO scenario meets all the defined market requirement for fuel energy (no virgin fuel production and combustion is required to meet the specified market demand) and therefore a sensitivity that addresses the use of gas, coal or other mix of fuels is unnecessary.

Figure 6.9 shows that the extreme RFO scenario is relatively insensitive to the use of alternate virgin product production data. The most significant change from replacing the production impact profiles for virgin products was a 7% increase in the human health (particulate) impact category.

Table 6.5 Extreme RFO pollution control sensitivity

Impact	Unit	Extreme RFO	LPC	% Change	HPC	% Change
Acidification	kg SO_2-Equiv.	5,396,831.60	7,055,105	31%	4,520,726	-16%
Ecotoxicity	CTUe	1,836,222,530.22	3,161,279,319	72%	683,014,105	-63%
Eutrophication	kg N-Equiv.	301,111.55	516,936	72%	134,369	-55%
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,199,131,950.52	2,250,453,543	2%	2,197,539,173	0%
Human health particulate air	kg $PM_{2.5}$-Equiv.	950,447.32	2,423,668	155%	328,865	-65%
Human toxicity, cancer	CTUh	1.77	5	171%	2	-13%
Human toxicity, non- canc.	CTUh	1,168.71	2,205	89%	134	-89%
Ozone depletion air	kg CFC 11-Equiv.	0.01	0	0%	0	0%
Resources, fossil fuels	MJ surplus energy	6,312,161,390.23	6,312,161,390	0%	6,312,161,390	0%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	415.37	415	0%	415	0%
Abiotic depletion (ADP fossil)	MJ	46,495,876,888.19	46,495,876,888	0%	46,495,876,888	0%
Smog air	kg O_3-Equiv.	53,731,052.96	106,363,129	98%	36,516,143	-32%

Figure 6.9 Extreme RFO scenario sensitivity to alternate virgin production (relative performance, where 1=Extreme RFO)



6.4.3 Extreme MDO scenario

Figure 6.10 is the summary system diagram for the extreme MDO scenario. The diagram identifies the major flows associated with the used oil management system and the contribution from the virgin system to meet any shortfall in the defined constant commercial market. The diagram illustrates that the MDO process delivers 56% of the market requirement for energy, 90% of the asphalt product requirement and none of the lubricant base oil requirement.

Table 6.6 provides LCIA results for the environmental impact of the extreme MDO scenario for used oil management in California over one calendar year. Absolute values are presented for the total system for each impact category investigated in this study. The units for each are also displayed in the table.

The contributions of formal management and virgin top-up (per impact category) are also presented in *Table 6.6* and illustrated in *Figure 6.11*. For all of the environmental impact categories, virgin top-up contributed the majority of the impact, with the remaining burden associated with formal management. Informal management did not contribute to the environmental impact of any impact category as the quantity of used oil sent to this route was set to zero.

Table 6.7 and *Figure 6.12* explore the sensitivity of the extreme MDO scenario to alternative levels of pollution control. The 'high pollution control' sensitivity analysis delivers a small impact reduction, the largest benefit being an 18% reduction in the smog impact category as a result of improved NOx emissions (largest contributor this impact category). The lack of sensitivity to imposing high levels of pollution control is as a result of the MDO process removing the majority of contaminants from the used oil. Reducing the level of pollution control has a far more dramatic effect and demonstrates the importance of pollution control, irrespective of fuel composition.

For the MDO process, the majority of the contaminants of used oil are concentrated in the VTAE fraction and will be contained in asphalt products. This poses an interesting question as to their ultimate fate if such asphalt products are subsequently used (eg for roofing).

On the basis that asphalt has shown to be stable and resistant to leaching, it is likely that, if disposed with other inert construction waste, the contaminants will remain stabilized. However, if asphalt waste or VTAE products were to be combusted as a fuel (as appears to be the case in at least some jurisdictions), then the contaminants will be released to the environment in varying amounts depending on the level of pollution control.

To investigate this potential source of impact and its likely significance, we have undertaken a sensitivity analysis assuming that VTAE is combusted as a fuel with a default level of pollution control. *Table 6.8* and *Table 6.9* show the consequence of this change both on the total system impact profile and on the

formal management profile. As would be expected, the following impacts are significantly increased:

- Human toxicity, non-cancer;
- Human health particulate air;
- Ecotoxicity; and
- Eutrophication.

Figure 6.13 appraises the significance of fuel substitution and clearly reinforces the work of previous LCAs in demonstrating that, for fuel based systems, the pollution-related environmental impacts are highly dependent on the virgin market that is affected by production of secondary products. A near doubling of the acidification impact and the human health (particulate) impacts categories is seen if the defined energy market is satisfied by coal. In the extreme MDO scenario, 56% of the defined market requirement for energy is met by used oil management.

The use of 100% No 2 fuel oil causes a minimum variation, as it is already assumed in this scenario that the market fuel requirement is 90% met by No 2 fuel oil.

Figure 6.10 ***System summary diagram for extreme MDO scenario***

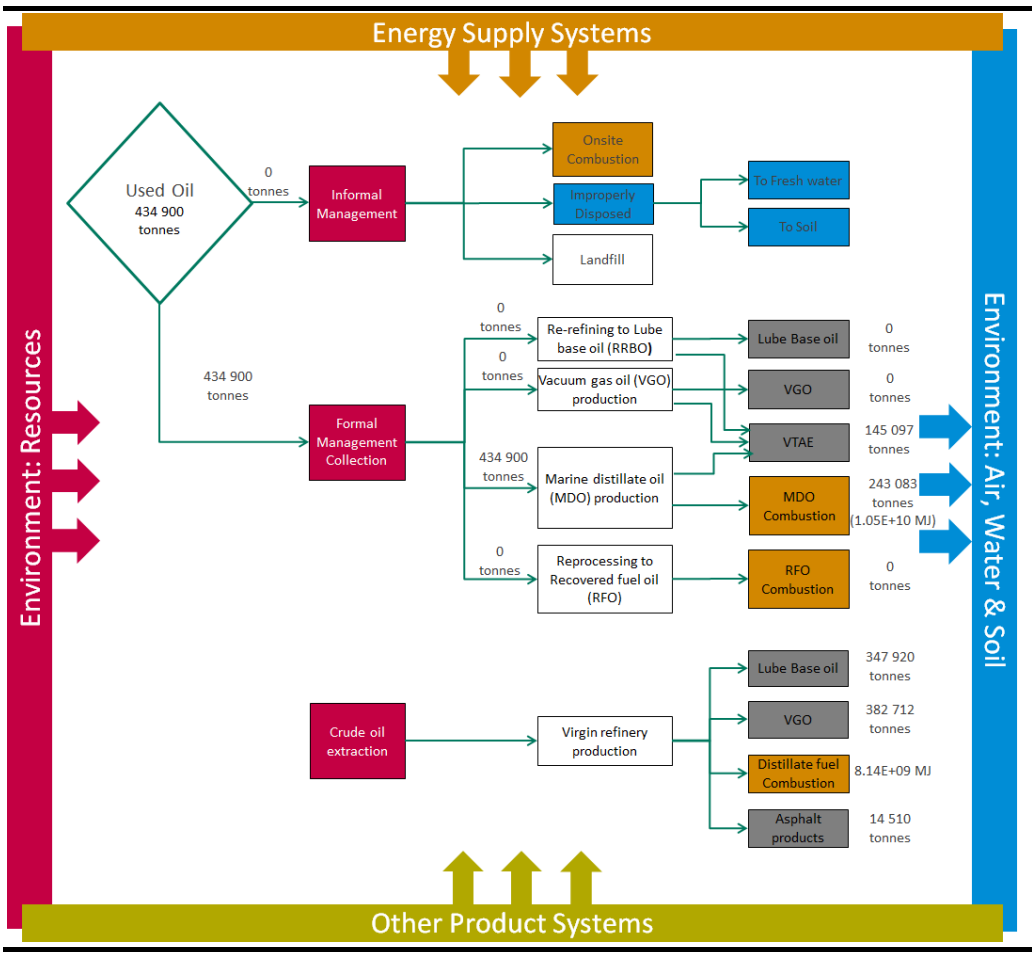


Table 6.6 Life Cycle Impact Assessment (LCIA) results for extreme MDO scenario

Impact	Unit	Extreme MDO Total	Formal mgmt.	Virgin top-up	Formal contribution to California (1)	Total contribution to California[1]
Acidification	kg SO_2-Equiv.	7,508,031	2,410,134	5,090,961	0.37%	1.14%
Ecotoxicity (recommended)	CTUe	974,278,495	273,088,074	700,920,722		
Eutrophication	kg N-Equiv.	190,735	49,877	140,096		
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,555,441,624	1,121,586,173	1,431,631,077	0.25%	0.56%
Human health particulate air	kg $PM_{2.5}$-Equiv.	487,417	134,627	352,269	0.001%	0.003%
Human toxicity, cancer (recommended)	CTUh	2	0	2		
Human toxicity, non-canc. (recommended)	CTUh	159	20	139		
Ozone depletion air	kg CFC 11-Equiv.	0	0	0	0.097%	0.000%
Resources, fossil fuels	MJ surplus energy	7,209,723,196	519,842,839	6,685,652,868		
Abiotic depletion (ADP elements)	kg Sb-Equiv.	467	26	441		
Abiotic depletion (ADP fossil)	MJ	53,038,835,505	3,762,278,639	49,245,310,635	0.04%	0.55%
Smog air	kg O_3-Equiv.	62,583,652	19,236,885	43,143,218	0.09%	0.30%

(1) Section 6.3 explains how the percentage contribution to California emissions is derived

Figure 6.11 Extreme MDO scenario impact contribution

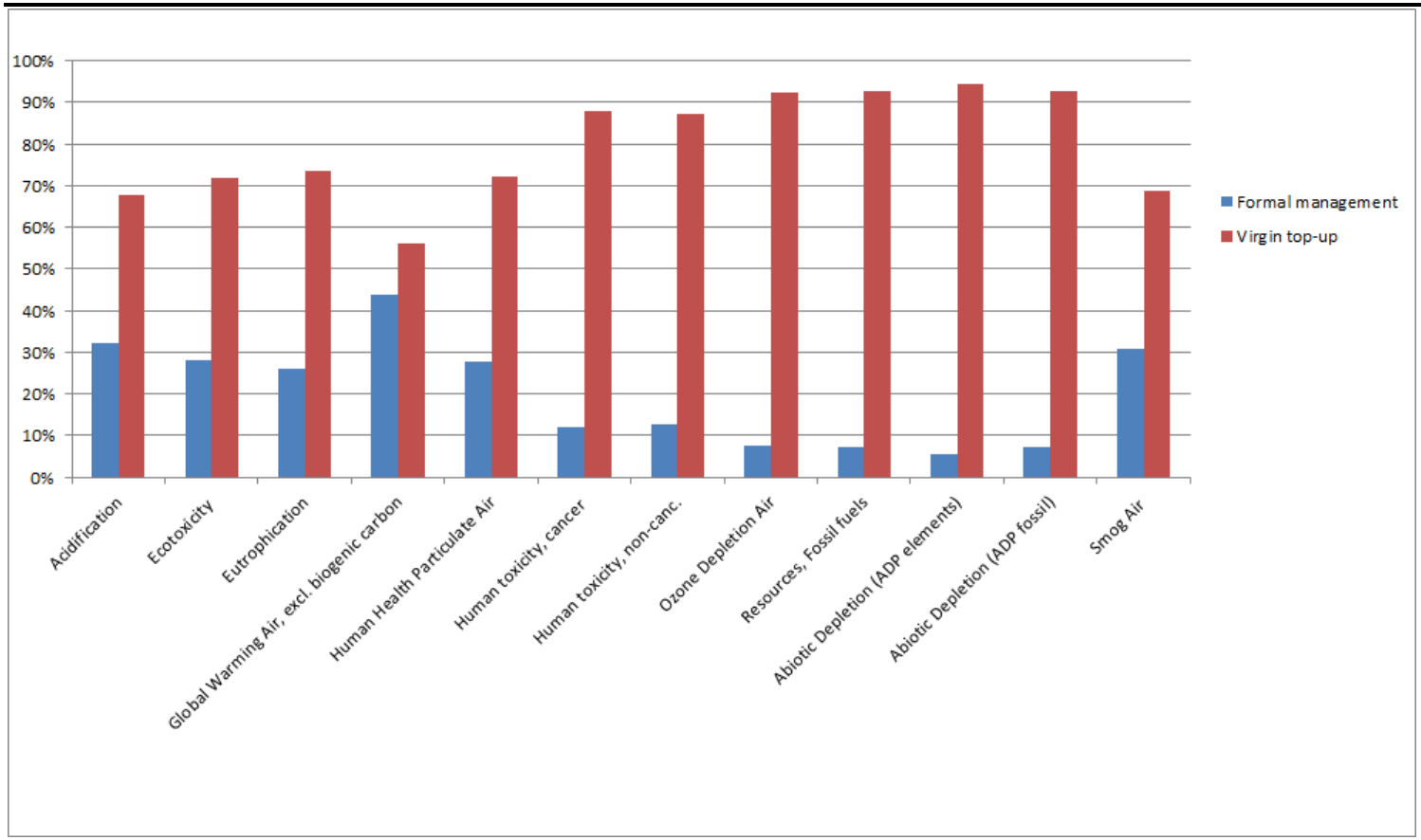
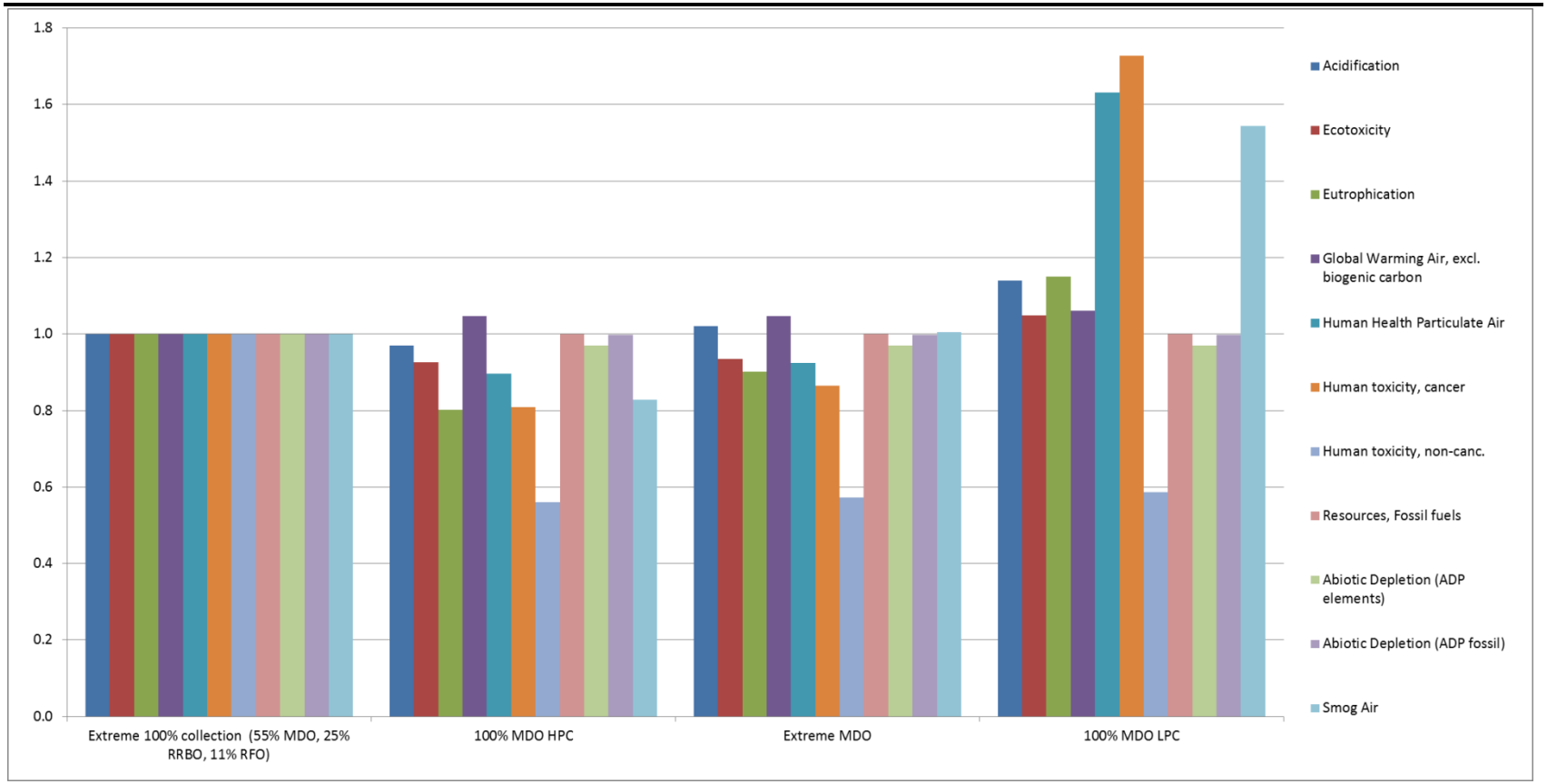


Table 6.7 Extreme MDO scenario pollution control sensitivity

Impact	Unit	Extreme MDO	HPC	% Change	LPC	% Change
Acidification	kg SO_2-Equiv.	7,508,031	7,131,086	-5%	8,380,901	12%
Ecotoxicity	CTUe	974,278,495	965,430,776	-1%	1,092,687,987	12%
Eutrophication	kg N-Equiv.	190,735	169,630	-11%	243,216	28%
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,555,441,624	2,554,426,095	0%	2,588,163,445	1%
Human health particulate air	kg $PM_{2.5}$-Equiv.	487,417	472,975	-3%	860,063	76%
Human toxicity, cancer	CTUh	2	2	-6%	4	100%
Human toxicity, non- canc.	CTUh	159	156	-2%	163	3%
Ozone depletion air	kg CFC 11-Equiv.	0	0	0%	0	0%
Resources, fossil fuels	MJ surplus energy	7,209,723,196	7,209,723,196	0%	7,209,723,196	0%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	467	467	0%	467	0%
Abiotic depletion (ADP fossil)	MJ	53,038,835,505	53,038,835,505	0%	53,038,835,505	0%
Smog air	kg O_3-Equiv.	62,583,652	51,607,703	-18%	96,141,016	54%

Figure 6.12 Pollution control sensitivity for extreme MDO scenario (relative performance, where 1= Extreme collection)



HPC – High Pollution Control, LPC – Low Pollution Control

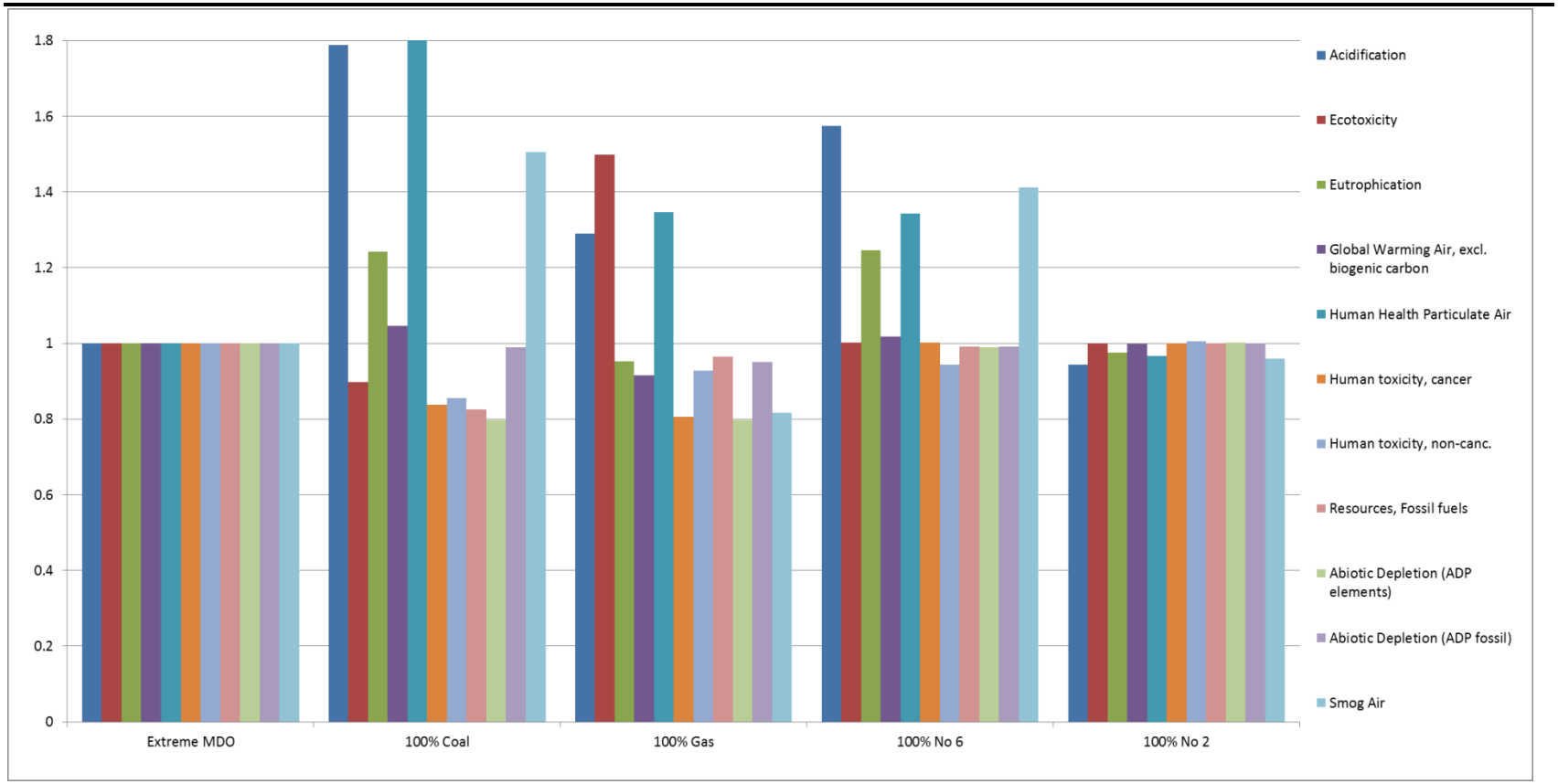
Table 6.8 Extreme MDO scenario sensitivity VTAE combusted as a fuel

Impact	Unit	Extreme MDO Total	VTAE combusted as fuel	% Change
Acidification	kg SO2-Equiv.	7,508,031	7,948,744	6%
Ecotoxicity	CTUe	974,278,495	2,133,253,463	119%
Eutrophication	kg N-Equiv.	190,735	326,870	71%
Global warming air, excl. biogenic carbon	kg CO2-Equiv.	2,555,441,624	2,581,274,049	1%
Human health particulate air	kg PM2.5-Equiv.	487,417	721,326	48%
Human toxicity, cancer	CTUh	2	2	4%
Human toxicity, non-canc.	CTUh	159	1,197	651%
Ozone depletion air	kg CFC 11-Equiv.	0	0	-1%
Resources, fossil fuels	MJ surplus energy	7,209,723,196	7,164,551,614	-1%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	467	463	-1%
Abiotic depletion (ADP fossil)	MJ	53,038,835,505	52,700,781,089	-1%
Smog air	kg O3-Equiv.	62,583,652	61,395,693	-2%

Table 6.9 Extreme MDO scenario sensitivity VTAE combusted as a fuel – formal management

Impact	Unit	Extreme MDO formal mgmt.	VTAE combusted as fuel formal mgmt.	% Change
Acidification	kg SO2-Equiv.	2,410,134	3,672,414	52%
Ecotoxicity	CTUe	273,088,074	1,441,591,596	428%
Eutrophication	kg N-Equiv.	49,877	200,076	301%
Global warming air, excl. biogenic carbon	kg CO2-Equiv.	1,121,586,173	1,573,189,858	40%
Human health particulate air	kg PM2.5-Equiv.	134,627	385,900	187%
Human toxicity, cancer	CTUh	0	0	78%
Human toxicity, non-canc.	CTUh	20	1,068	5234%
Ozone depletion air	kg CFC 11-Equiv.	0	0	0%
Resources, fossil fuels	MJ surplus energy	519,842,839	519,842,839	0%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	26	26	0%
Abiotic depletion (ADP fossil)	MJ	3,762,278,639	3,762,278,639	0%
Smog air	kg O3-Equiv.	19,236,885	25,750,269	34%

Figure 6.13 Relative effect of the choice of substituted fuels – extreme MDO scenario (relative performance, where 1=Extreme MDO)



6.4.4 Extreme VGO scenario

Figure 6.14 is the summary system diagram for the extreme VGO scenario. The diagram identifies the major flows associated with the used oil management system and the contribution from the virgin system to meet any shortfall in the defined constant commercial market. The diagram illustrates that the VGO process delivers 4% of the market requirement for energy, 44% of the asphalt product requirement and none of the lubricant base oil requirement.

Table 6.10 presents LCIA results for the environmental impact of the extreme VGO scenario (scenario 4) for used oil management in California over one calendar year. Absolute values are presented for the total system for each impact category investigated in this study. The units for each are also displayed in the table.

For example, in this extreme VGO scenario, the carbon footprint associated with annual used oil management in California was ~ 2.2 million metric tonnes CO_2e and the associated fossil fuel depletion was ~ 49 million MJ.

The proportion of the total that formal management, informal management and virgin top-up represent (per impact category) is also provided in *Table 6.10*. For all of the impact categories, virgin top-up contributed the majority of environmental impact, with the remaining burden associated with formal management. This is not surprising, as the VGO management route delivers only 4% of the fuel energy required by the market as it is defined. Informal management did not contribute to the environmental impact of any impact category, as the quantity of used oil sent to this route was set to zero.

Figure 6.13 appraises the significance fuel substitution and clearly reinforces the work of previous LCAs in demonstrating that, for fuel-based systems, the pollution-related environmental impacts are highly dependent on the virgin market that is affected by production of secondary products. A dramatic increase of the acidification and the human health (particulate) impact categories is seen if the defined energy market is satisfied by coal. In the extreme VGO scenario only 4% of the defined market requirement for energy is met by used oil management. The extreme VGO scenario as a result is extremely sensitive to how the market energy requirement is satisfied.

The use of 100% No 2 fuel oil causes a minimum variation, as it is already assumed in this scenario that the market fuel requirement is met by 90%No 2 fuel oil.

Table 6.11 shows how use of alternate data for the production of virgin refinery fuels and base oil (i.e., using the US profiles in place of the California profiles) does not show a significant influence on the extreme VGO scenario results, with the exception of ozone depletion, which sees a large change of a very small number.

Figure 6.14 System summary diagram for extreme VGO scenario

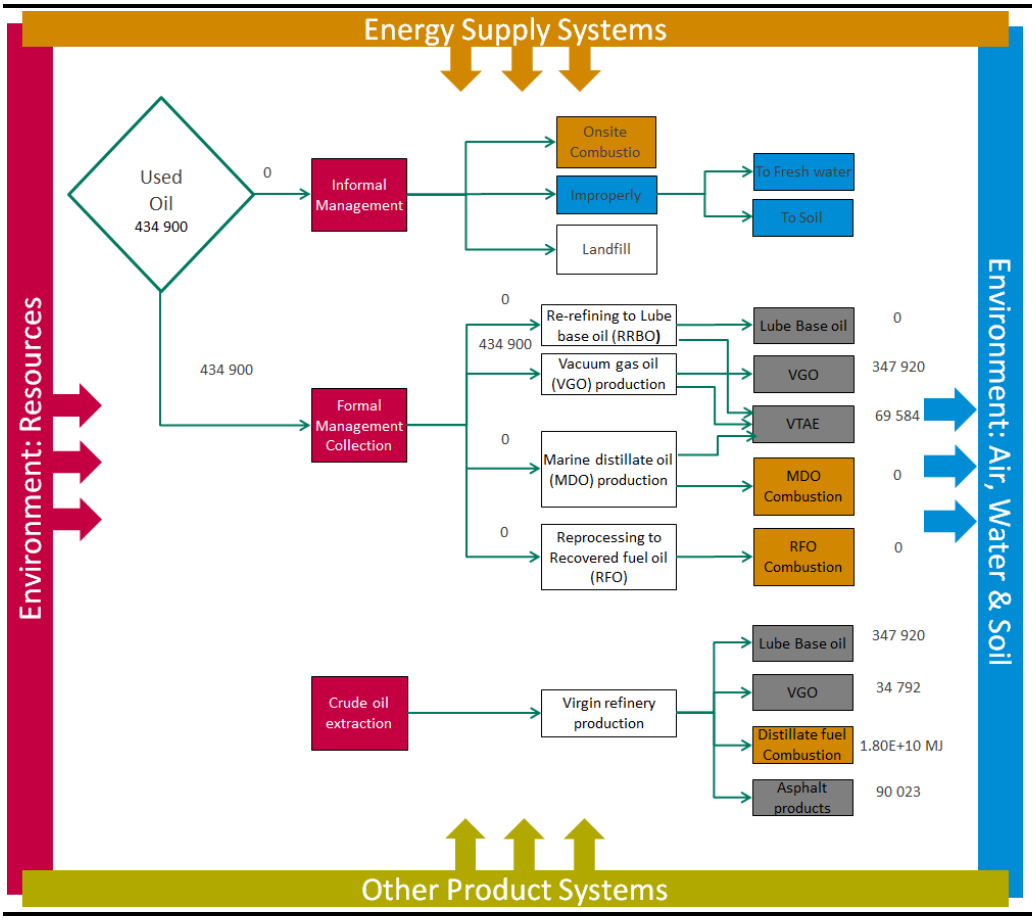


Table 6.10 Life Cycle Impact Assessment (LCIA) results for extreme VGO scenario

Impact	Unit	Extreme VGO Total	Formal mgmt.	Virgin top-up	Informal & formal contribution to California (1)	Total contribution to California[1]
Acidification	kg SO_2-Equiv.	6,900,297	536,273	6,357,087	0.08%	1.05%
Ecotoxicity	CTUe	746,749,648	47,958,108	698,521,841		
Eutrophication	kg N-Equiv.	179,385	19,444	159,179		
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,240,403,257	117,360,345	2,120,818,539	0.03%	0.49%
Human health particulate air	kg $PM_{2.5}$-Equiv.	400,509	27,491	372,496	0.000%	0.002%
Human toxicity, cancer	CTUh	2	0	2		
Human toxicity, non-canc.	CTUh	156	3	153		
Ozone depletion air	kg CFC 11-Equiv.	0	0	0	0.097%	0.000%
Resources, fossil fuels	MJ surplus energy	6,707,125,559	135,312,977	6,567,585,092		
Abiotic depletion (ADP elements)	kg Sb-Equiv.	439	4	434		
Abiotic depletion (ADP fossil)	MJ	49,362,320,506	947,113,161	48,383,961,114	0.01%	0.51%
Smog air	kg O_3-Equiv.	61,975,177	7,010,617	54,761,012	0.03%	0.29%

(1) Section 6.3 explains how the percentage contribution to California emissions is derived.

Figure 6.15 Extreme VGO scenario impact contribution

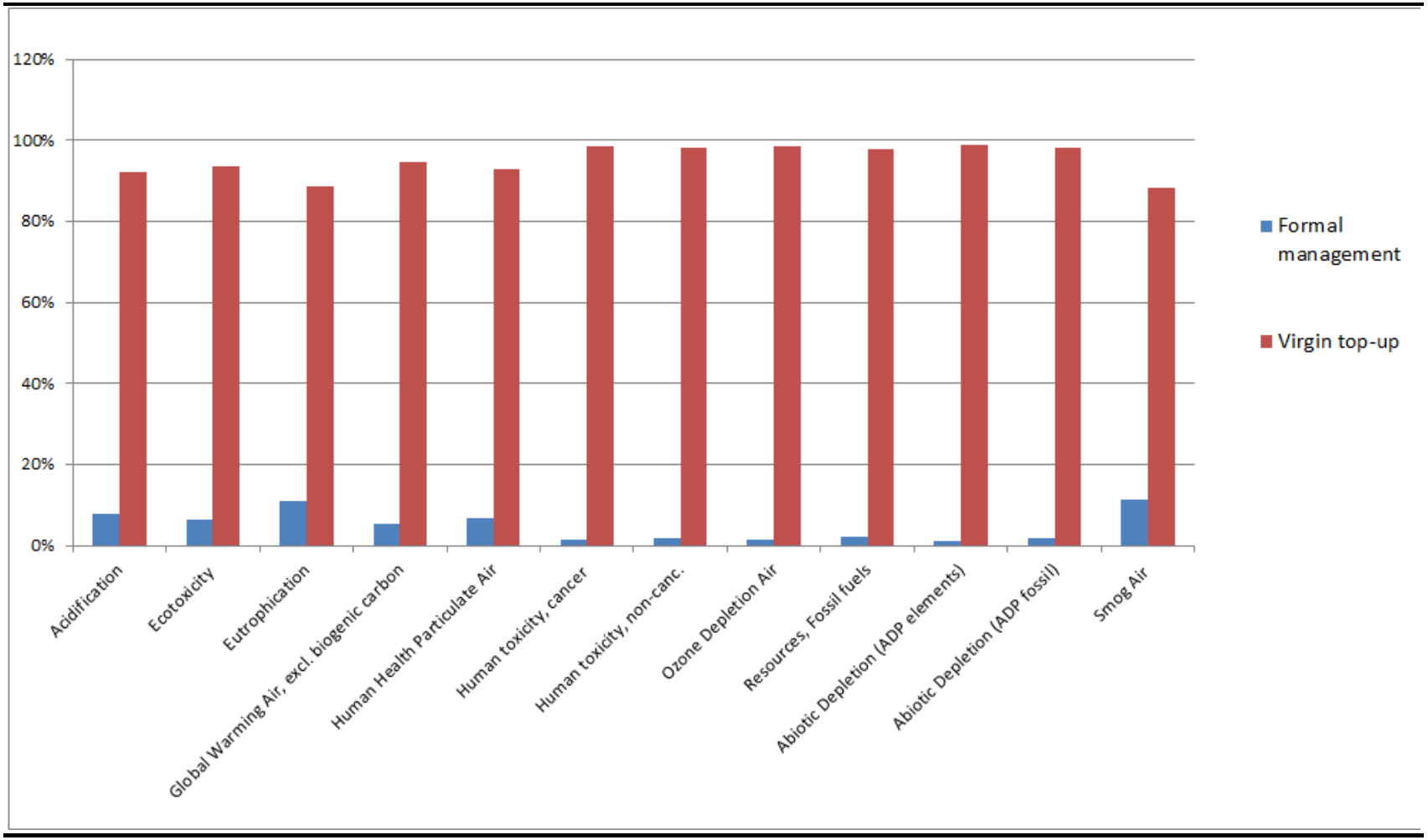


Figure 6.16 Relative effect of the choice of substituted fuels – extreme VGO scenario (relative performance, where 1=Extreme VGO)

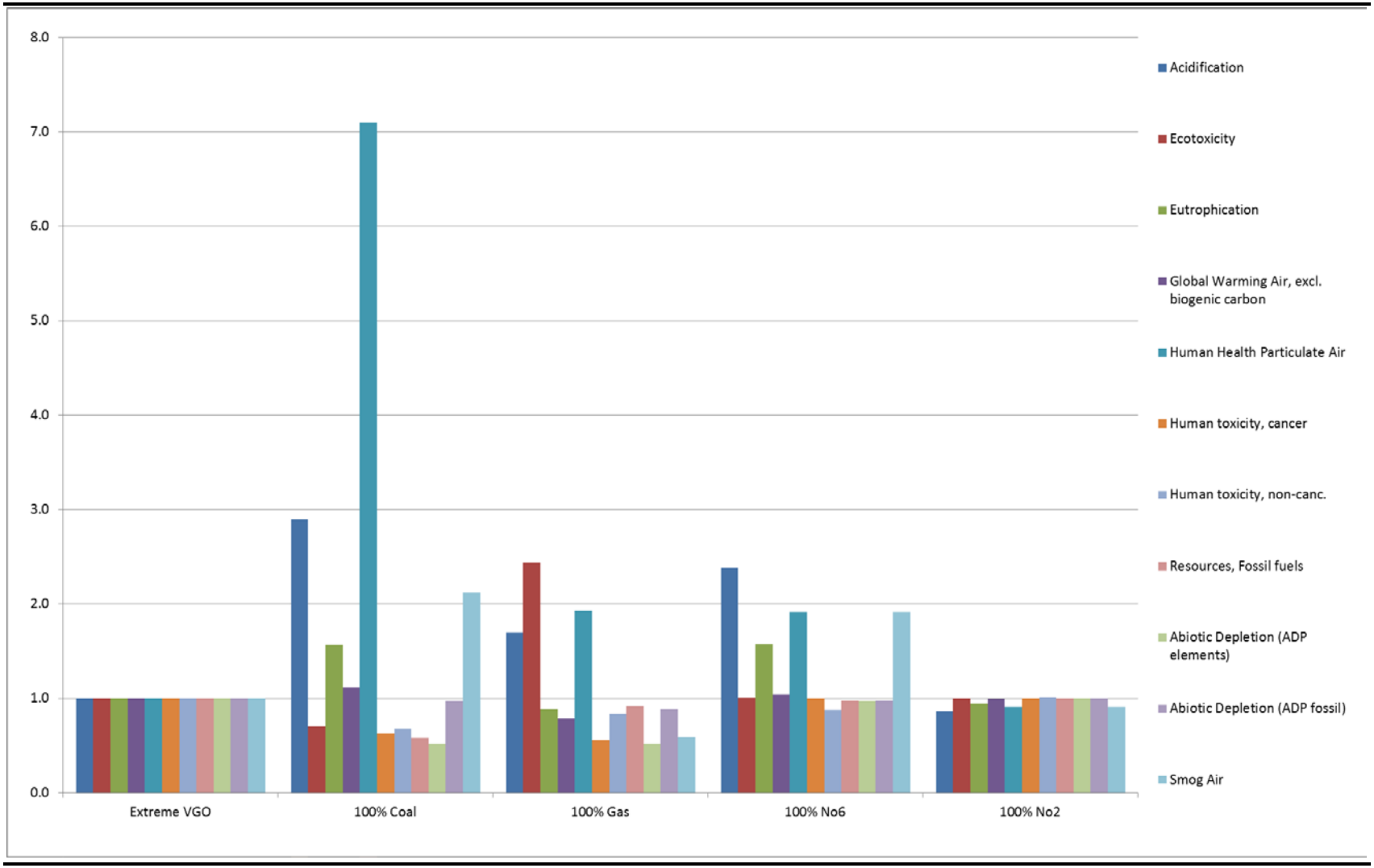


Table 6.11 VGO scenario sensitivity to virgin product production

Impact	Unit	Extreme VGO	Alternate virgin production (US)	% Change
Acidification	kg SO_2-Equiv.	6,900,297	6,601,367	-4%
Ecotoxicity	CTUe	746,749,648	657,516,152	-12%
Eutrophication	kg N-Equiv.	179,385	182,050	1%
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,240,403,257	2,149,554,575	-4%
Human health particulate air	kg $PM_{2.5}$-Equiv.	400,509	462,109	15%
Human toxicity, cancer	CTUh	2	2	-1%
Human toxicity, non-canc.	CTUh	156	157	0%
Ozone depletion air	kg CFC 11-Equiv.	0.01	0.31	2206%
Resources, fossil fuels	MJ surplus energy	6,707,125,559	6,491,073,452	-3%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	439	436	-1%
Abiotic depletion (ADP fossil)	MJ	49,362,320,506	48,075,965,851	-3%
Smog air	kg O_3-Equiv.	61,975,177	64,803,740	5%

6.4.5 *Extreme RRBO scenario*

Figure 6.17 is the summary system diagram for the extreme RRBO scenario. The diagram identifies the major flows associated with the used oil management system and the contribution from the virgin system to meet any shortfall in the defined constant commercial market. The diagram illustrates that the RRBO process delivers 11% of the market requirement for energy, 42% of the asphalt product requirement and 89% of the lubricant base oil requirement as defined in the functional unit.

Table 6.12 presents LCIA results for the environmental impact of the extreme RRBO scenario (scenario 4) for used oil management in California over one calendar year. Absolute values are presented for the total system for each impact category investigated in this study. The units for each are also displayed in the table.

For example, in this extreme RRBO scenario, the carbon footprint associated with annual used oil management in California was ~ 2.2 million metric tonnes CO_2e and the associated fossil fuel depletion was ~ 50 million MJ. The proportion of the total impact for each impact category that formal management and virgin top-up represent is also provided in *Table 6.12* and *Figure 6.18*. For all of the impact categories, virgin top-up contributed the majority of the environmental impact, with the remaining burden associated with formal management. This is not surprising as the RRBO management

route delivers only 9% of the fuel energy required by the market as it is defined. Informal management did not contribute to the environmental impact of any impact category, as the quantity of used oil sent to this route was set as zero.

Figure 6.19 appraises the significance fuel substitution and clearly reinforces the work of previous LCAs in demonstrating that, for fuel-based systems, the pollution-related environmental impacts are highly dependent on the virgin market that is affected by production of secondary products. A dramatic increase of the acidification and the human health (particulate) impact categories is seen if the defined energy market is satisfied by coal. In the extreme RRBO scenario only 9% of the defined market requirement for energy is met by used oil management. The extreme RRBO scenario as a result is extremely sensitive to how the market energy requirement is satisfied.

The use of 100% No 2 fuel oil causes a minimum variation as it is already assumed in this scenario that the market fuel requirement is 90% met by No 2 fuel oil.

Table 6.13 shows how the use of alternative data for the production of virgin refinery fuels and base oil (i.e., using the US profiles in place of the California profiles) does not show a significant influence on the extreme RRBO scenario results, with the exception of ozone depletion which sees a large change of a very small number.

Figure 6.17 System summary diagram for extreme RRBO scenario

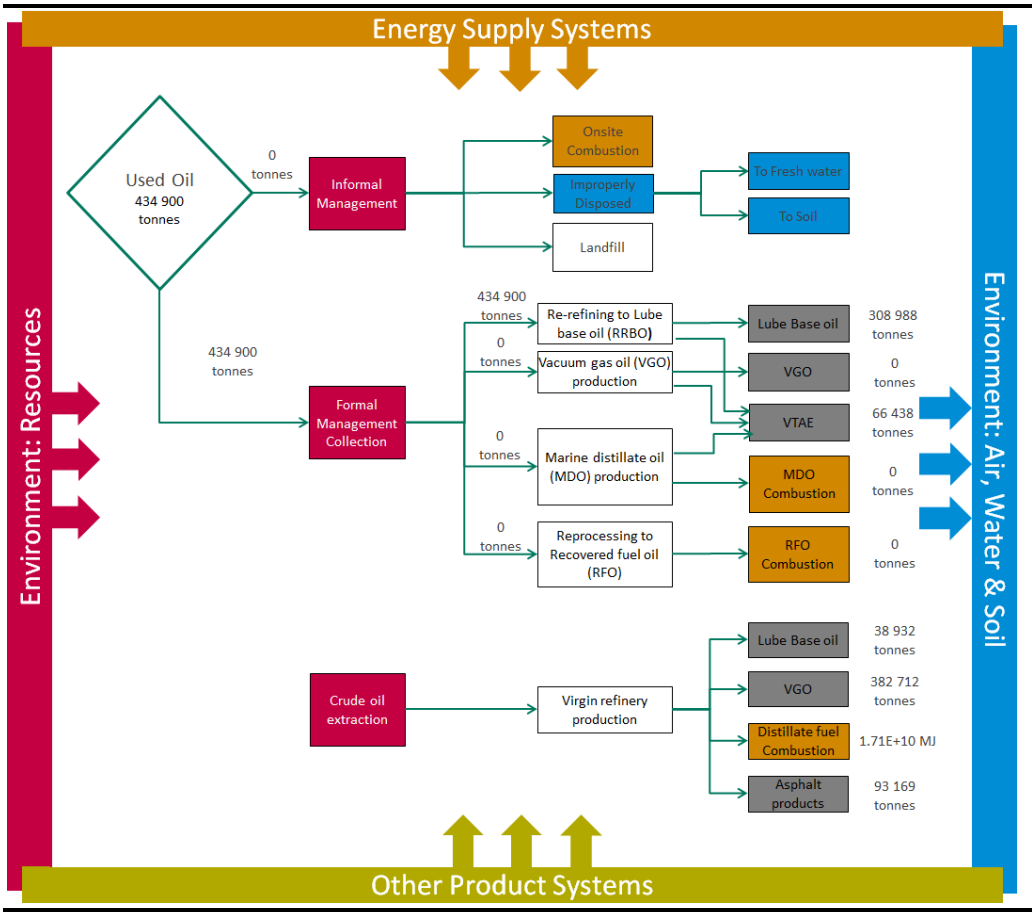


Table 6.12 Life Cycle Impact Assessment (LCIA) results for extreme RRBO scenario

Impact	**Unit**	**Extreme RRBO Total**	**Formal mgmt.**	**Virgin top-up**	Formal contribution to California (1)	**Total contribution to California[1]**
Acidification	kg SO_2-Equiv.	7,296,667	1,694,606	5,595,124	0.26%	1.11%
Ecotoxicity	CTUe	771,807,256	160,962,249	610,575,309		
Eutrophication	kg N-Equiv.	170,137	26,620	142,755		
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,197,660,765	296,547,669	1,898,888,723	0.07%	0.49%
Human health particulate air	kg $PM_{2.5}$-Equiv.	398,366	86,166	311,679	0.001%	0.002%
Human toxicity, cancer	CTUh	2	0	2		
Human toxicity, non-canc.	CTUh	155	9	146		
Ozone depletion air	kg CFC 11-Equiv.	0.01	0.00	0.01	0.000%	0.000%
Resources, fossil fuels	MJ surplus energy	6,730,232,359	372,300,350	6,353,704,520		
Abiotic depletion (ADP elements)	kg Sb-Equiv.	487	58	429		
Abiotic depletion (ADP fossil)	MJ	49,676,282,373	2,812,895,498	46,832,140,644	0.03%	0.51%
Smog air	kg O_3-Equiv.	60,614,076	8,323,666	52,086,862	0.04%	0.29%

(1) Section 6.3 explains how the percentage contribution to California emissions is derived.

Figure 6.18 Extreme RRBO scenario impact contribution

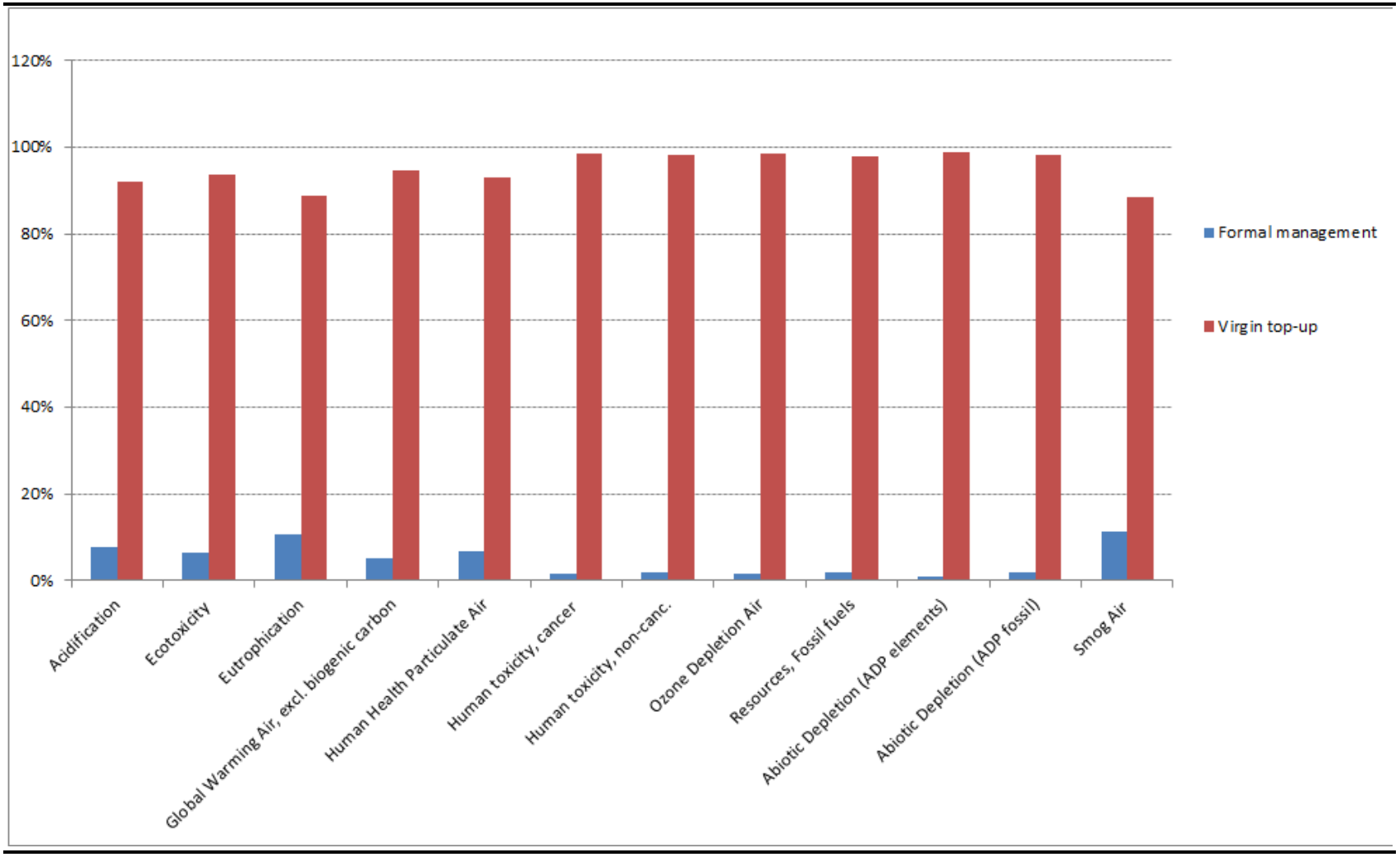


Figure 6.19 Relative effect of the choice of substituted fuels – extreme RRBO (relative performance, where 1=Extreme RRBO)

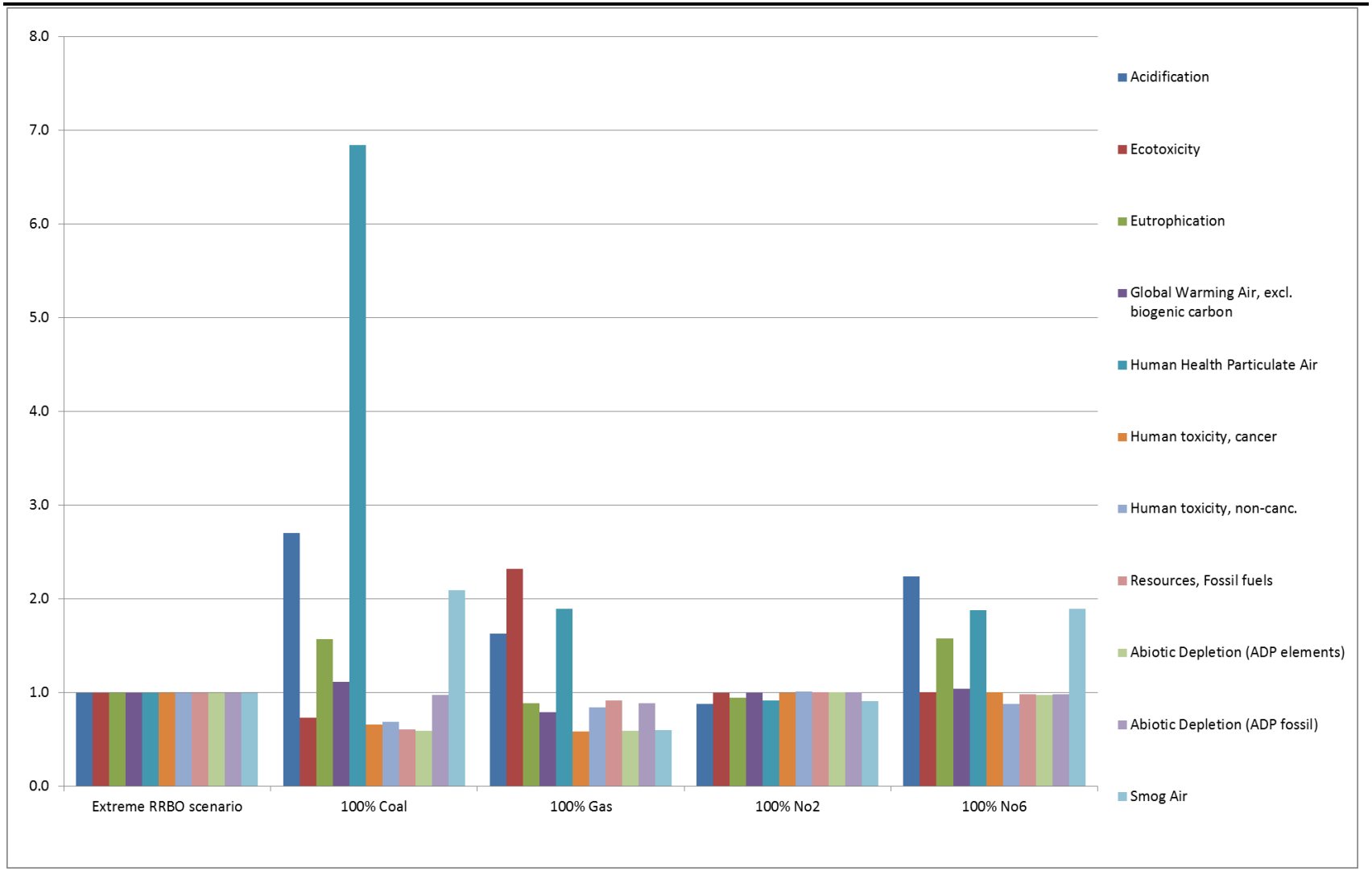


Table 6.13 Extreme RRBO scenario sensitivity to virgin product production

Impact	Unit	Extreme RRBO	Alternate virgin production (US)	% Change
Acidification	kg SO_2-Equiv.	7,296,667	6,784,988	-7%
Ecotoxicity	CTUe	771,807,256	672,197,770	-13%
Eutrophication	kg N-Equiv.	170,137	165,722	-3%
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,197,660,765	2,084,517,850	-5%
Human health particulate air	kg $PM_{2.5}$-Equiv.	398,366	402,939	1%
Human toxicity, cancer	CTUh	2	2	-1%
Human toxicity, non-canc.	CTUh	155	153	-1%
Ozone depletion air	kg CFC 11-Equiv.	0	0	1124%
Resources, fossil fuels	MJ surplus energy	6,730,232,359	6,540,820,218	-3%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	487	488	0%
Abiotic depletion (ADP fossil)	MJ	49,676,282,373	48,506,385,953	-2%
Smog air	kg O_3-Equiv.	60,614,076	61,829,421	2%

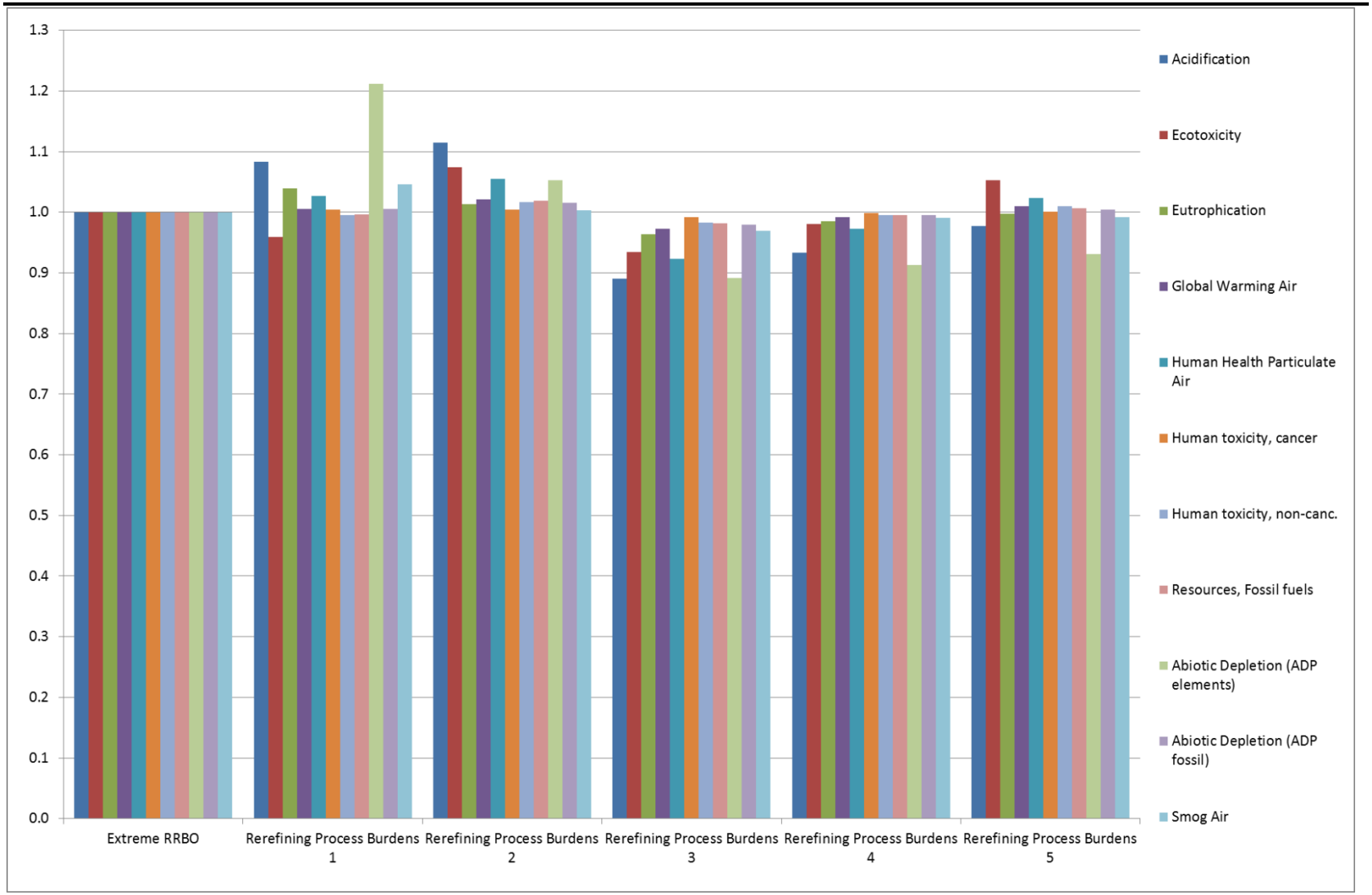
Re-refining process burden sensitivity

The five re-refining processes in the inventory section, which were used to model the extreme RRBO scenario, demonstrated a large variation in process requirements in terms of energy and ancillary materials. However, even though the base oil yields varied widely (from under 60% to over 80%), the variation was relatively small in terms of total petroleum product yields (1) (84-96% petroleum products excluding the light ends which, if included, would push yield to nearly 100% on a dry basis for the data in all but one of the five processes). *Figure 6.20* shows the potential influence on the overall extreme RRBO scenario. In general it can be said that, although there is a large variation in processing requirements, the variation is not significant to the overall system. This sensitivity analysis ignores the variation in product output and solely addresses processing intensity.

The global warming impact for processing for a kg of dry used oil ranged between 0.21 and 0.46 kg CO_2e and the fossil energy impact (extracted resource) ranged between 3.2 and 7.3 MJ per kg used oil.

(1) See Table 5.2 presented earlier in Section 5

Figure 6.20 RRBO processing burden sensitivity (influence on the Extreme RRBO scenario, where Extreme RRBO =1)



The goal of the study was to develop environmental profiles for the management of used oil in California in 2010 and to analyze the effects of changes in collection rate and disposition on the profile. It became clear through this study and previous work that the comparative impacts of different used oil treatment options were highly sensitive to assumptions that were made, and that these assumptions needed to be clearly and explicitly conveyed alongside all results in order for a policy maker to make informed decisions that are likely to result in the desired outcome. This work has built on UCSB's Phase I work to show the significance of used oil collection rates and how, even set against the inherent uncertainty, increased collection reduces overall environmental impacts.

This is consistent with the goal of the phase I study "The goal of this LCA was to generate a quantitative environmental profile of the management system for all of the used oil generated in California".

CA Senate Bill 546 required the used oil LCA to provide a basis for statutory recommendations to "*promote increased collection and responsible management of used oil*". Therefore, this LCA should help to address the following questions:

- what are the environmental impacts if policy changes resulted in different used oil collection rates; and

- what are the environmental impacts if policy changes resulted in differing disposition mixes ('responsible management of used oil') through re-refining (RRBO), reprocessed fuel oil (RFO) and distillation to produce VGO and/or Marine Distillate Oil (MDO)?

To speak directly to the aims of SB546, we have examined the effects of increasing used oil collection and considered different formal dispositions (responsible management). In the following sections, we provide some context based on the results of the study represented so far, and explore some of the questions around comparison of the different dispositions and tipping points.

We also used system expansion rather than avoided burden so that we could address the effects of increased collection and deal explicitly with the make-up of virgin products that is required to meet a constant market demand condition. In constructing a suitable expanded product system that accommodates the functions delivered by each scenario, the virgin make up is a substantial contribution. This approach aids the understanding of the

system in context. However, it means that the overall analysis is broader than just the management of used oil.

This is done because the formal management of used oil is, at its root, intended to remove used oil from the environment and to use a set of processes to provide fuel or lubricant petroleum products to the commercial marketplace by employing that used oil rather than crude oil (or natural gas or coal) as the raw material input (feed stock) for those production processes. Thus, an overall analysis is prudent in this LCA (and any that follow) that is sufficiently broad to encompass those portions of the wider lubricant and fuel product markets that can be directly affected by (displaced by) the formal used oil management system product outputs – meaning with collection at its 100% peak, and disposition skewed toward one or another of the primary products of the management system (e.g., RRBO or RFO).

To aid interpretation by the reader, the following measures for 2010 may provide a useful reference:

- population of California was 37.25 million (US Department of Commerce);
- per capita GHG emissions were 12 160 kg CO_2 equivalents (California Greenhouse Gas Emission Inventory);
- total collectable dry used oil arising is estimated to be 434 900 metric tonnes (Phase I);
- per capita collectable dry used oil is estimated at 11.7 kg;
- dry used oil collection was 74% of estimated per capita collectible dry used oil, i.e. 8.6 kg per capita;
- used oil management (formal management) released 644 500 metric tonnes CO_2 equivalents;
- used oil management (formal management) released 17.3 kg CO_2 equivalents per capita or 2 kg per kg of collected used oil (includes combustion as secondary fuel);
- used oil management (formal management) required 2 244 million MJ of fossil fuel energy to process the collected used oil;
- used oil management (formal management) required 60 MJ fossil energy per capita or 5MJ per kg of collected used oil;
- the disposal of uncollected used oil (informal management) resulted in 343 657 metric tonnes CO_2 equivalents, or 9.2 kg CO_2 equivalents per capita;

- if the used oil collection rate were increased to 85% the kg CO_2 equivalents per capita from the disposal of uncollected used oil would reduce to 5.3kg (a 42% reduction in impact).

7.1.1 Key drivers and sensitivities

The impact assessment results clearly show that the calculated environmental impacts of the overall system for used oil management and associated virgin production required to deliver a constant volume of commercial products is highly dependent on the real world variation in pollution control and the virgin products that are substituted by secondary products. This variation has been tested through parameters built into the model (summarized in *Figure 7.1* through *Figure 7.12* for each impact below) and discussed further in the context of increasing collection and changing disposition.

Each of these figures shows the range of results for each case. Although there are discrete points on each graph to reflect the specific cases, it is important to remember that results will fall within the ranges where a mix of fuels or level of pollution control is found in practice. For example, a fuel mix to consider for substitution in the market might consist of differing fractions of natural gas, No 6 fuel oil, No 2 fuel oil and coal - and results would fall in the range shown. Given that the fuels in use in a market may change over time and the levels of pollution control may not be readily determined, or controlled, for a whole system, it is appropriate to consider a range of possible results.

7.1.2 Increasing collection

To examine the magnitude of the effect of changing collection rates on overall environmental impacts of the system, we constructed scenarios with all of the used oil being uncollected (extreme uncollected – effectively a theoretical scenario where all used oil is wasted) and with different collection rates to compare against the baseline (leaving the treatment proportions as per the baseline for comparison).

To illustrate the significance of illegal (informal management) disposal of used oil, we can inspect *Figure 7.2*, the comparison chart for ecotoxicity, and review the baseline (74% collection) and sensitivity scenarios for 85%, 0% and 100% collection. From the impact assessment section, we know that informal management contributed approximately 80% of the ecotoxicity impact for the baseline scenario. *Figure 7.2* dramatically highlights the importance of addressing uncollected oil. Although the fate of uncollected oil is unknown, the results highlight the potential for harm and the clear and consistent benefits of increasing collection.

Table 7.1 gives an indication of the environmental benefits that can be achieved through an increase in collection from a baseline of 74% to a collection rate of 85%. The results reflect total system impact and therefore include the effects

of reduced needs for make-up product that is required from virgin (primary oil refineries) sources to meet constant commercial market demand.

Figure 7.1 through *Figure 7.12* demonstrate further the benefit of collection by also presenting results for a zero collection rate and 100% collection alongside sensitivities for pollution control. The collection sensitivities show that there is the potential for the benefits from collection to be lost for some impacts if poor pollution control occurs, e.g. when secondary fuels that are produced from used oil reprocessing are combusted. The human health (particulate) impact provides a good example of this potential loss of benefit.

Table 7.1 Reduction in impact from increasing collection to 85%

Impact	Unit	Baseline	85% collection	Reduction	Reduction %
Acidification	kg SO_2-Equiv.	7,574,619	7,480,792	93,827	1%
Ecotoxicity	CTUe	4,358,638,296	2,955,555,246	1,403,083,049	32%
Eutrophication	kg N-Equiv.	449,301	348,628	100,673	22%
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,792,735,162	2,643,477,244	149,257,918	5%
Human health particulate air	kg $PM_{2.5}$-Equiv.	567,665	550,580	17,085	3%
Human toxicity, cancer	CTUh	3	3	0	9%
Human toxicity, non-canc.	CTUh	1,440	948	491	34%
Ozone depletion air	kg CFC 11-Equiv.	0	0	-0	-7%
Resources, fossil fuels	MJ surplus energy	7,792,924,733	7,546,444,886	246,479,847	3%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	520	504	16	3%
Abiotic depletion (ADP fossil)	MJ	57,404,070,661	55,586,168,196	1,817,902,466	3%
Smog air	kg O_3-Equiv.	65,900,949	64,356,586	1,544,363	2%

7.1.3 Percentage of improper disposal to fresh water

The study assumes a 50/50 split between improper disposal of used oil to freshwater and to land, due to a lack of data on this type of illegal dumping. However, this division might not be representative of a real-life scenario. To illustrate the impact of the split, *Table 7.2* reflects the results of a 90/10 split between land and freshwater dumping respectively, for those scenarios that include informal management. The results show that only the toxicity and eutrophication impact categories are affected, where a decrease in ecotoxicity and eutrophication and an increase in human toxicity, non-cancer, is found.

Table 7.2 Impact results for baseline, 85% collection and extreme uncollected scenarios with illegal dumping set at 90% to land and 10% to freshwater

Impact	Unit	Baseline at 90/10	Diff. vs 50/50 (%)	85% collection at 90/10	Diff. vs 50/50 (%)	Extreme uncollected at 90/10	Diff. vs 50/50 (%)
Acidification	kg SO_2-Equiv.	7,574,619	0%	7,480,792	0%	8,205,801	0%
Ecotoxicity	CTUe	2,628,002,756	-40%	1,957,111,666	-34%	7,141,260,218	-48%
Eutrophication	kg N-Equiv.	265,732	-41%	242,723	-30%	420,521	-63%
Global warming air, excl. biogenic carbon	kg CO_2-Equiv.	2,792,735,162	0%	2,643,477,244	0%	3,796,845,262	0%
Human health particulate air	kg $PM_{2.5}$-Equiv.	567,665	0%	550,580	0%	682,596	0%
Human toxicity, cancer	CTUh	3	-4%	2	-3%	4	-10%
Human toxicity, non-canc.	CTUh	2,293	59%	1,440	52%	8,025	69%
Ozone depletion air	kg CFC 11-Equiv.	0	0%	0	0%	0	0%
Resources, fossil fuels	MJ surplus energy	7,792,924,733	0%	7,546,444,886	0%	9,450,988,134	0%
Abiotic depletion (ADP elements)	kg Sb-Equiv.	520	0%	504	0%	628	0%
Abiotic depletion (ADP fossil)	MJ	57,404,070,661	0%	55,586,168,196	0%	69,633,054,429	0%
Smog air	kg O_3-Equiv.	65,900,949	0%	64,356,586	0%	76,290,366	0%

7.1.4 Changing recovery disposition

The study has appraised the environmental impacts if policy changes resulted in differing recovery disposition mixes ('responsible management of used oil') through re-refining (RRBO), recovered fuel oil (RFO) and distillation to produce VGO and/or Marine Distillate Oil (MDO). This has been achieved by modelling 100% collection and diversion of all collected used oil to each potential disposition:

- **'Extreme RFO' –** 100% of used oil produced in California is reprocessed into RFO. No used oil is managed informally;
- **'Extreme MDO' –** 100% of used oil produced in California is reprocessed into MDO. No used oil is managed informally;
- **'Extreme VGO' –** 100% of used oil produced in California is reprocessed into VGO. No used oil is managed informally;
- **'Extreme RRBO' –** 100% of used oil produced in California is re-refined into RRBO. No used oil is managed informally.

On reviewing *Figure 7.1* through *Figure 7.12* in tandem with the detailed impact assessment results, the analysis suggests that all processing routes are beneficial and, depending on scenario and impact category specifics, may suggest that no one re-refining/reprocessing route is preferred within the uncertainty of the assessment. The displaced fuel mix (No 6 fuel oil, No 2 fuel oil, natural gas, coal) and levels of pollution control have a significant influence on the results and on any order of preference for a deposition route.

The study utilizes three indicators of resource depletion, all three show the same trends and demonstrate that all routes deliver equivalent resource depletion benefits through the supply of secondary products and the substitution of virgin products, see *Figure 7.9*, *Figure 7.10*, and *Figure 7.11*. The choice of coal or natural gas in place of virgin liquid fuels can change the order of preference.

As can be seen, the displacement choice (be it a mix of liquid fuels, coal or natural gas) has a significant influence on the results and the relative performance of the scenarios.

This analysis highlights the need for caution and detailed scrutiny when reviewing results of an LCA where a single choice or single mix of displacements is employed. Such assessment choices, taken without a firm basis, can result in diametrically opposed conclusions. It is extremely difficult in an open market to be certain of where fuels will be used and what displacement is occurring.

It can be hypothesized that, in the short term, fuels will be used in existing equipment that can accept them directly or with limited retrofitting. Longer term, the increased availability of fuel (or cheaper fuel) could see industrial users invest in alternate fuels and equipment, resulting in a different displacement mix. There is little doubt that employing secondary fuels to replace coal and residual fuels has been demonstrated to offer environmental benefits for the acidification, global warming, human health (particulate), and smog air impacts and should continue to be a direction of travel encouraged by policy makers.

7.1.5 Level of pollution control, restrictions on process types

The analysis can be used to illustrate the potential impact on the environmental profile of used oil management through increasing levels of pollution control on use of used oil derived fuels.

The inventory data show that large contributions to overall impacts result from the use of secondary fuels and that these depend to a great degree on the level of pollution control in use.

There are at least three ways in which emissions from the use of used oil derived fuels (in particular RFO, but also MDO and the other by-product fuels) can be controlled through:

a) restricting the use of RFO to processes able to meet high levels of environmental control (such as cement kilns and plants with effective pollution controls);

b) requiring improved pollution controls for plants using waste-derived fuels, frequently done through plant permits; and

c) imposing concentration limits on key constituents in the used oil derived products.

Such measures may not be feasible everywhere and there are places where used oil derived fuels are blended into the liquid fuel supply. This will dilute the used oil derived fuel, but will not remove the effects of some contaminants, such as the metals.

Since the products that are substituted by used oil derived products have such a major impact on the results of the analysis for certain impacts, policy makers could consider measures to restrict these substitutions. In broad terms, substituting a dirtier fuel with a used oil derived fuel would generally give improvements in environmental profile. So, for example, if RFO replaced heavy oil or coal, and emission limits were met, this would result in a comparative benefit compared to substituting a clean fuel such as natural gas.

The results suggest that policy and legislative effort should focus on levels of pollution control for combustion of fuels, as there is significant potential for affecting the resultant environmental impacts from combustion for energy supply.

The greatest influence can be seen on the environmental impact profiles of:

- **'Extreme RFO' –** 100% of used oil produced in California is reprocessed into RFO - no used oil is managed informally; and

- **'Extreme MDO' –** 100% of used oil produced in California is reprocessed into MDO - no used oil is managed informally, as these scenarios result in the largest quantity of secondary fuels.

The level of pollution control applied has the greatest influence on RFO due to the greater likelihood of presence of used oil contaminants.

The impact contributions for used oil management processes are influenced mainly by sulfur content, NOx and particulate emissions factors, zinc, phosphorous, arsenic and lead content of used oil, with zinc dominating the toxicity impact categories (see *Annex C*).

As described earlier, there is significant uncertainty over the toxicity contribution of metals and it is generally accepted that toxicity models are not good at characterizing metals. Zinc clearly demonstrates this issue when we consider its use in a diverse range of consumer products, for galvanizing, and in direct release to the environment as sacrificial anodes.

There is also significant uncertainty associated with used oil composition and the treatment of contaminants that are below detection limits. Arsenic was found to be below detection limit in all the used oil samples. For zinc, the Phase I used oil composition, which relies on old and varied data, contained zinc at 1030 ppm. This study, using the more recent analysis of used oil samples, appraised 498 ppm zinc. This finding is considered more representative and in line with the move away from zinc-dithio/dialky phosphate as additives to reduce wear/provide anti-oxidant properties in engine oils, due to the detrimental impact of phosphorous on catalytic converter operation. Ignoring the high level of uncertainty around the appraisal of metals by the impact assessment methods, the differences in composition will result in a potential 100% plus variation in ecotoxicity and human health (non-cancer) impact values.

This uncertainty associated with used oil composition makes any previous comparative conclusions of disposition preference for ecotoxicity and human toxicity impacts tenuous at best. This is compounded when this uncertainty is then combined with other uncertainties associated with pollution control and combustion device performance.

The impact results from used oil virgin refinery operations and crude oil extraction are a result of sulfur oxide, NOx, arsenic, barium, copper, silver and R 114 (dichlorotetrafluoroethane) emissions. Virgin product production dominates for acidification, human toxicity (cancer), ozone depletion and smog impacts.

Figure 7.1 *Comparison of all scenarios for acidification*

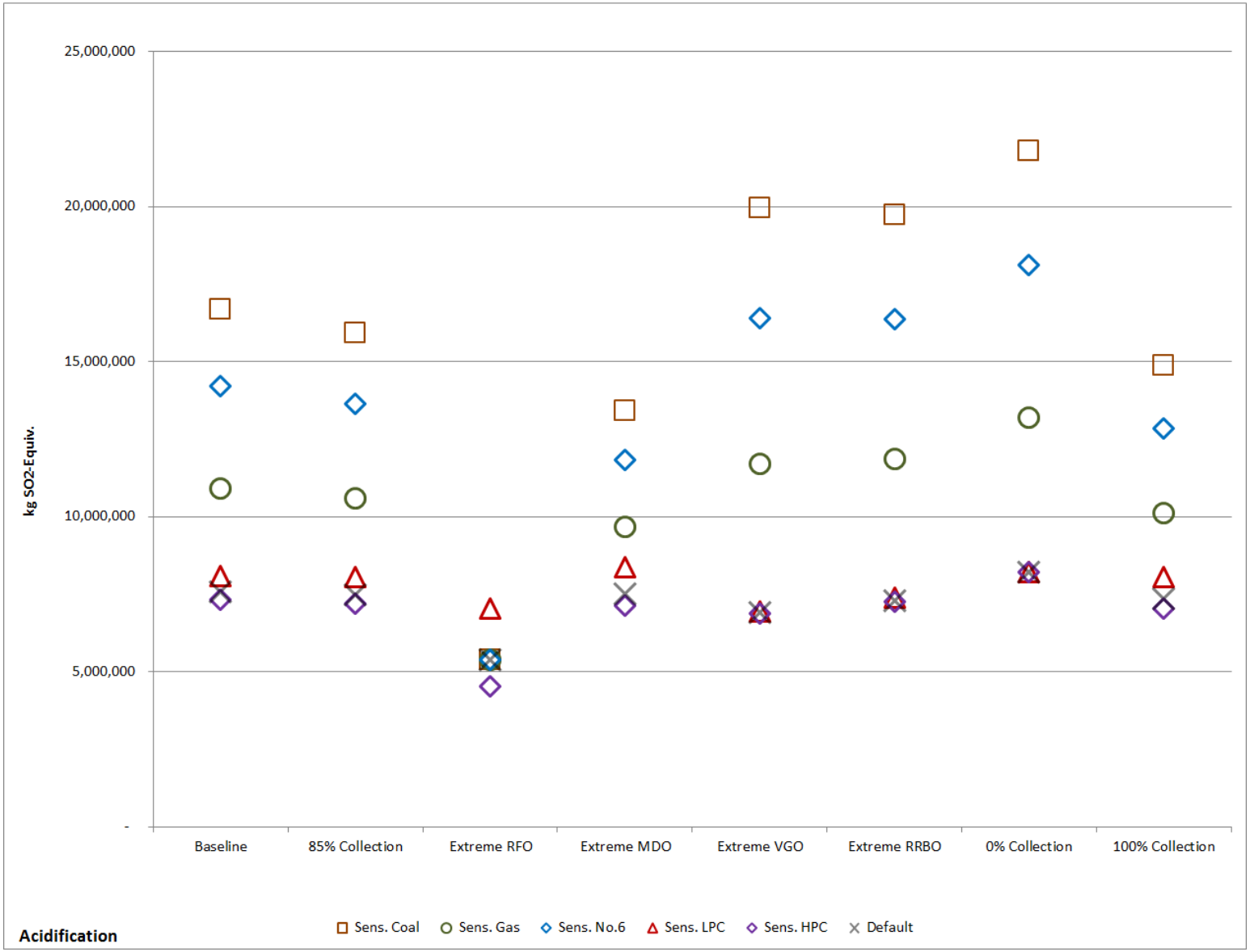


Figure 7.2 *Comparison of all scenarios for ecotoxicity impact*

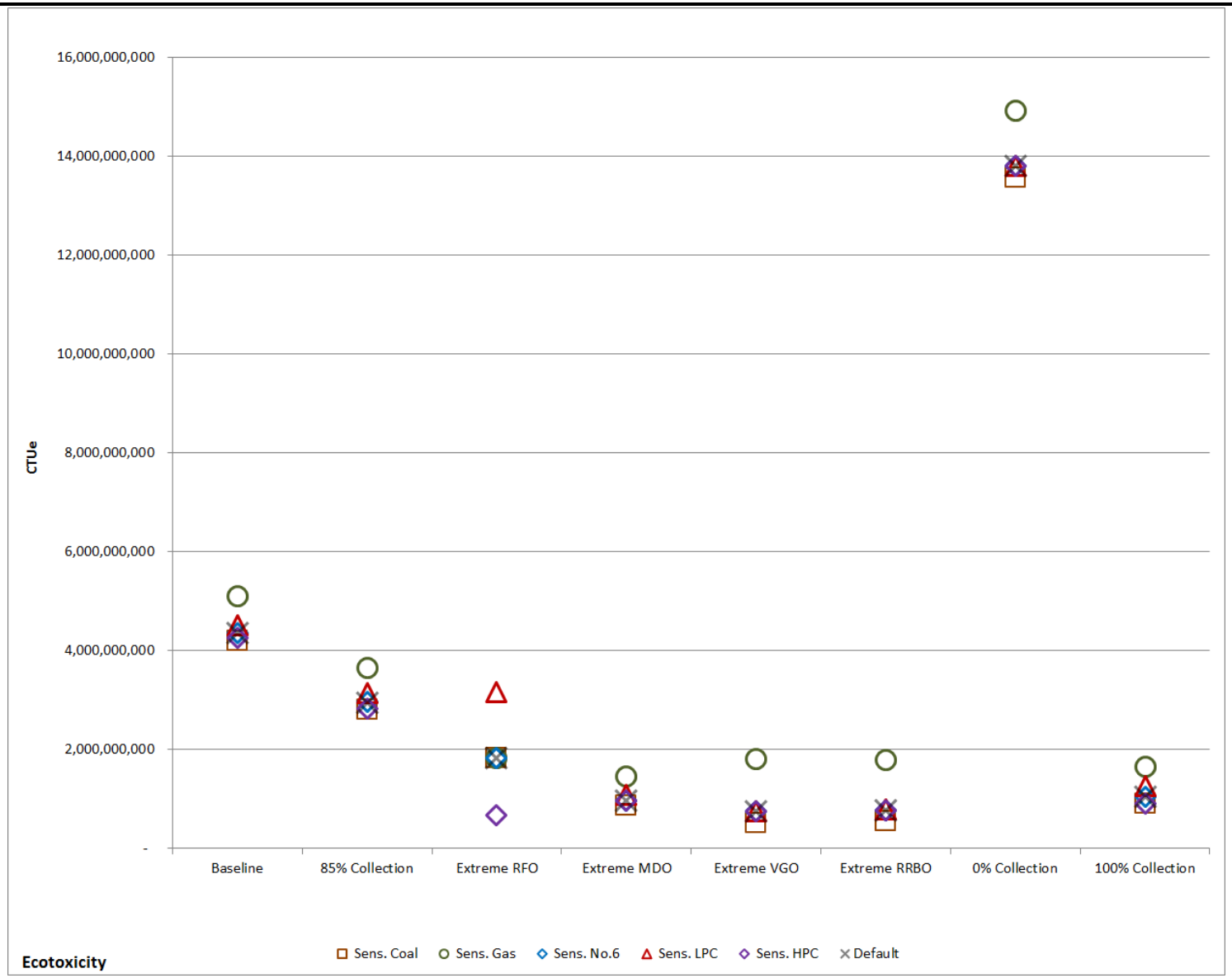


Figure 7.3 *Comparison of all scenarios for eutrophication*

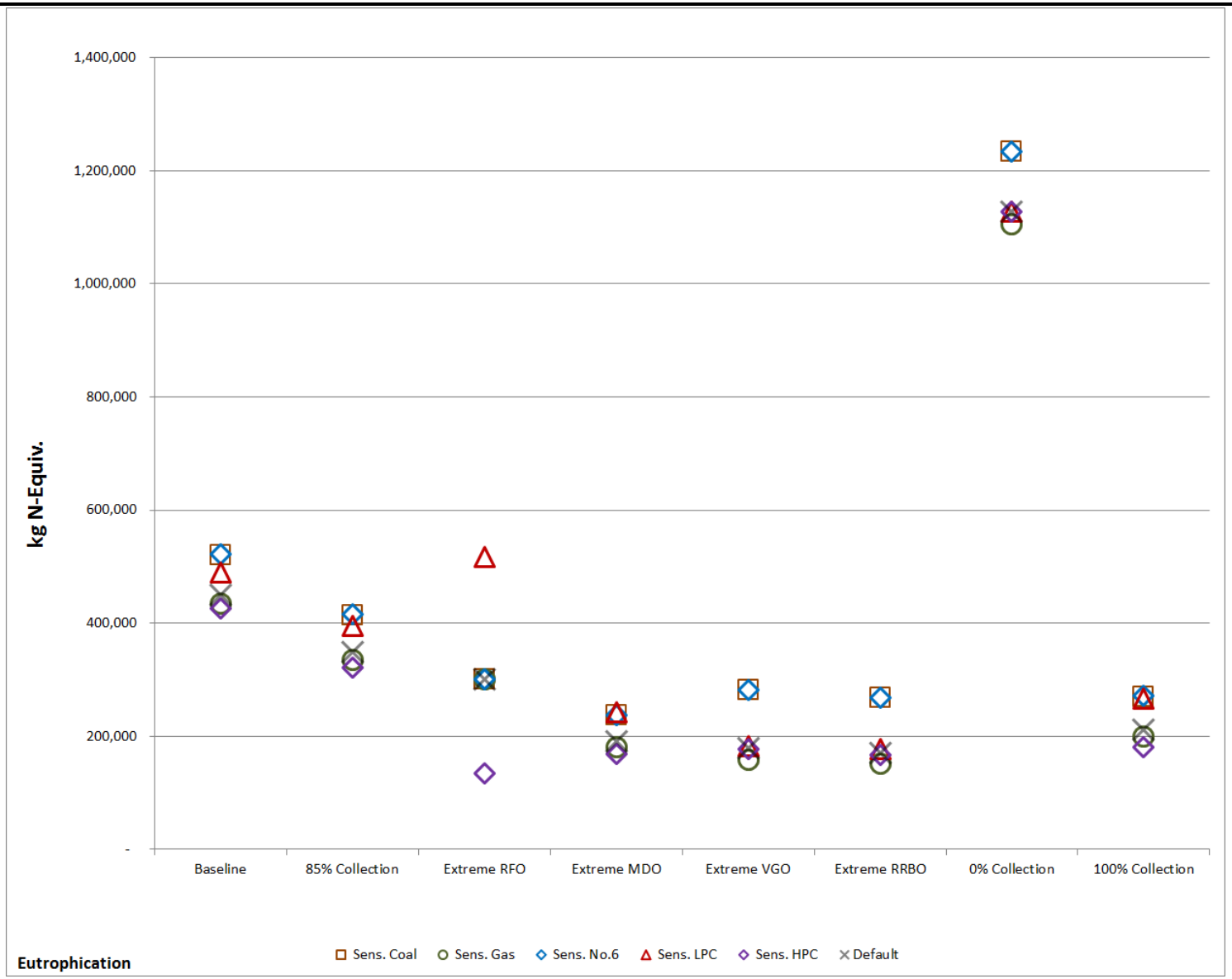


Figure 7.4 *Comparison of all scenarios for global warming*

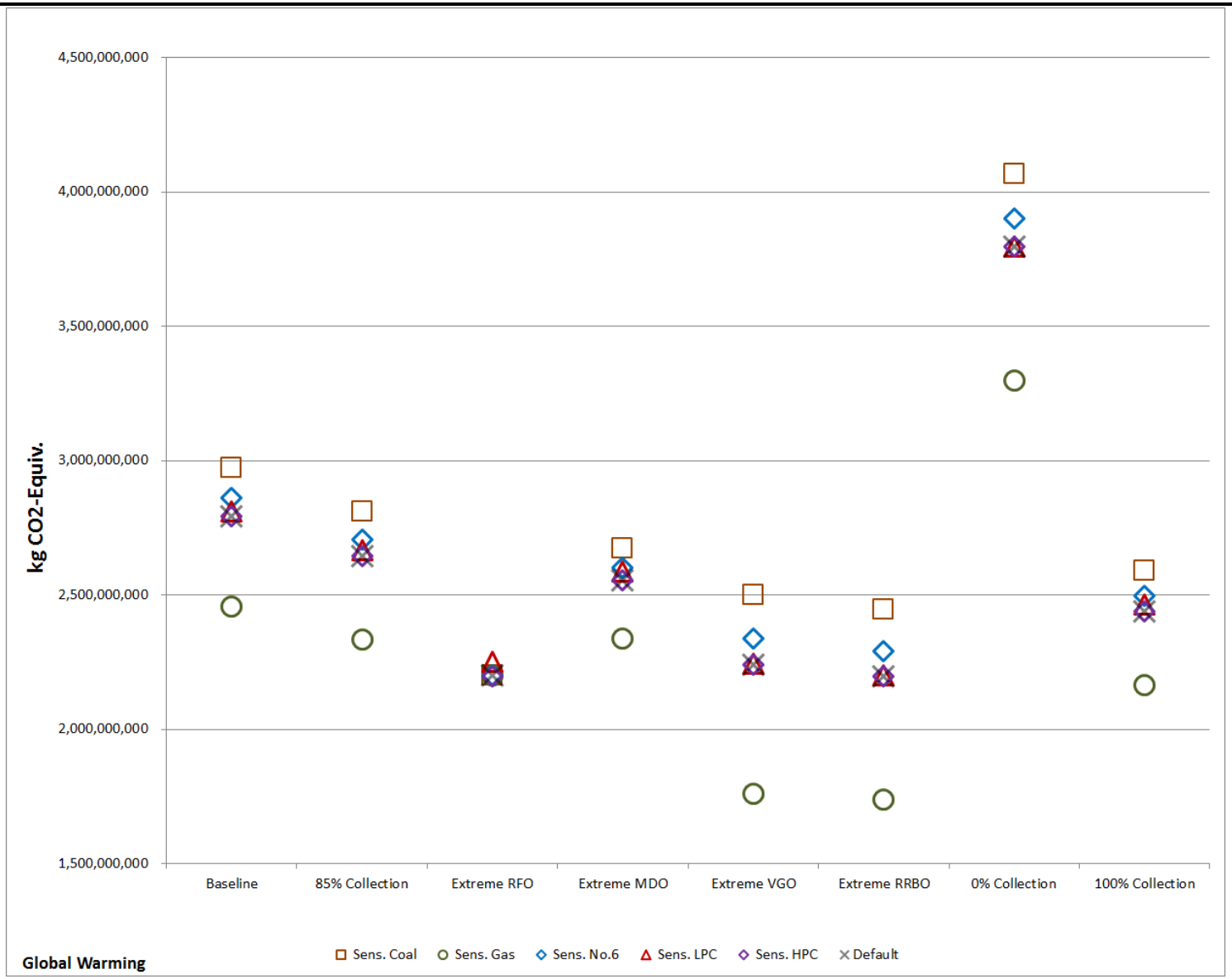


Figure 7.5 Comparison of all scenarios for human health (particulate)

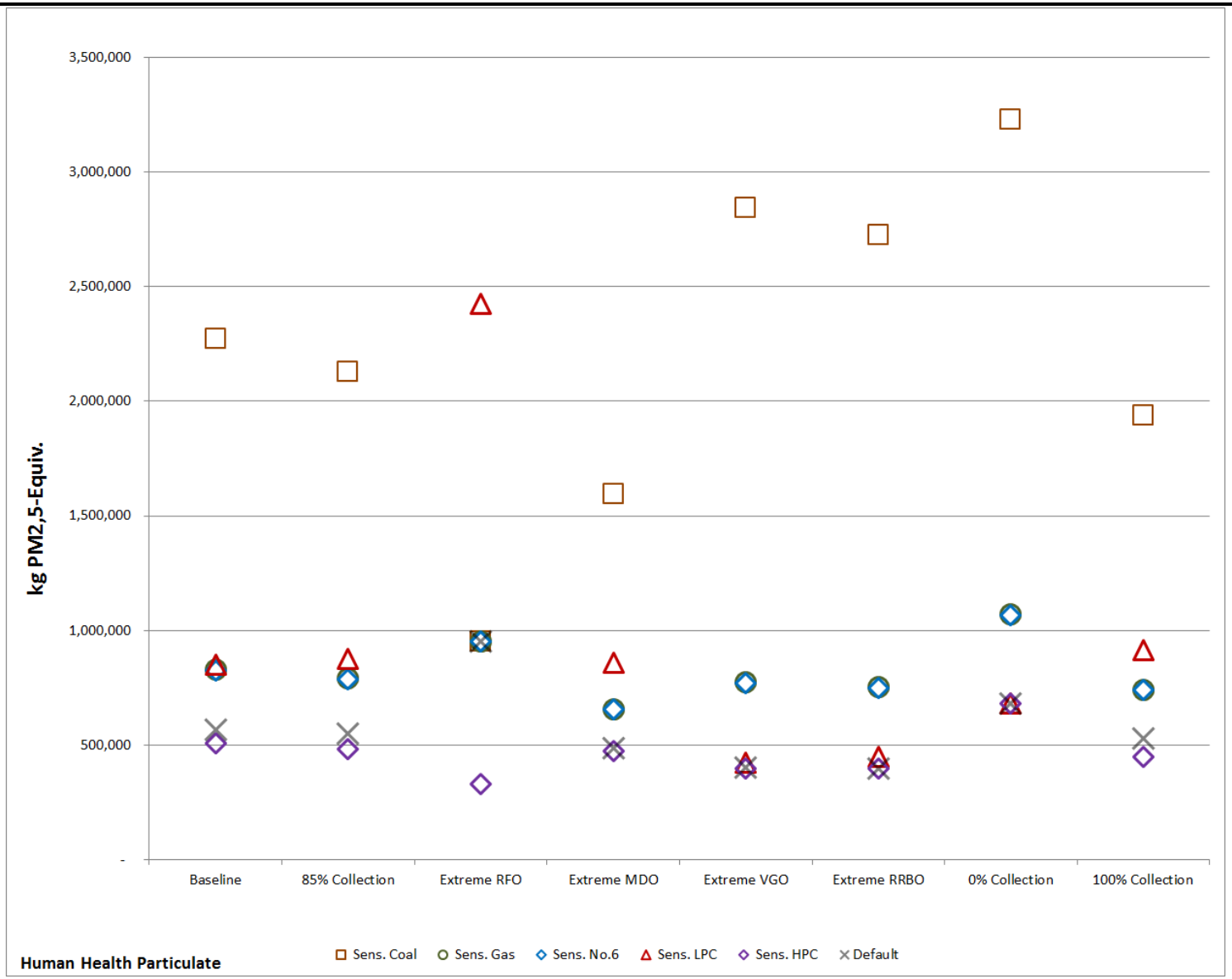


Figure 7.6 Comparison of all scenarios for human toxicity (canc.)

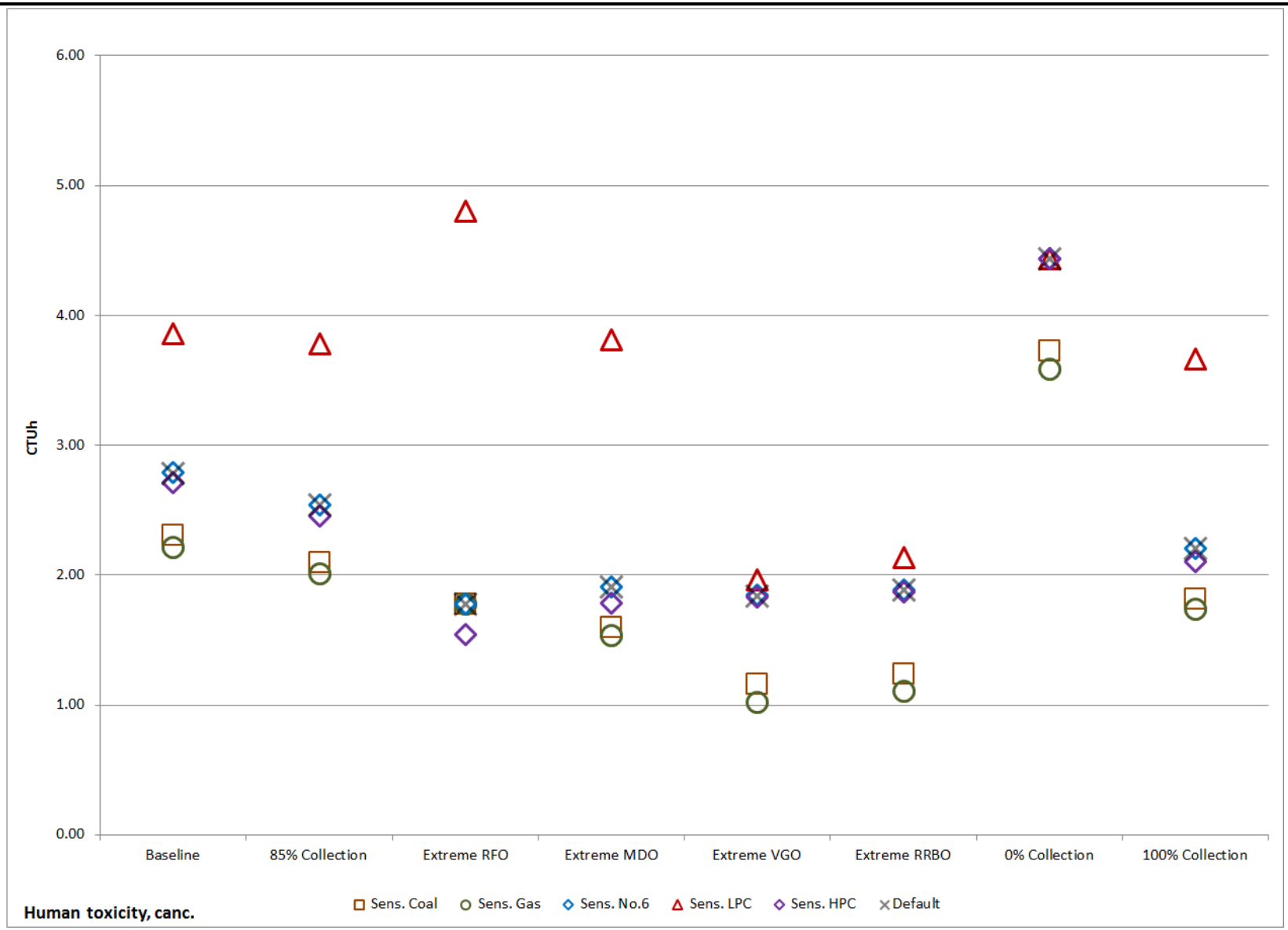


Figure 7.7 *Comparison of all scenarios for human toxicity (non-canc.)*

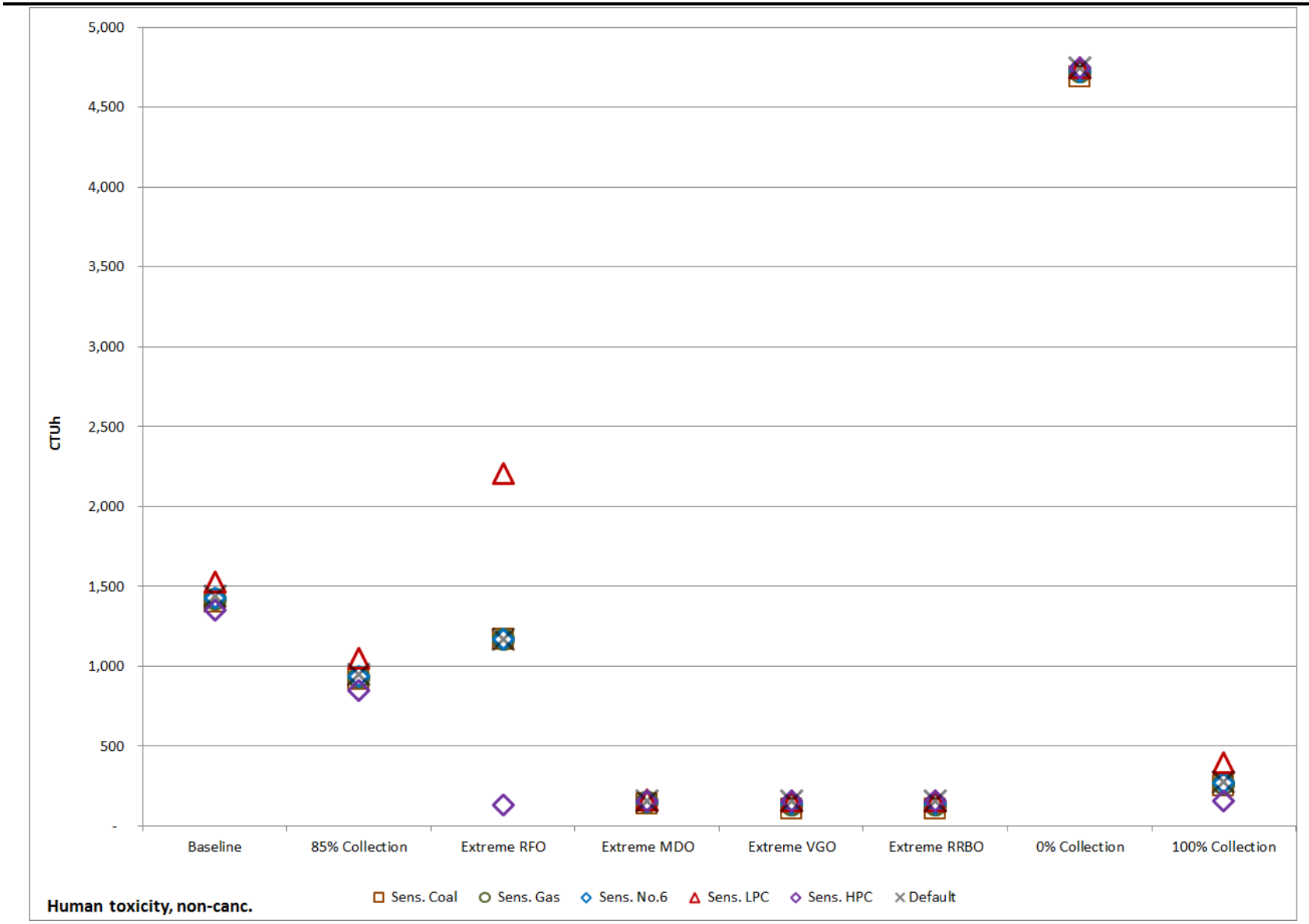


Figure 7.8 *Comparison of all scenarios for ozone depletion air impact*

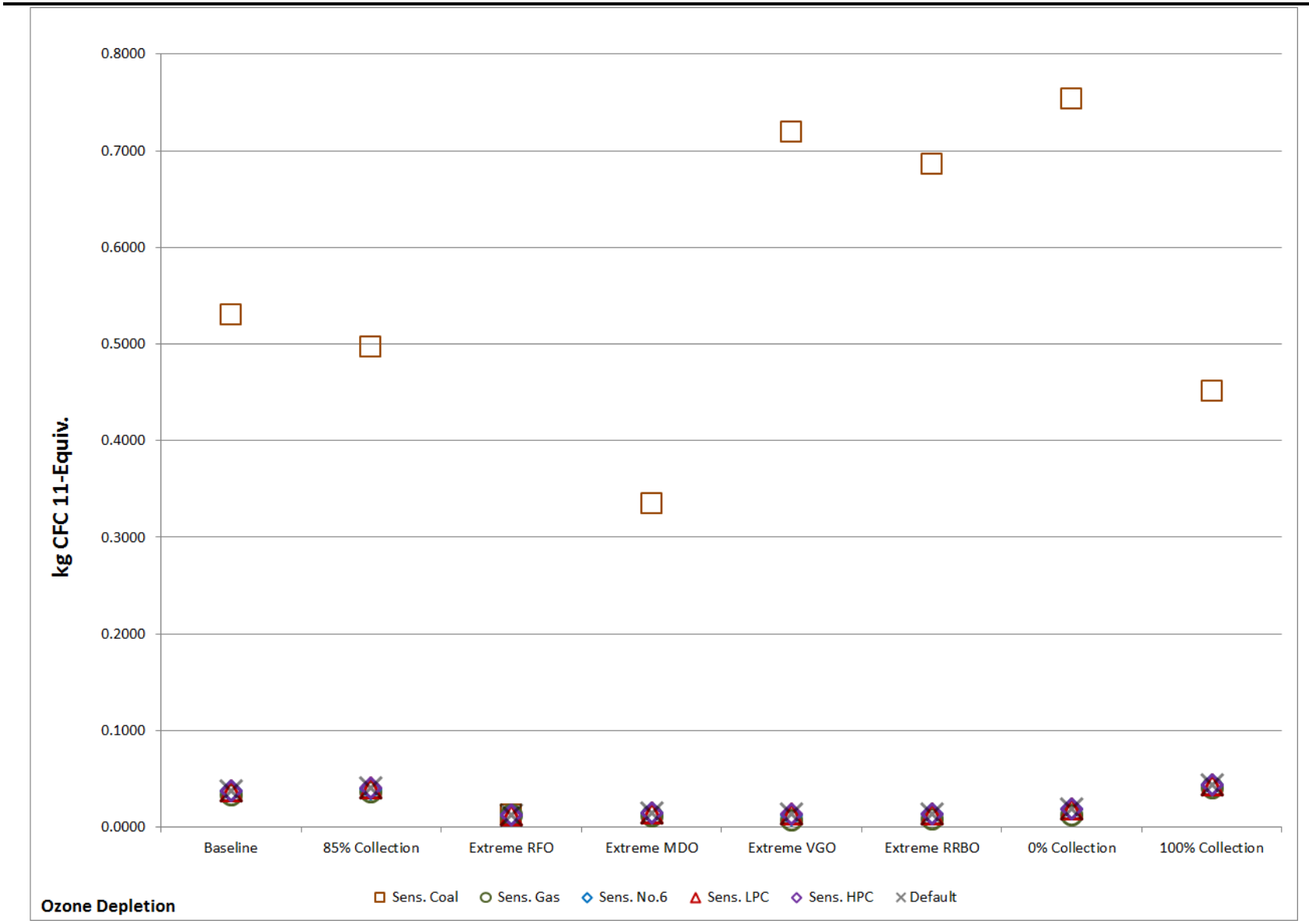


Figure 7.9 *Comparison of all scenarios for resources (fossil fuels)*

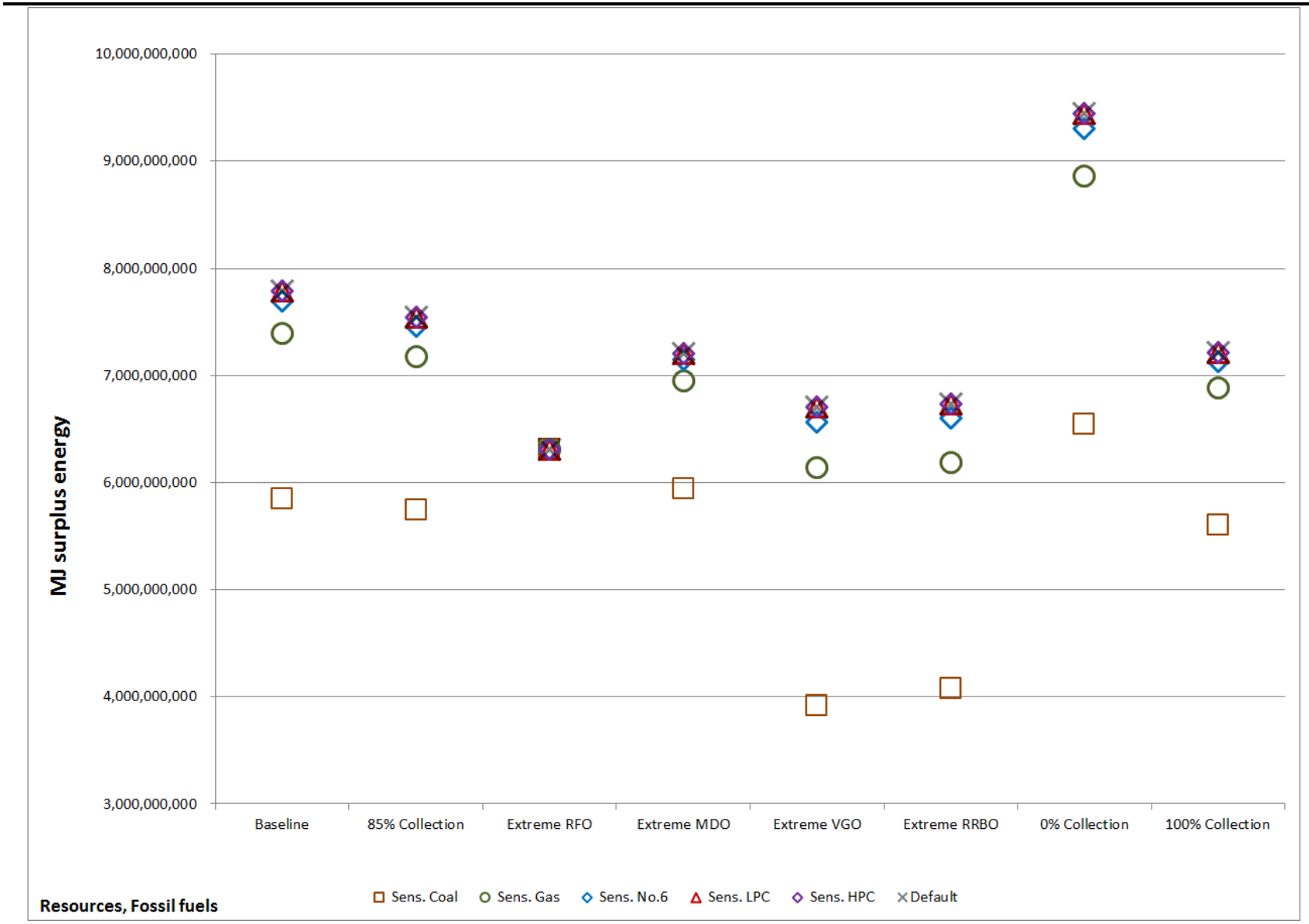


Figure 7.10 Comparison of all scenarios for abiotic depletion (ADP elements)

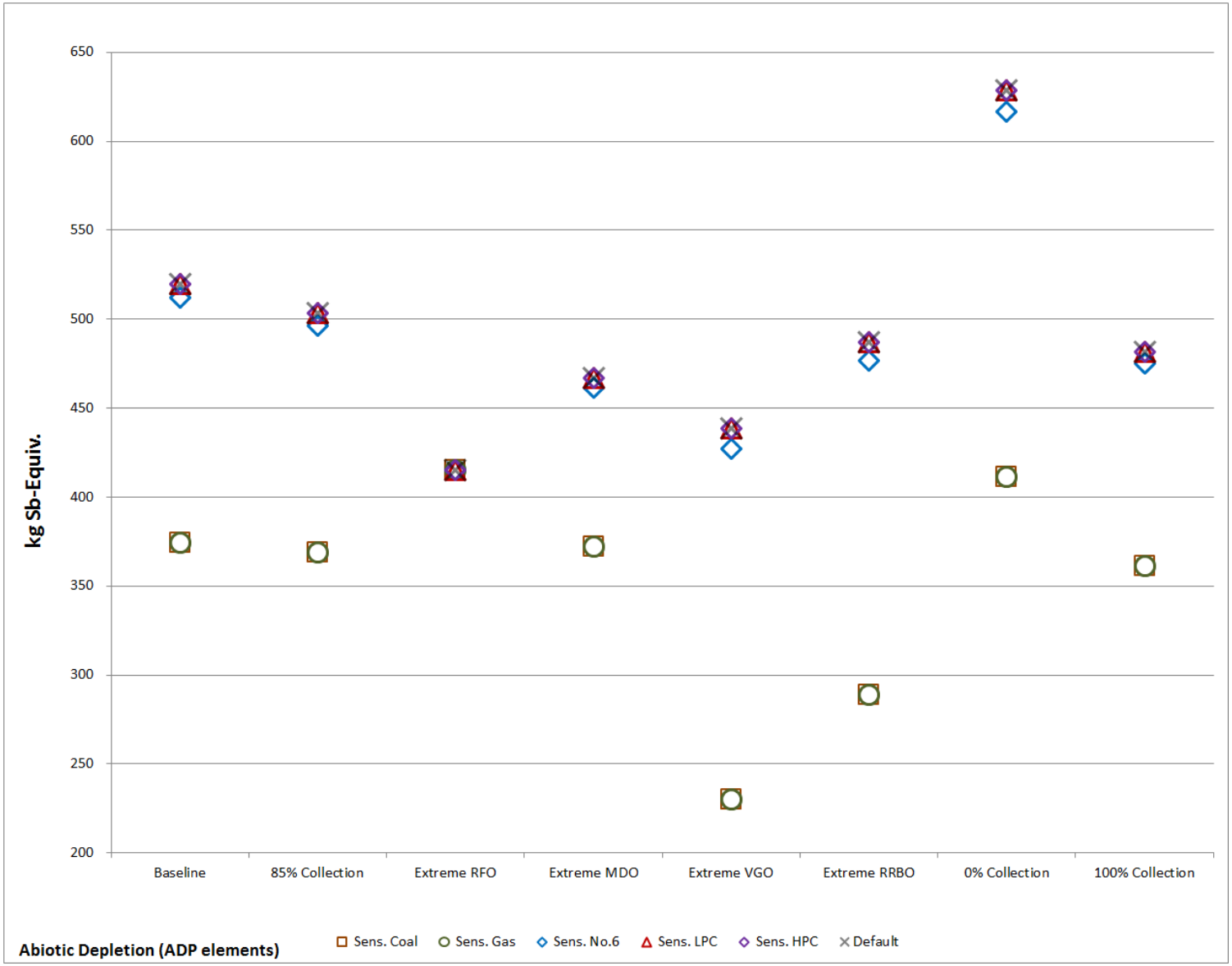


Figure 7.11 Comparison of all scenarios for abiotic depletion (ADP fossil)

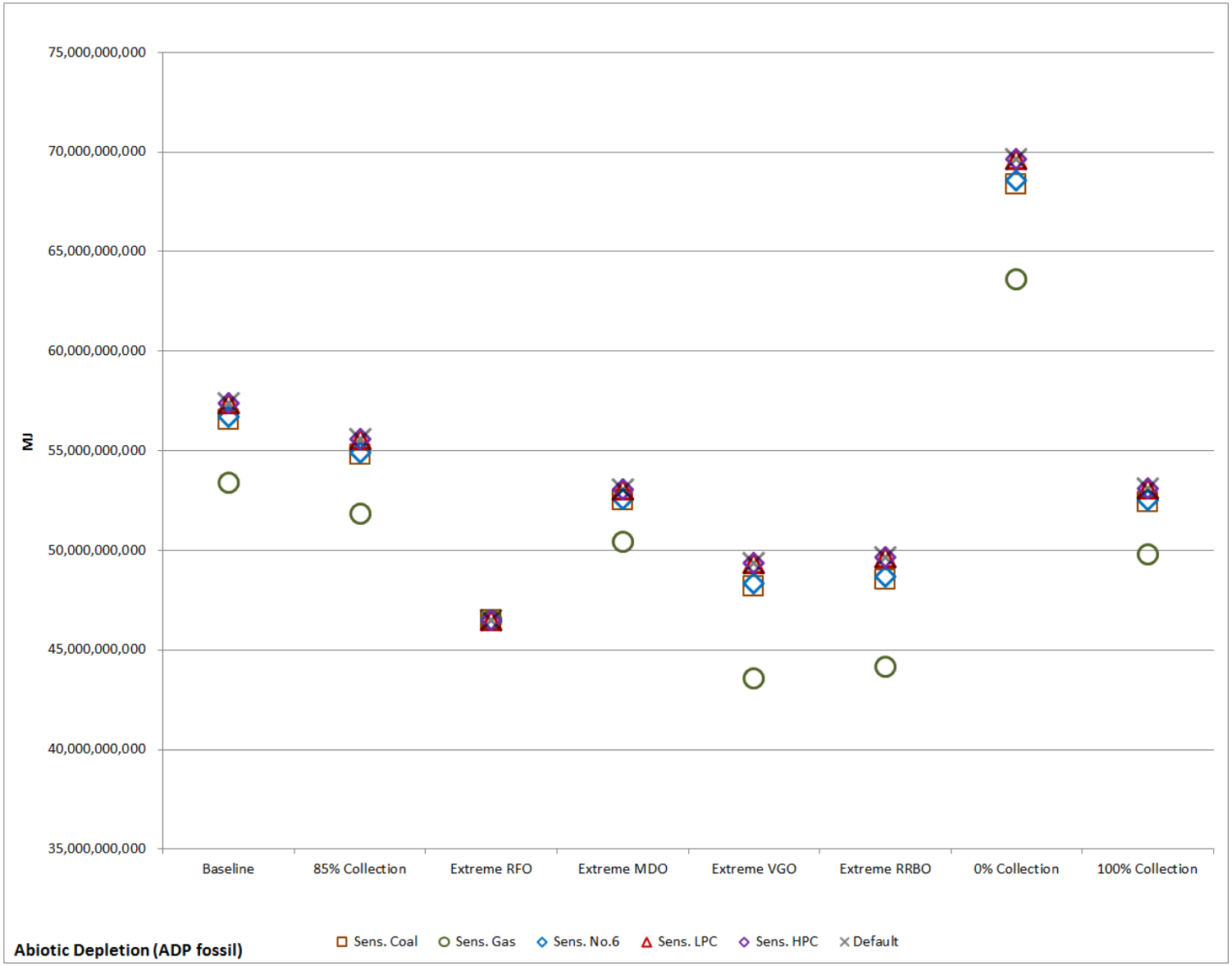
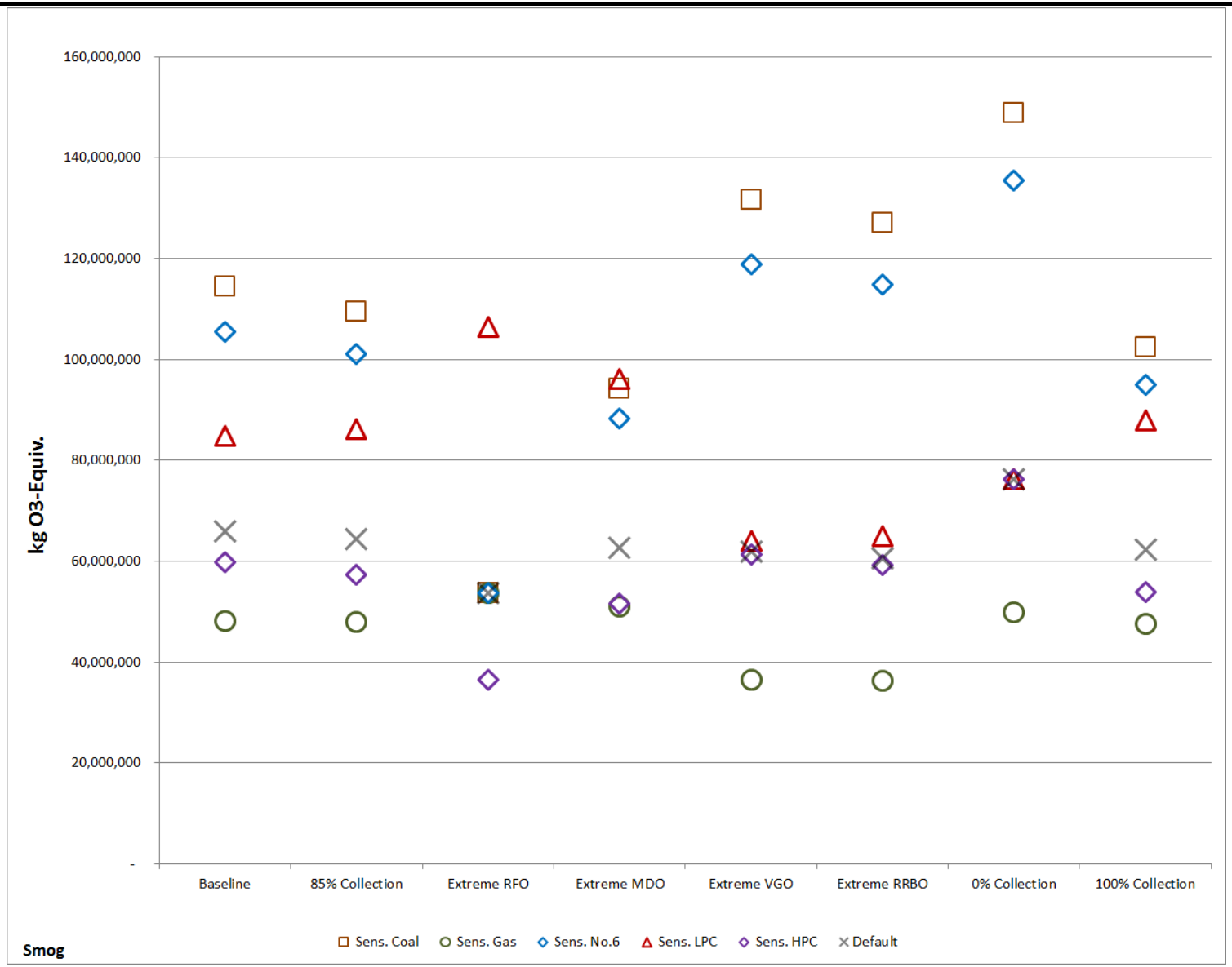


Figure 7.12 Comparison of all scenarios for smog



7.1.6 *Interpreting Figure 7.1 through Figure 7.12*

Figure 7.1 through *Figure 7.12* demonstrates the sensitivity of results to the market conditions and level of pollution control that is employed. They also identify, through a qualitative review, the tipping points, under which conditions each recovery route appraised can be said to be, preferred, has equivalent performance and under which conditions it is least preferred. For example, *Table 7.3* and Table 7.4 summarise, the conditions if we consider the RFO and RRBO recovery routes for each impact, the same approach can be taken with the other routes when reviewing *Figure 7.1* through *Figure 7.12.*

Table 7.3 Comparison of RFO with other recovery routes (conditions required)

Impact Category	Preferred	Equivalent	Least preferred
Acidification	Under all conditions	-	-
Ecotoxicity	-	High level of pollution control employed	Market energy requirement is met by coal Market energy requirement is met by Gas Market energy requirement is met by No.6 Default Low level of pollution control encountered
Eutrophication	High level of pollution control employed		Market energy requirement is met by coal Market energy requirement is met by gas Market energy requirement is met by No.6 Default Low pollution control encountered
Global warming		All other except when market is supplied by gas	
Human Health Particulate	High level of pollution control employed	Default Market energy requirement is met by coal Market energy requirement is met by gas Market energy requirement is met by No.6	Low level of pollution control employed
Human toxicity, canc.	High level of pollution control employed when market is supplied by liquid fuels	Default Market energy requirement is met by coal Market energy requirement is met by gas Market energy requirement is met by No.6	Low level of pollution control employed
Human toxicity, non-canc.		High level of pollution control employed	Market energy requirement is met by coal

Impact Category	Preferred	Equivalent	Least preferred
			Market energy requirement is met by gas
			Market energy requirement is met by No.6
			Default
			Low level of pollution control employed
Resources, Fossil fuels	All when market supplied by liquid fuels		
Abiotic depletion (elements)	High level of pollution control employed	Default	Low level of pollution control employed
		Market energy requirement is met by coal	
		Market energy requirement is met by gas	
		Market energy requirement is met by No.6	
Abiotic depletion (fossil)	All other except when market is supplied by gas		
Smog	All other except when market is supplied by gas		

Table 7.4 Comparison of RRBO with other recovery routes (conditions required)

Impact category	Preferred	Equivalent	Least preferred
Acidification		Default	Market energy requirement is met by coal
		High level of pollution control employed	Market energy requirement is met by No.6
		Low level of pollution control employed	Market energy requirement is met by gas
Ecotoxicity		Under all conditions	
Eutrophication		Under all conditions	
Global warming	Market energy requirement is met by gas	All other except when market is supplied by gas	
Human Health Particulate		Under all conditions	
Human toxicity, canc.	Market energy requirement is met by coal	All when market supplied by liquid fuels	
	Market energy requirement is met by gas		
Human toxicity, non-canc.		Under all conditions	
Resources, Fossil fuels	Market energy requirement is met by coal	All other except when market supplied by coal	
Abiotic depletion (elements)	Market energy requirement is met by coal		All when market supplied by liquid fuels
	Market energy requirement is met by gas		
Abiotic depletion (fossil)	Market energy requirement is met by gas	All other except when market is supplied by gas	
Smog		Market energy requirement is met by gas	All other except when market is supplied by gas

This Phase II report builds on the Phase I report by UCSB/CalRecycle to provide a detailed quantitative LCA of used oil management in California in 2010 and a number of disposition scenarios selected to assess: key uncertainties beyond the direct control of a policy maker; the effect of changing collection rates; the relative effects of alternate recovery routes; alternative conventional/virgin product displacement; and levels of pollution control. The assessment does not include an economic appraisal of the options, nor does it consider processing capacity and infrastructure needs. The findings of this study will need to be interpreted in the context of available and projected/potential capacity for the different formal used oil management routes.

Twelve indicators of environmental impacts (e.g. global climate change, localized human health and ecosystem effects, resource conservation) have been applied, quantifying the potential contribution for each of the scenarios. The assessment does not predict impact *per se*, but instead provides a relative measure of the potential contribution that might be made by each scenario, process, and environmental flow. The study highlights the uncertainty and limitations of the analyses to aid policy makers in interpreting used oil LCA study results within these constraints.

In order to provide some context, the analysis estimated in the baseline case that the direct formal and informal management, of the approximately 435 thousand metric tonnes of dry used oil generated each year in California, contributed less than 0.25% to total acidification and climate change impacts for California and below 0.06% of smog, abiotic depletion, and human health particulate impacts.

The use of system expansion rather than an avoided burden approach enabled a meaningful analysis of the effects of increased collection rates to be made. The results show clearly that increasing rates of used oil collection lead to benefits, through reduced environmental impacts, for the system as a whole and for all impacts considered. This finding is clear and consistent despite the uncertainties.

This analysis shows that the improper disposal of used oil (i.e. uncollected oil) increases resource depletion (through requiring more virgin product make up to satisfy demand) and has the potential to cause significant environmental impacts. There is inevitably uncertainty over the fate of uncollected, improperly disposed, used oil and the potential impacts depend upon the way in which it is disposed. Disposal through dumping to water leads to high impacts.

The uncertainty analysis showed that several factors had a very significant effect on results (and could change the apparent preferences between treatment options).

The analysis also shows that the most important uncertainties that were assessed are:

- The product substitutions that are assumed, in particular the fuels; and
- The level of pollution control that is applied to the combustion of RFO.

Key assumptions that have been built into previous LCA models bias the results and obscure the fact that the results can be driven by assumptions that cannot be delivered or reasonably be assumed to be constant. The fuel market, for example, is international and a wide range of fuels can be used in many process configurations to deliver the market-required energy. These configurations may use different systems and very different levels of pollution control. This can give a misleading impression that one route is clearly "better" than others – though, in reality it depends to a great degree on the actual substitutions and technologies employed in any jurisdiction.

Fuel and product substitution depend to a large degree on forces outside the control of a used oil policy maker, for example: the relative price of different fuels at any given time; and projections of how those prices will change; as well as process requirements, technology and applicable regulations.

In an international market place, it is also not defensible to fix the source and impacts from the production of virgin products in the system. In a system involving base oil, energy and other refinery outputs, the products may come from almost any part of the world, have quite different burdens associated with their production and transportation, and will change depending on a variety of market factors. The range of impacts associated with such production needs to be taken into account as another uncontrollable uncertainty in the analysis.

Our work builds on, and strongly supports, the Phase I work of UCSB (and others) showing that there is no inherent advantage for a 'closed loop' recycling route over an 'open loop' recycling or recovery route for resource consumption- or pollution-related environmental impacts, provided that there are markets for all of the products.

In this study, alternative used oil dispositions have been appraised through "extreme scenarios" where all used oil was assumed collected and treated by one route at a time (removing the effect of collection rate and improper disposal from each, while serving to highlight impact differences among the disposition options).

Analysis of uncertainty and sensitivity demonstrate how the environmental profile of each treatment and use option is highly dependent on a range of

variables including: used oil composition; recovered product use (fuel substitution); and process characteristics/controls.

The analysis shows that no one single disposition can be said to result in a clearly and consistently better environmental profile for the whole system in all situations. Therefore, on environmental grounds, a mix of recovery routes can deliver the same benefits as employing a single route. In addition, having a mix of treatment options may also offer system resilience and flexibility benefits.

In developing policies that would favor one or more disposition routes over others it is important that supporting studies are tailored to the specific circumstances and take account of inherent and any unavoidable uncertainty to reach sound conclusions. As demonstrated, apparent advantages of one route over another may depend entirely on factors beyond the control of a policy maker and assumptions that are made within the model.

The delivery of any useful product (whether this is RFO, RRBO, MDO, VGO or VTAE) will deliver benefit, but also incur some environmental impact, through process operation. In each case, all are preferable when compared to no beneficial reuse (i.e. informal disposal). Key levers to increase the benefits and reduce the impact of each route can be identified. These include: maximizing the yield of recovery; ensuring efficient pollution abatement (directly reducing releases to the environment); ensuring that contaminated streams are appropriately managed and contaminants effectively trapped and excluded from the environment; and the use of secondary fuels to displace more polluting conventional fuel combustion processes.

The overall impacts from the use of RFO depend very strongly on the levels of pollution control that are in place at the point of use. High pollution control (such as burning in a well-controlled cement kiln or asphalt plant with high levels of pollution control) can result in RFO having lower impacts in many categories than the alternative treatment routes. Conversely, low levels of pollution control (such as burning with no dust or acid gas controls) can lead to the highest impact in certain categories. Consequently the impacts from the RFO route depend to a significant extent on the pollution controls at the point of use rather than the point of production. Comparative impacts are also strongly driven by the fuels that are substituted in the market.

Impacts from processes that distill used oil, including re-refined base oil production, MDO (or equivalent) and VGO, that concentrate contaminants in the heavy residue stream (known as VTAE), would obviously increase significantly if the VTAE stream is not managed in such a way as to prevent release of those contaminants to the environment.

When considering the system as a whole, it is clear that increasing collection yields significant benefits despite the inherent uncertainty. It follows that policies that lead to increased collection will reduce impacts and therefore

policies, market conditions, technology constraints that might inadvertently decrease collection would (though inadvertently) increase impacts.

Although we appraised alternate levels of collection, we did not explicitly consider changes in the overall supply of used oil (other than through increasing collection). Phase I projected future trends and Kline forecast reducing volumes, in particular where increased drain intervals become more common. This model allows the effect of changed volumes to be assessed (Phase I implied that decreased volume gave environmental disbenefits). In this structure, the change in environmental profile will depend on the virgin make up required to meet the specified demand.

It is important to recognize that there is significant uncertainty in impact assessment methodologies and these continue to develop. Any LCA must be seen in the light of inherent modelling uncertainty and caution used in considering the results. The study highlights concerns expressed regarding the use, to inform policy, of toxicity methods and the results that they generate, especially when these results are reported without stating any associated uncertainty. To make this clear, it is worth referring to the work of Rosenbaum et al (1) that documented the uncertainty related to LCIA toxicity methods and reported this in some cases to be orders of magnitude, due to variation in chemical characterization factors and uncertainty surrounding individual substance characterization factors. With the current state of knowledge, the methods are not suited for comparative purposes, unless the comparison is undertaken with extreme caution and in the context of the associated uncertainty.

In addition to meeting its goal, this Phase II study offers lessons, data, and a model that can be readily applied beyond California (with suitable modifications and adaptions to local conditions) to inform considerations around used oil management and the types of control necessary to deliver the maximum environmental benefits from management approaches.

A key lesson for any interested party, regulator, or potential policy maker is the need for a clear appreciation of the circumstances that will be found in a given jurisdiction. With different context, different energy markets, different levels of pollution control and different used oil compositions the preferred options can be expected to be different.

(1) Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MAJ, Jolliet O, Juraske R, Koehler A, Larsen HF, MacLeod M, Margni M, McKone TE, Payet J, Schuhmacher M, Van de Meent D, Hauschild MZ. 2008. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment. International Journal of Life Cycle Assessment 13(7) 532-546 (http://dx.doi.org/10.1007/s11367-008-0038-4).

8.1 RECOMMENDATIONS FOR ADDITIONAL WORK

A great deal more work can be done to develop and apply the models and provide analysis of where the greatest improvements to the environmental impacts of the used oil management system may be found.

Further work is needed fully to develop suitable representative ranges for burdens from key processes, in particular, in this instance, for production of refinery products and re-processing performance. Capturing the effects of different crude sources, different refinery configurations and pollution controls, and different operational practices would be valuable to better understand this LCA and to inform many other LCAs that involve similar products.

In any jurisdiction considering policies for used oil management, it would be important to make reasonable projections for how the market is likely to develop. These should take account of changes in the volume of used oil, as well as compositional variation resulting from changes in lubricant formulation and application – particularly formulations for increased performance and extended life with reduced losses. The markets for products should also be considered, as changes that are underway, or could reasonably be anticipated, in possible user segments can impact on the viability of processes. In parts of the US like California, for example, markets for RFO have reduced resulting in higher levels of export.

Burdens associated with capital goods were not included in this Phase II study. In a finely balanced system where differences among treatment options can be small, both capital burdens associated with new plant construction and changes in logistics should be considered to see whether they impact on environmental profiles.

Neither can be confidently dismissed in this analysis and future analysis would benefit from the functionality to appraise existing capacity, and capacity shortfall, in the jurisdiction(s) of interest.

A supporting economic analysis can be valuable and this should make allowances for significant changes in variables such as oil and energy prices which can affect the choices of product substitution as well as overall activity.

CalRecycle should complete its work on the compositional analysis of used oil, the products of used oil processing, and extend the work to include representative ranges of relevant virgin products in order to provide better composition data.

This work has not considered the technical issues and barriers to use of re-refined base oil and any potential impacts on formulation and additive packages required or constraints on adoption of new and changed mixes of base oils. Further work would be needed to assess these implications.

The work has not considered health and safety aspects of any part of the used oil system or manufacture, use and recovery of used oils and products derived from them. Clearly this is an area for further work outside of a Life Cycle Assessment study.

This work has not addressed the issue of any constraints on market demand that could result from any particular set of policy decisions. Clearly, as the effect of changed collection rates is so significant any impacts on collection should be considered in any policy proposals.

Further work on the effects of different processes, performance and choice of energy sources for each of the re-refining and reprocessing options would be useful to test whether decisions, such as internal use of by-product streams for process energy, affect the overall impact assessment significantly.

The analysis should be expanded and extended to a wider range of treatment technologies so that it can be used to inform jurisdictions that have either better, or worse, performing processes. It would be relatively simple to consider both the latest state of the art processes and more basic technologies, so that the model could be used all over the world.

This Phase II work did not attempt to develop or recommend specific, detailed policies or regulatory measures to increase collection of used oil, although the results show most clearly that important benefits would flow from increased collection and reduced improper disposal.

The analysis did not examine policy measures that would favor one processing option over another, but it is clear that in order to help ensure environmental benefits through limitation of used oil disposition, it would be necessary to ensure the necessary levels of pollution control, allowable fuel substitution, minimum levels of process performance and ensure that contaminated streams were appropriately handled, controlled and disposed.

Impacts from different processing options often overlap and clear benefits of one over another appear to depend very much on being able to control the levels of pollution control applied to combustion of RFO and which fuels would be substituted in the market. No analysis was done on just how such conditions could be met if there was a desire to manage the environmental impacts of the system.

Boughton, B. and Horvath, A. (2004) Environmental Assessment of Used Oil Management Methods, *Environmental Science & Technology*, 38(2), pp. 353–358.

California Air Resources Board (2013) California Toxics Inventory, 2010 CTI Summary Table. November, 2013.

California Air Resources Board (2013) The California Almanac of Emissions and Air Quality, 2013 Edition.

California Air Resources Board (2014). California Greenhouse Gas Emission Inventory: 2000-2012, 2014 Edition. May, 2014.

California Energy Commission (2012). California Energy Balance Database. January, 2012.

CalRecycle (2013) Life Cycle Assessment of Used Oil Management in California. Pursuant to Senate Bill 546 (Lowenthal), R. Gayer et al. CalRecycle, July 29, 2013.

CalRecycle (2013) Final Report on Direct Impacts Model (DIM). Analysis of the California Used Oil Market. CalRecycle. July 26, 2013.

CalRecycle (2013). Rerefining Used Lubrication and Industrial Oils Effects on Virgin Crude Oil Refining, HSB Solomon Associates LLC. CalRecycle, May 24, 2013.

Dyke, P. (2007). Emissions from Small Waste Oil Burner Burning Drained Lubricating Oil.

IFEU (2005) Ecological and energetic assessment of re-refining used oils to base oils: Substitution of primarily produced base oils including semi-synthetic and synthetic compounds.

IPCC 2007, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avery KB, Tignor M, Miller HL (editors)]. Cambridge, UK: Cambridge University Press, 996 pp.

ISO 14040: Environmental management -- Life cycle assessment -- Principles and framework, 2nd edition. Geneva: International Standard Organization, 2006.

ISO 14044: Environmental management -- Life cycle assessment -- Requirements and guidelines, First edition. Geneva: International Standard Organization, 2006.

Kline & Company Inc. (2012). Lubricant Consumption and Used Oil Generation in California.

Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MAJ, Jolliet O, Juraske R, Koehler A, Larsen HF, MacLeod M, Margni M, McKone TE, Payet J, Schuhmacher M, Van de Meent D, Hauschild MZ. 2008. USEtox—the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment. International Journal of Life Cycle Assessment 13(7) 532-546 (http://dx.doi.org/10.1007/s11367-008-0038-4).

Yahaya DB and Diso IS, Thermophysical Properties of Nigerian Used Engine Oil. 2012. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 3 (2): 244-246

U.S. Department of Commerce. California: 2010 Population and Housing Unit Counts 2010 Census of Population and Housing Issued August 2012.

US Energy Information Administration. (2012). Annual Energy Outlook 2012.

US Energy Information Administration (2016), available at: http://www.eia.gov/dnav/pet/pet_sum_mkt_dcu_nus_m.htm

Table 10.1 in the Annex provides a complete summary of all processes used in this study, together with the life cycle stages in which they are used, the year in which the data were collected, the geographic location to which the data refer, the technological coverage of the data and the source from which they were taken.

Table 10.1 Differences between Phase I and Phase II LCA studies

Aspect	Phase II LCA	Phase I LCA	Reason for change
Functional equivalence	Functional equivalence considered using "maximum constant output to commercial market" concept, where a constant quantity of lubricants and fuels are delivered (from reprocessed / re-refined used oil and/or virgin crude oil feedstocks) to the market regardless of the management route selected.	Displacement of virgin products is considered.	The replacement of virgin products within the market by reprocessed products should not be defined using one single equivalency, as reprocessed products have enough flexibility in the marketplace to displace a number of different virgin products.
Formal disposal	100% of used oil sent to hazardous landfill through the informal management route was assumed to be landfilled	A proportion (unspecified) of used oil sent to hazardous landfill through the informal management route was assumed to be incinerated and the remainder landfilled.	
Re-refinery and reprocessor inventory data	Inventory data associated with re-refining and reprocessing of used oil represented on the basis of dry used oil.	Inventory data associated with re-refining and reprocessing of used oil presented on the basis of wet used oil in some cases and dry used oil in other cases.	Used oil (dry basis) used throughout the Phase II LCA report for consistency and to improve transparency so as to allow testing of process performance
	Inventory data for the RRBO re-refinery from publicly available data (IFEU, 2006).	Inventory data for the RRBO re-refinery from primary data.	Primary data in Phase I LCA protected by NDA and therefore not available to the public. Publicly available data used to improve transparency and flexibility

Aspect	Phase II LCA	Phase I LCA	Reason for change
	Used oil to VGO pathway included.	Used oil to VGO pathway absent.	Reprocessing of used oil to VGO is an emerging waste management option and is likely to become more widespread in California in the future. Therefore, it was thought prudent to include in the Phase II study.
	Inventory data for the MDO re-refinery from a publicly available data (Boughton and Horvarth, 2004).	Inventory data for the MDO re-refinery from primary data.	Primary data in Phase I LCA protected by NDA and therefore not available to the public. Publicly available data used to improve transparency.
	Inventory data for the RFO process estimated based on Phase I data	Inventory data for the RFO process from primary data.	Primary data in Phase I LCA protected by NDA and therefore not available to the public. Estimate was compared with Phase I and found consistent
Combustion of fuels	Used and virgin oil composition based on empirical data from Summit Laboratory LLC.	Not determined.	Analysis of used and virgin oils provided the Phase II study with representative chemical composition data and was used to better model elemental flows.
	Calorific values based on composition used and virgin oil composition.	Calorific values based on secondary data.	Through using empirical data on the chemical composition of used and virgin oils a more representative calorific value could be determined.
Informal management	Four scenarios were modeled for improper disposal (i.e., dumping): 'used oil to fresh water', 'used oil to salt water', 'used oil to agricultural soils' and 'used oil to industrial soils'.	Three scenarios were modeled for improper disposal (i.e. dumping): 'waterway', 'landfill' and 'soil'.	The informal management, improper disposal model was updated to make it better suited to answering the questions of the study, to remove errors and allow various extremes to be tested. The uncollected used oil model was simplified to remove errors and bias and to make it more widely applicable.
	No avoided burden from displaced products was	Avoided burden from displaced fuel through onsite combustion was	The authors of this Phase II LCA considered onsite combustion to be for a

Aspect	Phase II LCA	Phase I LCA	Reason for change
	considered.	considered.	range of purposes and any market consequences to be unknown. Therefore no displacement effect was included.

Table 10.2 ***Composition of used lubricating oil, used industrial oil and the weighted average for used oil. * indicates 100% of samples below PQL***

Analyte	Unit	Used Lubricating Oil	Used Industrial Oil	Used Oil	Used Lubricating Oil	Used Industrial Oil	Used Oil
No of Samples		20	125		Percentage of Samples < PQL (i.e. below detection limits)		
Aluminum	kg/kg	1.82E-05	5.61E-06	1.50E-05	10%	70%	0%
Antimony	kg/kg	6.11E-06	9.86E-07	4.81E-06	46%	80%	36%
Arsenic*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	97%
Ash	kg/kg	6.74E-03	2.57E-03	5.68E-03	3%	45%	3%
Barium	kg/kg	2.75E-06	2.42E-05	8.22E-06	43%	75%	6%
Beryllium*	kg/kg	5.19E-08	5.09E-08	5.17E-08	100%	100%	100%
Boron	kg/kg	1.39E-04	8.40E-05	1.25E-04	5%	55%	0%
Cadmium	kg/kg	7.16E-08	5.09E-08	6.63E-08	94%	100%	100%
Calcium	kg/kg	1.71E-03	8.39E-04	1.49E-03	1%	30%	0%
Chloride	kg/kg	1.50E-04	7.69E-05	1.31E-04	35%	75%	14%
Chromium	kg/kg	2.11E-06	2.45E-06	2.20E-06	99%	95%	100%
Cobalt*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Copper	kg/kg	2.07E-05	1.80E-05	2.00E-05	4%	60%	0%
Fluoride	kg/kg	3.56E-05	2.55E-05	3.30E-05	89%	100%	78%
Glycols	kg/kg	0.00E+00	0.00E+00	0.00E+00			
Halogens	kg/kg	0.00E+00	0.00E+00	0.00E+00			
Organic halogens	kg/kg	0.00E+00	0.00E+00	0.00E+00			
Iron	kg/kg	5.64E-05	3.17E-05	5.01E-05	2%	45%	0%
Lead	kg/kg	1.41E-05	1.60E-06	1.09E-05	14%	55%	0%
Magnesium	kg/kg	1.23E-04	4.86E-05	1.04E-04	2%	70%	0%
Manganese	kg/kg	1.94E-06	7.05E-07	1.62E-06	26%	85%	0%
Mercury	kg/kg	5.40E-08	1.02E-08	4.28E-08	99%	100%	100%
Molybdenum	kg/kg	5.49E-05	1.00E-05	4.35E-05	1%	75%	3%
Nickel	kg/kg	1.78E-06	1.45E-06	1.69E-06	66%	85%	78%
Nitrogen, total	kg/kg	5.96E-04	2.86E-04	5.17E-04	1%	45%	0%

Analyte	Unit	Used Lubricating Oil	Used Industrial Oil	Used Oil	Used Lubricating Oil	Used Industrial Oil	Used Oil
Oxygen	kg/kg	0.00E+00	0.00E+00	0.00E+00			
Phenanthrene	kg/kg	4.15E-05	2.73E-05	3.79E-05	91%	95%	100%
Phosphorus	kg/kg	6.33E-04	3.87E-04	5.70E-04	0%	0%	0%
Total PCBs*	kg/kg	5.19E-07	8.84E-07	6.12E-07	100%	95%	100%
PAH	kg/kg	0.00E+00	0.00E+00	0.00E+00			
Sediment	kg/kg	0.00E+00	0.00E+00	0.00E+00			
Selenium*	kg/kg	1.04E-06	1.02E-06	1.03E-06	100%	100%	100%
Silicon	kg/kg	4.49E-05	2.40E-04	9.45E-05	0%	35%	0%
Silver	kg/kg	5.86E-07	2.55E-07	5.01E-07	99%	100%	100%
Sodium	kg/kg	9.92E-05	1.99E-05	7.90E-05	4%	65%	0%
Sulfur	kg/kg	2.04E-03	2.22E-03	2.09E-03	9%	45%	0%
Thallium*	kg/kg	1.04E-07	1.02E-07	1.03E-07	100%	100%	100%
Tin	kg/kg	1.59E-05	1.07E-05	1.46E-05	55%	85%	22%
Titanium	kg/kg	3.09E-06	3.22E-06	3.12E-06	94%	95%	97%
Vanadium	kg/kg	3.03E-06	2.55E-07	2.32E-06	94%	100%	100%
Zinc	kg/kg	6.02E-04	1.94E-04	4.98E-04	0%	35%	0%
1,1,1,2-Tetrachloroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,1,1-Trichloroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,1,2,2-Tetrachloroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	97%
1,1,2-Trichloro-1,2,2-trifluoroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,1,2-Trichloroethane	kg/kg	2.63E-06	2.55E-06	2.61E-06	99%	100%	97%
1,1-Dichloroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,1-Dichloroethene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,1-Dichloropropene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,2,3-Trichlorobenzene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,2,3-Trichloropropane	kg/kg	2.69E-06	2.55E-06	2.65E-06	98%	100%	86%
1,2,4-Trichlorobenzene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,2,4-Trichlorobenzene2*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	97%
1,2-Dibromo-3-chloropropane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,2-Dibromoethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%

Analyte	Unit	Used Lubricating Oil	Used Industrial Oil	Used Oil	Used Lubricating Oil	Used Industrial Oil	Used Oil
1,2-Dichlorobenzene	kg/kg	2.63E-06	2.55E-06	2.61E-06	99%	100%	100%
1,2-Dichloroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,2-Dichloropropane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,3-Dichlorobenzene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,3-Dichloropropane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,4-Dichlorobenzene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
1,4-Dichlorobenzene2*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
2,2-Dichloropropane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
2,4-Dinitrotoluene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
2-Chloroethyl vinyl ether*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
2-Chlorophenol*	kg/kg	2.69E-05	2.55E-05	2.65E-05	99%	100%	100%
2-Chlorotoluene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
4-Chloro-3-methylphenol*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
4-Chlorotoluene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
4-Nitrophenol*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Acenaphthene	kg/kg	2.77E-05	2.55E-05	2.71E-05	94%	100%	100%
Acenaphthylene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Anthracene	kg/kg	2.80E-05	2.55E-05	2.73E-05	94%	100%	100%
Aroclor 1016*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	100%
Aroclor 1221*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	100%
Aroclor 1232*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	100%
Aroclor 1242*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	100%
Aroclor 1248*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	100%
Aroclor 1254*	kg/kg	5.19E-07	5.09E-07	5.17E-07	100%	100%	100%
Aroclor 1260	kg/kg	5.19E-07	8.84E-07	6.12E-07	100%	95%	100%
Benz(a)anthracene*	kg/kg	2.72E-05	2.55E-05	2.68E-05	95%	100%	100%
Benzo(a)pyrene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Benzo(b)fluoranthene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Benzo(g,h,i)perylene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Benzo(k)fluoranthene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%

Analyte	Unit	Used Lubricating Oil	Used Industrial Oil	Used Oil	Used Lubricating Oil	Used Industrial Oil	Used Oil
Bromochloromethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Bromodichloromethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Carbon tetrachloride*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Chlorobenzene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	97%
Chlorodibromomethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Chloroethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Chloroform*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Chloromethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Chromium, Hexavalent*	kg/kg	6.49E-07	6.37E-07	6.46E-07	100%	100%	100%
Chrysene	kg/kg	2.98E-05	2.55E-05	2.87E-05	94%	100%	100%
cis-1,2-dichloroethene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
cis-1,3-dichloropropene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Dibenz(a,h)anthracene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Dichlorodifluoromethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Diethylene glycol	kg/kg	6.36E-02	5.09E-03	4.87E-02	99%	100%	100%
Ethylene glycol	kg/kg	5.54E-03	5.09E-03	5.43E-03	98%	100%	100%
Fluoranthene*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Fluorene	kg/kg	3.09E-05	2.55E-05	2.95E-05	94%	100%	100%
Hexachlorobutadiene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
I0eno(1,2,3-cd)pyrene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Lithium*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Methylene chloride	kg/kg	1.41E-05	2.89E-06	1.13E-05	58%	90%	100%
Naphthalene	kg/kg	1.52E-04	3.03E-05	1.21E-04	21%	95%	0%
N-nitrosodipropylamine*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Pentachlorophenol*	kg/kg	2.60E-05	2.55E-05	2.58E-05	100%	100%	100%
Percent Water	kg/kg	3.11E-02	1.70E-02	2.75E-02	6%	55%	3%
Phenol	kg/kg	2.60E-05	3.12E-05	2.73E-05	100%	95%	100%
Potassium	kg/kg	1.11E-04	9.57E-05	1.07E-04	4%	0%	0%
Propylene glycol	kg/kg	5.19E-03	5.09E-03	5.17E-03	100%	100%	100%
Pyrene	kg/kg	3.01E-05	2.68E-05	2.93E-05	90%	95%	100%

Analyte	Unit	Used Lubricating Oil	Used Industrial Oil	Used Oil	Used Lubricating Oil	Used Industrial Oil	Used Oil
Silica, dissolved (as SiO_2)	kg/kg	9.47E-05	5.22E-04	2.03E-04	1%	40%	0%
Sulfur, ICP	kg/kg	6.80E-05	1.24E-04	8.23E-05	91%	70%	100%
Tetrachloroethene	kg/kg	4.18E-06	2.55E-06	3.76E-06	91%	100%	42%
Total PCBs	kg/kg	5.19E-07	8.84E-07	6.12E-07	100%	95%	100%
trans-1,2-dichloroethene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
trans-1,3-dichloropropene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Trichloroethene*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Trichlorofluoromethane*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	83%
Triethylene glycol	kg/kg	6.60E-02	5.09E-03	5.05E-02	99%	100%	100%
Vinyl chloride*	kg/kg	2.60E-06	2.55E-06	2.58E-06	100%	100%	100%
Viscosity		1.48E+02	1.01E+02	1.36E+02		0%	0%

Table 10.3 Analytical methods used to determine the composition of used oil

Analytical Method	Analytes
Determination of Viscosity Index (D-2270)	Viscosity Index
Glycols (8015)	Diethylene glycol, Ethylene glycol, Propylene glycol, Triethylene glycol
Hexavalent Chromium in Oil (SW-846: 7196A)	Chromium, Hexavalent
Mercury Analysis (7471)	Mercury
Metals Analysis in Oil (6010)	Aluminum, Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lead, Lithium, Magnesium, Manganese, Molybdenum, Nickel, Phosphorus, Potassium, Selenium, Silica, Dissolved (as SiO2), Silicon, Silver, Sodium, Thallium, Tin, Titanium, Vanadium, Zinc

Analytical Method	Analytes
Oil Bomb-Wash Analysis by Ion Chromatography (SW-846: 9056)	Chloride, Fluoride
Polychlorinated biphenols Analysis for Oils (8082)	Aroclor 1016, Aroclor 1221, Aroclor 1232, Aroclor 1242, Aroclor 1248, Aroclor 1254, Aroclor 1260, Total PCBs
Percent Water from Karl Fischer Coulometer (D-6304)	Percent Water
Percent Sulfur by X-Ray (D-4294)	Sulfur
Percentage of Ash in Petroleum Products (D-482)	Ash
Semi-volatile organic compounds 8270 Standard Master List	1,2,4-Trichlorobenzene, 1,4-Dichlorobenzene, 2,4-Dinitrotoluene, 2-Chlorophenol, 4-Chloro-3-methylphenol, 4-Nitrophenol, Acenaphthene, Acenaphthylene, Anthracene, Benz(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, N-nitrosodipropylamine, Pentachlorophenol, Phenanthrene, Phenol, Pyrene
Total Kjeldahl Nitrogen (351.2)	Nitrogen, Total
Volatile organic compounds in Oil by Gas Chromatography Mass Spectrometry (8260)	1,1,1,2-Tetrachloroethane, 1,1,1-Trichloroethane, 1,1,2,2-Tetrachloroethane, 1,1,2-Trichloro-1,2,2-trifluoroethane, 1,1,2-Trichloroethane, 1,1-Dichloroethane, 1,1-Dichloroethene, 1,1-Dichloropropene, 1,2,3-Trichlorobenzene, 1,2,3-Trichloropropane, 1,2,4-Trichlorobenzene, 1,2-Dibromo-3-chloropropane, 1,2-Dibromoethane, 1,2-Dichlorobenzene, 1,2-Dichloroethane, 1,2-Dichloropropane, 1,3-Dichlorobenzene, 1,3-Dichloropropane, 1,4-Dichlorobenzene, 2,2-Dichloropropane, 2-Chloroethyl vinyl ether, 2-Chlorotoluene, 4-Chlorotoluene, Bromochloromethane, Bromodichloromethane, Carbon tetrachloride, Chlorobenzene, Chlorodibromomethane, Chloroethane, Chloroform, Chloromethane, cis-1,2-Dichloroethene, cis-1,3-Dichloropropene, Dichlorodifluoromethane, Hexachlorobutadiene, Methylene chloride, Tetrachloroethene, trans-1,2-Dichloroethene, trans-1,3-Dichloropropene, Trichloroethene, Trichlorofluoromethane, Vinyl chloride

Table 10.4 Practical Quantification Limit (PQL) for Analytical Methods Used in this Study (source: Summit analysis)

Analytical Method	Analyte	Practical Quantification Limit (PQL)	
		Value	Unit
Determination of Viscosity Index (D-2270)	Viscosity Index		
Glycols (8015)	Diethylene glycol	1	%
Glycols (8015)	Ethylene glycol	1	%
Glycols (8015)	Propylene glycol	1	%
Glycols (8015)	Triethylene glycol	1	%
Hexavalent Chromium in Oil (SW-846: 7196A)	Chromium, hexavalent	1.25	ppm
Mercury Analysis (7471)	Mercury	0.02	ppm
Metals Analysis in Oil (6010)	Aluminum	1	ppm
Metals Analysis in Oil (6010)	Antimony	0.5	ppm
Metals Analysis in Oil (6010)	Arsenic	1	ppm
Metals Analysis in Oil (6010)	Barium	0.5	ppm
Metals Analysis in Oil (6010)	Beryllium	0.1	ppm
Metals Analysis in Oil (6010)	Boron	5	ppm
Metals Analysis in Oil (6010)	Cadmium	0.1	ppm
Metals Analysis in Oil (6010)	Calcium	1	ppm
Metals Analysis in Oil (6010)	Chromium	4	ppm
Metals Analysis in Oil (6010)	Cobalt	5	ppm
Metals Analysis in Oil (6010)	Copper	5	ppm
Metals Analysis in Oil (6010)	Iron	5	ppm
Metals Analysis in Oil (6010)	Lead	1	ppm
Metals Analysis in Oil (6010)	Lithium	5	ppm
Metals Analysis in Oil (6010)	Magnesium	5	ppm
Metals Analysis in Oil (6010)	Manganese	1	ppm
Metals Analysis in Oil (6010)	Molybdenum	5	ppm
Metals Analysis in Oil (6010)	Nickel	1	ppm
Metals Analysis in Oil (6010)	Phosphorus	5	ppm
Metals Analysis in Oil (6010)	Potassium	5	ppm
Metals Analysis in Oil (6010)	Selenium	2	ppm
Metals Analysis in Oil (6010)	Silica, dissolved (as SiO_2)	5	ppm

Analytical Method	Analyte	Practical Quantification Limit (PQL)	
		Value	Unit
Metals Analysis in Oil (6010)	Silicon	2	ppm
Metals Analysis in Oil (6010)	Silver	0.5	ppm
Metals Analysis in Oil (6010)	Sodium	5	ppm
Metals Analysis in Oil (6010)	Thallium	0.2	ppm
Metals Analysis in Oil (6010)	Tin	5	ppm
Metals Analysis in Oil (6010)	Titanium	5	ppm
Metals Analysis in Oil (6010)	Vanadium	0.5	ppm
Metals Analysis in Oil (6010)	Zinc	1	ppm
Oil Bomb-Wash Analysis by IC (SW-846: 9056)	Chloride	50	ppm
Oil Bomb-Wash Analysis by IC (SW-846: 9056)	Fluoride	50	ppm
PCB Analysis for Oils (8082)	Aroclor 1016	1	ppm
PCB Analysis for Oils (8082)	Aroclor 1221	1	ppm
PCB Analysis for Oils (8082)	Aroclor 1232	1	ppm
PCB Analysis for Oils (8082)	Aroclor 1242	1	ppm
PCB Analysis for Oils (8082)	Aroclor 1248	1	ppm
PCB Analysis for Oils (8082)	Aroclor 1254	1	ppm
PCB Analysis for Oils (8082)	Aroclor 1260	1	ppm
PCB Analysis for Oils (8082)	Total PCBs	1	ppm
Percent Water from Karl Fisher Coulometer (D-6304)	Percent water	0.01	wt%
Percent Sulfur by X-Ray (D-4294)	Sulfur	0.1	%
Percentage of Ash in Petroleum Products (D-482)	Ash	0.1	%
SVOC 8270 Standard Master List	1,2,4-Trichlorobenzene	50	ppm
SVOC 8270 Standard Master List	1,4-Dichlorobenzene	50	ppm
SVOC 8270 Standard Master List	2,4-Dinitrotoluene	50	ppm
SVOC 8270 Standard Master List	2-Chlorophenol	50	ppm
SVOC 8270 Standard Master List	4-Chloro-3-methylphenol	50	ppm
SVOC 8270 Standard Master List	4-Nitrophenol	50	ppm
SVOC 8270 Standard Master List	Acenaphthene	50	ppm
SVOC 8270 Standard Master List	Acenaphthylene	50	ppm
SVOC 8270 Standard Master List	Anthracene	50	ppm
SVOC 8270 Standard Master List	Benz(a)anthracene	50	ppm

Analytical Method	Analyte	Practical Quantification Limit (PQL)	
		Value	Unit
SVOC 8270 Standard Master List	Benzo(a)pyrene	50	ppm
SVOC 8270 Standard Master List	Benzo(b)fluoranthene	50	ppm
SVOC 8270 Standard Master List	Benzo(g,h,i)perylene	50	ppm
SVOC 8270 Standard Master List	Benzo(k)fluoranthene	50	ppm
SVOC 8270 Standard Master List	Chrysene	50	ppm
SVOC 8270 Standard Master List	Dibenz(a,h)anthracene	50	ppm
SVOC 8270 Standard Master List	Fluoranthene	50	ppm
SVOC 8270 Standard Master List	Fluorene	50	ppm
SVOC 8270 Standard Master List	Indeno(1,2,3-cd)pyrene	50	ppm
SVOC 8270 Standard Master List	Naphthalene	50	ppm
SVOC 8270 Standard Master List	N-nitrosodipropylamine	50	ppm
SVOC 8270 Standard Master List	Pentachlorophenol	50	ppm
SVOC 8270 Standard Master List	Phenanthrene	50	ppm
SVOC 8270 Standard Master List	Phenol	50	ppm
SVOC 8270 Standard Master List	Pyrene	50	ppm
Total Kjeldahl Nitrogen (351.2)	Nitrogen, total	200	ppm
VOC in Oil by GC/MS (8260)	1,1,1,2-Ttetrachloroethane	5	ppm
VOC in Oil by GC/MS (8260)	1,1,1-trichloroethane	5	ppm
VOC in Oil by GC/MS (8260)	1,1,2,2-tetrachloroethane	5	ppm
VOC in Oil by GC/MS (8260)	1,1,2-trichloro-1,2,2-trifluoroethane	5	ppm
VOC in Oil by GC/MS (8260)	1,1,2-trichloroethane	5	ppm
VOC in Oil by GC/MS (8260)	1,1-dichloroethane	5	ppm
VOC in Oil by GC/MS (8260)	1,1-dichloroethene	5	ppm
VOC in Oil by GC/MS (8260)	1,1-dichloropropene	5	ppm
VOC in Oil by GC/MS (8260)	1,2,3-trichlorobenzene	5	ppm
VOC in Oil by GC/MS (8260)	1,2,3-trichloropropane	5	ppm
VOC in Oil by GC/MS (8260)	1,2,4-trichlorobenzene	5	ppm
VOC in Oil by GC/MS (8260)	1,2-dibromo-3-chloropropane	5	ppm
VOC in Oil by GC/MS (8260)	1,2-dibromoethane	5	ppm
VOC in Oil by GC/MS (8260)	1,2-dichlorobenzene	5	ppm
VOC in Oil by GC/MS (8260)	1,2-dichloroethane	5	ppm

Analytical Method	Analyte	Practical Quantification Limit (PQL)	
		Value	Unit
VOC in Oil by GC/MS (8260)	1,2-dichloropropane	5	ppm
VOC in Oil by GC/MS (8260)	1,3-dichlorobenzene	5	ppm
VOC in Oil by GC/MS (8260)	1,3-dichloropropane	5	ppm
VOC in Oil by GC/MS (8260)	1,4-dichlorobenzene	5	ppm
VOC in Oil by GC/MS (8260)	2,2-dichloropropane	5	ppm
VOC in Oil by GC/MS (8260)	2-chloroethyl vinyl ether	5	ppm
VOC in Oil by GC/MS (8260)	2-chlorotoluene	5	ppm
VOC in Oil by GC/MS (8260)	4-chlorotoluene	5	ppm
VOC in Oil by GC/MS (8260)	Bromochloromethane	5	ppm
VOC in Oil by GC/MS (8260)	Bromodichloromethane	5	ppm
VOC in Oil by GC/MS (8260)	Carbon tetrachloride	5	ppm
VOC in Oil by GC/MS (8260)	Chlorobenzene	5	ppm
VOC in Oil by GC/MS (8260)	Chlorodibromomethane	5	ppm
VOC in Oil by GC/MS (8260)	Chloroethane	5	ppm
VOC in Oil by GC/MS (8260)	Chloroform	5	ppm
VOC in Oil by GC/MS (8260)	Chloromethane	5	ppm
VOC in Oil by GC/MS (8260)	cis-1,2-dichloroethene	5	ppm
VOC in Oil by GC/MS (8260)	cis-1,3-dichloropropene	5	ppm
VOC in Oil by GC/MS (8260)	Dichlorodifluoromethane	5	ppm
VOC in Oil by GC/MS (8260)	Hexachlorobutadiene	5	ppm
VOC in Oil by GC/MS (8260)	Methylene chloride	5	ppm
VOC in Oil by GC/MS (8260)	Tetrachloroethene	5	ppm
VOC in Oil by GC/MS (8260)	trans-1,2-dichloroethene	5	ppm
VOC in Oil by GC/MS (8260)	trans-1,3-dichloropropene	5	ppm
VOC in Oil by GC/MS (8260)	Trichloroethene	5	ppm
VOC in Oil by GC/MS (8260)	Trichlorofluoromethane	5	ppm
VOC in Oil by GC/MS (8260)	Vinyl chloride	5	ppm

Table 10.5 Composition of virgin fuels (source: Summit analysis)

Analyte	Unit	Off-Road (high-sulfur) diesel	No.below PQL	Low-sulfur Diesel	No.below PQL	Kerosene (K1)	No.below PQL	Heavy (#6) Fuel Oil	No.below PQL	Jet Fuel	No.below PQL
No.Samples		26		7		6		24		1	
Aluminum	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	3.73E-06	13	5.00E-07	1
Antimony	kg/kg	2.50E-07	26	2.50E-07	7	2.50E-07	6	2.50E-07	24	2.50E-07	1
Arsenic	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Ash	kg/kg	6.12E-04	14	5.00E-04	7	5.00E-04	6	8.00E-04	11	5.00E-04	1
Barium	kg/kg	2.50E-07	26	2.50E-07	7	2.50E-07	6	2.50E-07	24	2.50E-07	1
Beryllium	kg/kg	5.00E-08	26	5.00E-08	7	5.00E-08	6	5.00E-08	24	5.00E-08	1
Boron	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	3.67E-06	21	2.50E-06	1
Cadmium	kg/kg	5.00E-08	26	5.00E-08	7	5.00E-08	6	5.00E-08	24	5.00E-08	1
Calcium	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	1.09E-05	1	5.00E-07	1
Chloride	kg/kg	2.75E-05	25	2.50E-05	7	2.50E-05	6	1.42E-04	1	2.50E-05	1
Chromium	kg/kg	2.00E-06	26	2.00E-06	7	2.00E-06	6	2.20E-06	23	2.00E-06	1
Cobalt	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Copper	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Fluoride	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Iron	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	1.43E-05	0	2.50E-06	1
Lead	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Magnesium	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.25E-06	17	2.50E-06	1
Manganese	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Mercury	kg/kg	1.00E-08	26	1.00E-08	7	1.00E-08	6	1.00E-08	24	1.00E-08	1
Molybdenum	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Nickel	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	8.11E-06	0	5.00E-07	1
Nitrogen, total	kg/kg	1.00E-04	26	1.00E-04	7	1.00E-04	6	2.49E-04	13	1.00E-04	1
Phenanthrene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	4.50E-05	23	2.50E-05	1
Phosphorus	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	1.09E-05	0	2.50E-06	1
Total PCBs	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Selenium	kg/kg	1.00E-06	26	1.00E-06	7	1.00E-06	6	1.00E-06	24	1.00E-06	1

Analyte	Unit	Off-Road (high-sulfur) diesel	No.below PQL	Low-sulfur Diesel	No.below PQL	Kerosene (K1)	No.below PQL	Heavy (#6) Fuel Oil	No.below PQL	Jet Fuel	No.below PQL
Silicon	kg/kg	1.00E-06	26	1.00E-06	7	1.00E-06	6	6.07E-06	0	1.00E-06	1
Silver	kg/kg	2.50E-07	26	2.50E-07	7	2.50E-07	6	2.50E-07	24	2.50E-07	1
Sodium	kg/kg	9.33E-06	25	2.50E-06	7	2.50E-06	6	5.99E-06	14	2.50E-06	1
Sulfur	kg/kg	5.00E-04	26	5.00E-04	7	5.00E-04	6	1.60E-02	0	1.77E-03	0
Thallium	kg/kg	1.00E-07	26	1.00E-07	7	1.00E-07	6	1.00E-07	24	1.00E-07	1
Tin	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Titanium	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Vanadium	kg/kg	2.50E-07	26	2.50E-07	7	2.50E-07	6	1.74E-05	0	2.50E-07	1
Zinc	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	1.60E-06	15	5.00E-07	1
1,1,1,2-tetrachloroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,1,1-trichloroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,1,2,2-tetrachloroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.27E-04	3	2.50E-06	24	2.50E-06	1
1,1,2-trichloro-1,2,2-trifluoroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,1,2-trichloroethane	kg/kg	2.50E-06	26	6.79E-05	5	1.67E-04	3	2.50E-06	24	2.50E-06	1
1,1-dichloroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,1-dichloroethene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,1-dichloropropene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2,3-trichlorobenzene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2,3-trichloropropane	kg/kg	2.50E-06	26	4.61E-05	5	1.98E-04	3	2.50E-06	24	2.50E-06	1
1,2,4-trichlorobenzene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2,4-trichlorobenzene2	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2-dibromo-3-chloropropane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2-dibromoethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2-dichlorobenzene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,2-dichloroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1

Analyte	Unit	Off-Road (high-sulfur) diesel	No.below PQL	Low-sulfur Diesel	No.below PQL	Kerosene (K1)	No.below PQL	Heavy (#6) Fuel Oil	No.below PQL	Jet Fuel	No.below PQL
1,2-dichloropropane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,3-dichlorobenzene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,3-dichloropropane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,4-dichlorobenzene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
1,4-dichlorobenzene2	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
2,2-dichloropropane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
2,4-dinitrotoluene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
2-chloroethyl vinyl ether	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
2-chlorophenol	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
2-chlorotoluene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
4-chloro-3-methylphenol	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
4-chlorotoluene	kg/kg	2.50E-06	26	3.02E-05	5	7.56E-05	3	2.50E-06	24	2.50E-06	1
4-Nitrophenol	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	1.08E-03	20	2.50E-05	1
Acenaphthene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	3.80E-05	23	2.50E-05	1
Acenaphthylene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	4.91E-05	23	2.50E-05	1
Anthracene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.86E-05	23	2.50E-05	1
Aroclor 1016	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Aroclor 1221	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Aroclor 1232	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Aroclor 1242	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Aroclor 1248	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Aroclor 1254	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Aroclor 1260	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
Benz(a)anthracene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.81E-05	23	2.50E-05	1
Benzo(a)pyrene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.69E-05	23	2.50E-05	1
Benzo(b)fluoranthene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Benzo(g,h,i)perylene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	3.83E-05	23	2.50E-05	1

Analyte	Unit	Off-Road (high-sulfur) diesel	No.below PQL	Low-sulfur Diesel	No.below PQL	Kerosene (K1)	No.below PQL	Heavy (#6) Fuel Oil	No.below PQL	Jet Fuel	No.below PQL
Benzo(k)fluoranthene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Bromochloromethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Bromodichloromethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Carbon tetrachloride	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Chlorobenzene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Chlorodibromomethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Chloroethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Chloroform	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Chloromethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Chromium, Hexavalent	kg/kg	6.25E-07	26	6.25E-07	7	6.25E-07	6	6.25E-07	24	6.25E-07	1
Chrysene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	3.30E-05	23	2.50E-05	1
cis-1,2-dichloroethene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
cis-1,3-dichloropropene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Dibenz(a,h)anthracene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Dichlorodifluoromethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Diethylene glycol	kg/kg	5.00E-03	26	5.00E-03	7	5.00E-03	6	5.00E-03	24	5.00E-03	1
Ethylene glycol	kg/kg	5.00E-03	26	5.00E-03	7	5.00E-03	6	5.00E-03	24	5.00E-03	1
Fluoranthene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Fluorene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	4.18E-05	23	2.50E-05	1
Hexachlorobutadiene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
I0eno(1,2,3-cd)pyrene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Lithium	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Methylene chloride	kg/kg	1.46E-04	20	2.50E-06	7	2.50E-06	6	9.00E-04	0	2.50E-06	1
Naphthalene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	7.99E-03	1	2.50E-05	1
N-	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1

Analyte	Unit	Off-Road (high-sulfur) diesel	No.below PQL	Low-sulfur Diesel	No.below PQL	Kerosene (K1)	No.below PQL	Heavy (#6) Fuel Oil	No.below PQL	Jet Fuel	No.below PQL
nitrosodipropylamine											
Pentachlorophenol	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Percent Water	kg/kg	2.67E-04	11	5.71E-05	6	5.83E-05	5	3.96E-04	2	5.00E-05	1
Phenol	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Potassium	kg/kg	5.34E-06	16	1.05E-05	5	5.97E-06	5	3.07E-05	0	1.22E-05	0
Propylene glycol	kg/kg	5.00E-03	26	5.00E-03	7	5.00E-03	6	5.00E-03	24	5.00E-03	1
Pyrene	kg/kg	2.50E-05	26	2.50E-05	7	2.50E-05	6	2.50E-05	24	2.50E-05	1
Silica, dissolved (as SiO_2)	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	1.30E-05	0	2.50E-06	1
Sulfur, ICP	kg/kg	5.00E-06	26	5.00E-06	7	5.00E-06	6	5.00E-06	24	5.00E-06	1
Tetrachloroethene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Total PCBs	kg/kg	5.00E-07	26	5.00E-07	7	5.00E-07	6	5.00E-07	24	5.00E-07	1
trans-1,2-dichloroethene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
trans-1,3-dichloropropene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Trichloroethene	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Trichlorofluoromethane	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Triethylene glycol	kg/kg	5.00E-03	26	5.00E-03	7	5.00E-03	6	5.00E-03	24	5.00E-03	1
Vinyl chloride	kg/kg	2.50E-06	26	2.50E-06	7	2.50E-06	6	2.50E-06	24	2.50E-06	1
Viscosity index			0		0		0	9.48E+01	0		0

Table 10.6 Composition of re-refined petroleum products from used oil (source: Summit analysis)

Analyte	Unit	MDO Used Oil-derived fuel oil[a]	No.below PQL	RFO: Used Oil-derived fuel oil[b]	No.below PQL	VTAE: Asphalt Flux Oils	No.below PQL	VGO: Used Oil-derived [c]	No.below PQL
No of Samples		18		36		16		48	

Analyte	Unit	MDO Used Oil-derived fuel oil[a]	No.below PQL	RFO: Used Oil-derived fuel oil[b]	No.below PQL	VTAE: Asphalt Flux Oils	No.below PQL	VGO: Used Oil-derived [c]	No.below PQL
Aluminum	kg/kg	7.89E-07	11	9.26E-06	0	2.57E-04	0	5.00E-07	48
Antimony	kg/kg	3.03E-07	17	1.50E-06	13	4.61E-06	6	2.50E-07	48
Arsenic	kg/kg	5.00E-07	18	6.68E-07	35	5.00E-07	16	5.00E-07	48
Ash	kg/kg	5.78E-04	17	6.44E-03	1	5.29E-02	1	5.00E-04	48
Barium	kg/kg	2.50E-07	18	3.57E-06	2	1.93E-05	0	2.50E-07	48
Beryllium	kg/kg	5.00E-08	18	5.11E-08	36	5.00E-08	16	5.00E-08	48
Boron	kg/kg	4.32E-06	17	1.15E-04	0	2.75E-04	0	2.15E-05	3
Cadmium	kg/kg	5.00E-08	18	5.11E-08	36	2.55E-07	10	4.66E-07	47
Calcium	kg/kg	4.72E-06	3	2.05E-03	0	7.05E-03	0	5.96E-06	2
Chloride	kg/kg	7.78E-05	6	1.95E-04	5	7.11E-04	0	1.51E-04	23
Chromium	kg/kg	2.00E-06	18	2.04E-06	36	7.36E-06	0	2.00E-06	48
Cobalt	kg/kg	2.50E-06	18	2.55E-06	36	2.68E-06	15	2.50E-06	48
Copper	kg/kg	2.50E-06	18	2.60E-05	0	1.12E-04	0	2.50E-06	48
Fluoride	kg/kg	2.50E-05	18	3.79E-05	28	1.37E-04	4	2.50E-05	48
Iron	kg/kg	2.50E-06	18	4.85E-05	0	5.18E-04	0	2.50E-06	48
Lead	kg/kg	5.00E-07	18	1.11E-05	0	6.64E-05	0	5.00E-07	48
Magnesium	kg/kg	2.50E-06	18	9.51E-05	0	8.07E-04	0	2.50E-06	48
Manganese	kg/kg	5.00E-07	18	1.91E-06	0	1.75E-05	0	5.00E-07	48
Mercury	kg/kg	1.00E-08	18	1.02E-08	36	1.00E-07	16	1.00E-08	48
Molybdenum	kg/kg	2.50E-06	18	4.40E-05	1	2.75E-04	0	2.50E-06	48
Nickel	kg/kg	5.00E-07	18	8.52E-07	28	5.89E-06	0	5.00E-07	48
Nitrogen, total	kg/kg	4.71E-04	2	5.50E-04	0	1.56E-03	0	3.41E-04	0
Phenanthrene	kg/kg	2.50E-05	18	2.55E-05	36			2.67E-05	45
Phosphorus	kg/kg	1.49E-05	3	6.15E-04	0	3.66E-03	0	2.75E-05	1
Total PCBs	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Selenium	kg/kg	1.00E-06	18	1.02E-06	36	1.00E-06	16	1.17E-06	47
Silicon	kg/kg	1.93E-05	1	1.44E-04	0	2.68E-04	0	2.52E-05	0
Silver	kg/kg	2.50E-07	18	2.55E-07	36	4.53E-07	11	2.50E-07	48
Sodium	kg/kg	2.50E-06	18	9.15E-05	0	4.44E-03	1	2.55E-06	47

Analyte	Unit	MDO Used Oil-derived fuel oil[a]	No.below PQL	RFO: Used Oil-derived fuel oil[b]	No.below PQL	VTAE: Asphalt Flux Oils	No.below PQL	VGO: Used Oil-derived [c]	No.below PQL
Sulfur	kg/kg	5.00E-04	18	1.63E-03	0	7.31E-03	0	5.00E-04	48
Thallium	kg/kg	1.00E-07	18	1.02E-07	36	1.00E-07	16	1.00E-07	48
Tin	kg/kg	2.50E-06	18	1.35E-05	8	2.13E-05	4	2.50E-06	48
Titanium	kg/kg	2.50E-06	18	2.62E-06	35	1.24E-05	3	2.50E-06	48
Vanadium	kg/kg	2.50E-07	18	2.55E-07	36	2.21E-06	9	2.50E-07	48
Zinc	kg/kg	1.24E-06	3	6.02E-04	0	3.07E-03	0	1.33E-06	43
1,1,1,2-tetrachloroethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,1,1-trichloroethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,1,2,2-tetrachloroethane	kg/kg	1.89E-05	17	2.87E-06	35			2.55E-06	47
1,1,2-trichloro-1,2,2-trifluoroethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,1,2-trichloroethane	kg/kg	3.16E-05	17	2.66E-06	35			2.50E-06	48
1,1-dichloroethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,1-dichloroethene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,1-dichloropropene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,2,3-trichlorobenzene	kg/kg	2.50E-06	18	2.55E-06	36			3.04E-06	47
1,2,3-trichloropropane	kg/kg	3.74E-05	17	5.20E-06	31			2.50E-06	48
1,2,4-trichlorobenzene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,2,4-trichlorobenzene2	kg/kg	2.50E-06	18	1.55E-05	35			2.50E-06	48
1,2-dibromo-3-chloropropane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,2-dibromoethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,2-dichlorobenzene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,2-dichloroethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,2-dichloropropane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,3-dichlorobenzene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,3-dichloropropane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,4-dichlorobenzene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
1,4-dichlorobenzene2	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48

Analyte	Unit	MDO Used Oil-derived fuel oil[a]	No.below PQL	RFO: Used Oil-derived fuel oil[b]	No.below PQL	VTAE: Asphalt Flux Oils	No.below PQL	VGO: Used Oil-derived [c]	No.below PQL
2,2-dichloropropane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
2,4-dinitrotoluene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
2-chloroethyl vinyl ether	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
2-chlorophenol	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
2-chlorotoluene	kg/kg	2.50E-06	18	2.55E-06	36			2.92E-06	47
4-chloro-3-methylphenol	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
4-chlorotoluene	kg/kg	2.50E-06	18	2.55E-06	36			1.03E-04	47
4-nitrophenol	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Acenaphthene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Acenaphthylene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Anthracene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Aroclor 1016	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Aroclor 1221	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Aroclor 1232	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Aroclor 1242	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Aroclor 1248	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Aroclor 1254	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Aroclor 1260	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
Benz(a)anthracene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Benzo(a)pyrene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Benzo(b)fluoranthene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Benzo(g,h,i)perylene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Benzo(k)fluoranthene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Bromochloromethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Bromodichloromethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Carbon tetrachloride	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Chlorobenzene	kg/kg	2.50E-06	18	5.99E-06	35			2.50E-06	48
Chlorodibromomethan	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48

Analyte	Unit	MDO Used Oil-derived fuel oil[a]	No.below PQL	RFO: Used Oil-derived fuel oil[b]	No.below PQL	VTAE: Asphalt Flux Oils	No.below PQL	VGO: Used Oil-derived [c]	No.below PQL
e									
Chloroethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Chloroform	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Chloromethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Chromium, hexavalent	kg/kg	6.25E-07	18	6.38E-07	36	6.25E-07	16	6.25E-07	48
Chrysene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
cis-1,2-dichloroethene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
cis-1,3-dichloropropene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Dibenz(a,h)anthracene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Dichlorodifluoromethane	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Diethylene glycol	kg/kg	5.00E-03	18	5.11E-03	36			5.00E-03	48
Ethylene glycol	kg/kg	5.00E-03	18	5.11E-03	36			5.00E-03	48
Fluoranthene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Fluorene	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Hexachlorobutadiene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
I0eno(1,2,3-cd)pyrene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Lithium	kg/kg	2.50E-06	18	2.55E-06	36	2.50E-06	16	2.50E-06	48
Methylene chloride	kg/kg	8.89E-05	15	2.55E-06	36			1.46E-05	2
Naphthalene	kg/kg	6.77E-05	3	1.39E-04	0			8.24E-05	18
N-nitrosodipropylamine	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Pentachlorophenol	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Percent Water	kg/kg	3.49E-04	5	2.08E-02	1			6.60E-05	44
Phenol	kg/kg	2.50E-05	18	2.55E-05	36			2.50E-05	48
Potassium	kg/kg	1.02E-04	0	8.10E-05	0	1.06E-03	0	1.32E-05	29
Propylene glycol	kg/kg	5.00E-03	18	5.11E-03	36			5.00E-03	48
Pyrene	kg/kg	2.50E-05	18	2.55E-05	36			2.56E-05	47
Silica, dissolved (as SiO_2)	kg/kg	4.15E-05	2	3.03E-04	0	5.74E-04	0	5.48E-05	0

Analyte	Unit	MDO Used Oil-derived fuel oil[a]	No.below PQL	RFO: Used Oil-derived fuel oil[b]	No.below PQL	VTAE: Asphalt Flux Oils	No.below PQL	VGO: Used Oil-derived [c]	No.below PQL
Sulfur, ICP	kg/kg	3.70E-04	3	5.11E-06	36			5.96E-04	0
Tetrachloroethene	kg/kg	2.50E-06	18	4.48E-05	15			2.97E-06	41
Total PCBs	kg/kg	5.00E-07	18	5.11E-07	36			5.00E-07	48
trans-1,2-dichloroethene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
trans-1,3-dichloropropene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Trichloroethene	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Trichlorofluoromethane	kg/kg	2.50E-06	18	9.54E-06	30			2.50E-06	48
Triethylene glycol	kg/kg	5.00E-03	18	5.11E-03	36			5.00E-03	48
Vinyl chloride	kg/kg	2.50E-06	18	2.55E-06	36			2.50E-06	48
Viscosity Index		1.10E+02	0	1.54E+02	0			1.09E+02	0

[a] Produced via vacuum distillation

[b] Produced by removing water and minimal filtration but without distillation

[c] Produced via vacuum distillation and used as a feedstock to hydrotreating for production of re-refined base lubricant

Table 10.7 NMVOC speciation profile

Substance	Proportion (%)
Acetaldehyde (ethanal)	8.3%
Acetone (dimethylcetone)	8.3%
Butane	8.3%
Ethane	8.3%
Ethene (ethylene)	8.3%
Formaldehyde (methanal)	8.3%
Propane	8.3%
Propene (propylene)	8.3%
Benzene	4.1%
Butene (vinyl acetylene)	4.1%
Butyraldehyde	4.1%
Hexane (isomers)	4.1%
iso-Butane	4.1%
Pentane (n-pentane)	4.1%
Butanone (methyl ethyl ketone)	0.8%
Cyclohexane (hexahydro benzene)	0.8%
Ethine (acetylene)	0.8%
Glyoxal	0.8%
iso-butene	0.8%
Methyl glyoxal	0.8%
Toluene (methyl benzene)	0.8%
Xylene (dimethyl benzene)	0.8%
Butylbenzylphthalate	0.4%
Di(2-ethylhexyl)phthalate	0.4%
Dibutylphthalate	0.4%
Ethyl benzene	0.4%
Phenol (hydroxy benzene)	0.4%

Table 10.8 PAH speciation profile

Substance	
Benzo{a}anthracene	1.5%
Anthracene	1.5%
Fluoranthene	7.5%
Phenanthrene	7.5%
Benzo{a}pyrene	1.5%
Dibenz(a)anthracene	1.5%
Fluorene	1.5%
Acentaphthene	1.5%
Naphthalene	75%
2,3-Dimethylnapthtalene	1.5%

Table 10.9 Life cycle inventory data from proprietary databases

Inputs	Dataset	Source
Auxiliaries		
Caustic soda (NaOH)	Sodium hydroxide (caustic soda) mix (100%)	PE
Potassium hydroxide	Potassium hydroxide (KOH)	PE
Hydrogen	Hydrogen (cracker)	PE
Nitrogen	Nitrogen (liquid)	PE
Soda	Soda (Na_2CO_3)	PE
Propane	Propane at refinery	PE
n-methylpyrrolidon	n-methylpyrrolidone (NMP, Butyrolactone via Maleic anhydride)	PE
Energy demand		
Electricity	Electricity Mixer	US LCI
Process heat	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	ERM
Process heat a	Natural Gas Supply Mixer	US LCI
	Combustion - Natural Gas HHV	ERM
Process heat b (gross demand)	Natural Gas Supply Mixer	US LCI
Process heat b (net demand)	Combustion - Natural Gas HHV	ERM
	Natural Gas Supply Mixer	US LCI
Process steam	Combustion - Natural Gas HHV	ERM
Process steam a	Natural Gas Supply Mixer	US LCI
Process steam c	Combustion - Natural Gas HHV	ERM
Process water	Natural Gas Supply Mixer	US LCI
Natural gas	Combustion - Natural Gas HHV	ERM
	Natural Gas Supply Mixer	US LCI
Transportation		
Truck - light	Truck - Light Heavy-duty Diesel Truck / 6,667 lb payload - 2b	PE
Truck - medium	Truck - Medium Heavy-duty Diesel Truck / 9,333 lb payload - 3	PE
Diesel	Diesel mix at refinery	PE
Truck - medium/heavy	Truck - Medium Heavy-duty Diesel Truck / 17,333 lb payload - 6	PE

Inputs	Dataset	Source
Truck - heavy	Truck - Tank, liquid or gas / 50,000 lb payload - 8b	PE
Rail	Rail transport cargo - Diesel	PE
Lorry	Lorry (22t) incl. fuel	ELCD
Waste treatment		
Wastewater treatment	Waste water treatment (contains organic load)	PE
Hazardous waste disposal	disposal, hazardous waste, 0% water, to underground deposit	Ecoinvent
Hazardous waste incineration	disposal, used mineral oil, 10% water, to hazardous waste incineration	Ecoinvent

Table 10.10 *Data quality assessment*

Life cycle stage	Process	Data set	Source	Data Quality Assessment		
				Time-Related Coverage	Geographical Coverage	Technology Coverage
Used oil generation	Lubricating oil sales and quantities of used oil formally collected	Mass flow inventory	PHASE I/Phase I LCA	2007- 2011	CA	Good
	Used oil composition	Used oil composition	Summit Laboratory LLC	2015	CA	Very good
Formal collection and storage	Distances used oil transported	Mass flow inventory	Phase I LCA	2007- 2011	CA	Good
	Transportation of used oil by road	Truck - Medium Heavy-duty Diesel Truck / 17,333 lb payload - 6	PE	2012	US	Very good
		Truck - Tank, liquid or gas / 50,000 lb payload - 8b	PE	2012	US	Very good
	Transportation of used oil by rail	Rail transport cargo - Diesel	PE	2012	US	Very good
	Production of diesel fuel	Diesel mix at refinery	PE	2011	US	Good
Regulated disposal	Proportion of used oil sent to each disposal route	Mass flow inventory	Phase I LCA	2007- 2011	CA	Good
	Transportation of used oil by road	Truck - Light Heavy-duty Diesel Truck / 6,667 lb payload - 2b	PE	2012	US	Very good
		Truck - Medium Heavy-duty Diesel Truck / 9,333 lb payload - 3	PE	2012	US	Very good
	Production of diesel fuel	Diesel mix at refinery	PE	2011	US	Good
	Hazardous landfill	disposal, hazardous waste, 0% water, to underground deposit	ecoinvent	1993	DE	Unknown
	Hazardous incineration	disposal, used mineral oil,	ecoinvent	1997	CH	Unknown

Life cycle stage	Process	Data set	Source	Data Quality Assessment		
				Time-Related Coverage	Geographical Coverage	Technology Coverage
		10% water, to hazardous waste incineration				
	Wastewater treatment	Waste water treatment (contains organic load)	PE	2010	EU-27	Fair
Re-refining to RRBO	Proportion of used oil sent to RRBO re-refining	Mass flow inventory	Phase I LCA	2007- 2011	CA	Good
	Re-refining to RRBO	Inventory data for five re-refining techniques	IFEU	2003 - 2004	40% US, 20% Greece, 20% Germany, 20% Italy	Very good
	Production of caustic soda	Sodium hydroxide (caustic soda) mix (100%)	PE	2013	US	Very good
	Production of potassium hydroxide	Potassium hydroxide (KOH)	PE	2013	US	Fair
	Production of hydrogen	Hydrogen (cracker)	PE	2013	US	Very good
	Production of nitrogen	Nitrogen (liquid)	PE	2013	US	Good
	Production of soda	Soda (Na_2CO_3)	PE	2013	US	Very good
	Production of propane	Propane at refinery	PE	2011	US	Good
	Production of *n*-methylpyrrolidone	*n*-methylpyrrolidone (NMP, Butyrolactone via Maleic anhydride)	PE	2013	US	Very good
	Electricity	Electricity Mixer	US LCI	2013	CA & US	Good
	Process heat	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
	Process heat a	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
	Process heat b (gross demand)	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
	Process heat b (net	Natural Gas Supply Mixer	US LCI	2013	US	Unknown

Life cycle stage	Process	Data set	Source	Data Quality Assessment		
				Time-Related Coverage	Geographical Coverage	Technology Coverage
	demand)					
		Combustion - Natural Gas HHV	ERM		US	
	Process steam	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
	Process steam a	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
	Process steam c	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
	Process water	Water deionized	PE	2013	US	Good
	Natural gas	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
Reprocessing to VGO	Reprocessing to VGO	Re-refined VGO production (primary data collection)	NORA	2010	US (Gulf Coast)	Limited
	Natural Gas	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
Reprocessing to MDO	Proportion of used oil sent to MDO reprocessing	Mass flow inventory	Phase I LCA	2007- 2011	CA	Good
	Reprocessing to MDO	Re-refinery process model	Boughton and Horvarth (2004)	2001 - 2002	CA	Limited
	Electricity	Electricity Mixer	US LCI	2013	CA & US	Unknown
	Natural Gas	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
	Production of caustic soda	Sodium hydroxide (caustic soda) mix (100%)	PE	2013	US	Very good
Reprocessing to RFO	Proportion of used oil sent to RFO reprocessing	Mass flow inventory	Phase I LCA	2007- 2011	CA	Good
	Reprocessing to RFO	Production of RFO	Phase I LCA	2010	US	Good
	Electricity	Electricity Mixer	US LCI	2013	CA & US	Unknown

Life cycle stage	Process	Data set	Source	Data Quality Assessment		
				Time-Related Coverage	Geographical Coverage	Technology Coverage
	Natural Gas	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
		Combustion - Natural Gas HHV	ERM		US	
Informal disposal	Proportion of used oil informally managed	Mass flow inventory	Phase I LCA	2007- 2011	CA	Good
	Proportion of informally managed used oil improperly disposed, combusted onsite or sent to municipal landfill	Mass flow inventory	Phase I LCA	2007- 2011	CA	Unknown
	'Used oil to fresh water' disposal route	'Used oil to fresh water' disposal route	ERM	NA	US	NA
	'Used oil to salt water' disposal route	'Used oil to salt water' disposal route	ERM	NA	US	NA
	'Used oil to agricultural soils' disposal route	'Used oil to agricultural soils' disposal route	ERM	NA	US	NA
	'Used oil to industrial soils' disposal route	'Used oil to industrial soils' disposal route	ERM	NA	US	NA
	Transportation of used oil informally managed to municipal landfill	Lorry (22t) incl. fuel	ELCD	2005	RER	Unknown
	Municipal landfill	Used oil, in landfill	PE (adjusted in Phase I)	2010	AT, DE, IT, LU, NL, SE, CH	Unknown
Production of virgin products	Virgin refinery	Inventory parameters for production of virgin products	UCSB/Phase I LCA	2013	CA	Good
	Production of coal	US: Bituminous coal, at mine	Gabi			
	Electricity	Electricity Mixer	US LCI	2013	50% CA; 50% US	Unknown

Life cycle stage	Process	Data set	Source	Data Quality Assessment		
				Time-Related Coverage	Geographical Coverage	Technology Coverage
	Natural Gas Supply Mixer	Natural Gas Supply Mixer	US LCI	2013	US	Unknown
	Process water	Water deionized	PE	2013	US	Good
	Virgin product composition	Used oil composition	Summit Laboratory LLC	2015	CA	Good
Combustion of fuels	Proportion of liquid fuels	Proportion of total sales of liquid fuels in US from Jan to Dec 2010	US Energy Information Administration	2010	US	Very good
	Calorific value of fuels	Calorific values of RFO, VGO, RRBO, light distillates, light ends, middle distillates, heavy fuel oil (No.6), fuel oil (No.2) and off-road diesel	UCSB/Phase I	NA	NA	NA
		Calorific values of natural gas and coal	EPA 42	NA	NA	NA

Annex B. Selected LCI Emissions

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.30E+02	2.26E+01	3.15E+00	1.04E+02
Arsenic (+V)	8.22E+00	1.31E+00	9.00E-07	6.91E+00
Cadmium	2.30E+01	3.05E+00	3.11E-01	1.96E+01
Cadmium (+II)	1.10E+00	2.70E-01	2.85E-07	8.32E-01
Chromium	2.25E+02	9.16E+01	1.25E+01	1.21E+02
Chromium (+III)	2.06E-01	1.77E-03	2.48E-09	2.05E-01
Chromium (+VI)	6.50E-01	2.18E-01	0.00E+00	4.32E-01
Copper	4.48E+02	3.05E+02	1.22E+02	2.10E+01
Copper (+II)	1.69E+01	5.79E-01	1.79E-06	1.63E+01
Lead	3.37E+02	1.37E+02	6.68E+01	1.34E+02
Lead (+II)	1.74E+02	4.10E+00	4.44E-06	1.70E+02
Molybdenum	8.53E+02	5.64E+02	2.66E+02	2.35E+01
Nickel	1.85E+02	2.77E+01	5.20E+00	1.52E+02
Nickel (+II)	4.60E+01	2.79E+00	1.67E-05	4.31E+01
Zinc	8.90E+03	5.55E+03	3.04E+03	3.02E+02
Zinc (+II)	6.84E+01	3.81E+00	4.85E-06	6.43E+01
Inorganic emissions to air				
Ammonia	1.82E+04	1.24E+03	1.81E-03	1.68E+04
Carbon dioxide	2.65E+09	6.26E+08	3.42E+08	1.68E+09
Hydrogen sulphide	1.77E+04	2.04E+03	3.16E-04	1.56E+04
Nitrogen dioxide	3.94E+01	3.13E+00	1.21E-14	3.60E+01
Nitrogen oxides	2.57E+06	4.52E+05	5.90E+04	2.05E+06
Phosphorus	1.80E+04	1.14E+04	5.80E+03	8.26E+02
Sulphur dioxide	4.10E+06	9.52E+05	1.32E-01	3.14E+06
Sulphur oxides	1.58E+06	2.23E+05	3.25E+04	1.33E+06
Organic emissions to air (group VOC)				
Group NMVOC to air	9.86E+05	9.06E+04	3.73E+04	8.57E+05
Hydrocarbons (unspecified)	1.41E+06	8.29E+03	0.00E+00	1.40E+06
Methane	5.46E+06	6.94E+05	2.97E+04	4.73E+06
VOC (unspecified)	9.16E+04	2.80E+04	3.14E-05	6.36E+04
Particles to air				
Dust (> PM10)	7.39E+03	2.04E+03	0.00E+00	5.34E+03
Dust (PM10)	1.30E+05	5.51E+04	4.28E+04	3.24E+04
Dust (PM2,5 - PM10)	9.51E+04	3.48E+03	0.00E+00	9.14E+04
Dust (PM2.5)	1.25E+05	3.43E+04	2.68E+04	6.40E+04
Dust (unspecified)	1.99E+05	8.07E+04	5.35E+04	6.50E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.10E+05	2.80E+04	3.23E-04	8.16E+04
Chemical oxygen demand (COD)	5.85E+05	7.22E+04	6.65E-03	5.13E+05
Heavy metals to fresh water				
Arsenic	3.22E+02	5.28E+01	2.75E+01	2.41E+02
Arsenic (+V)	4.26E+03	6.28E+01	1.27E-05	4.20E+03
Cadmium	3.26E+00	8.63E-05	3.26E+00	5.17E-04
Cadmium (+II)	1.80E+03	1.62E+01	7.69E-06	1.78E+03
Chromium	8.38E+03	2.44E+02	1.09E+02	8.02E+03
Chromium (+III)	3.65E+00	1.47E+00	8.00E-08	2.02E+00
Chromium (+VI)	4.37E+00	4.27E+00	1.35E-15	1.00E-01
Copper	9.84E+02	3.33E-01	9.84E+02	3.13E-03
Copper (+II)	2.21E+03	4.57E+01	2.75E-05	2.17E+03
Lead	5.36E+02	2.28E-01	5.36E+02	2.68E-03
Lead (+II)	1.58E+03	6.60E+01	7.38E-06	1.51E+03
Nickel	8.49E+01	1.51E+00	8.31E+01	2.13E-01
Nickel (+II)	2.62E+03	8.93E+01	9.26E-06	2.53E+03
Zinc	2.45E+04	1.06E+00	2.45E+04	1.44E-02
Zinc (+II)	4.87E+02	1.02E+02	4.85E-06	3.86E+02
Inorganic emissions to fresh water				
Ammonia	6.60E+03	1.95E+03	1.12E-07	4.65E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	3.16E+02	2.05E+02	2.30E-04	1.10E+02
Barium	1.88E+05	4.66E+04	4.04E+02	1.41E+05
Nitrate	1.12E+04	2.83E+03	3.14E-05	8.10E+03
Nitrogen organic bounded	2.24E+04	1.94E+03	1.06E-03	2.02E+04
Phosphate	4.35E+03	6.16E+02	8.23E-05	3.68E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	1.34E+03	4.72E-02	1.33E+03	6.00E+00
Anthracene	1.35E+03	9.24E-02	1.34E+03	1.13E+01
Benzene	1.44E+04	3.48E+02	3.19E-05	1.41E+04
Benzo{a}anthracene	1.32E+03	4.20E-03	1.32E+03	6.72E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	6.97E+02	4.10E+00	1.57E-05	6.92E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.98E+02	1.75E+00	7.04E-06	2.96E+02
Chromium	1.09E+03	6.40E+00	2.50E-05	1.08E+03
Chromium (+VI)	1.97E-03	1.97E-03	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.58E+02	1.55E+00	2.49E-05	2.56E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	2.11E+02	1.25E+00	4.96E-06	2.10E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.91E+02	2.31E+00	1.79E-05	3.89E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	1.16E+01	3.87E-01	4.46E-04	1.12E+01
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	2.54E+01	0.00E+00	2.54E+01	0.00E+00
Arsenic (+V)	9.90E-05	9.90E-05	0.00E+00	1.59E-08
Cadmium	3.26E+00	0.00E+00	3.26E+00	0.00E+00
Cadmium (+II)	4.91E-01	8.69E-02	0.00E+00	3.96E-01
Chromium	1.08E+02	6.71E-03	1.08E+02	-1.70E-02
Chromium (+III)	6.70E+00	1.22E-01	0.00E+00	6.57E+00
Copper	9.84E+02	0.00E+00	9.84E+02	0.00E+00
Copper (+II)	5.84E+00	9.15E-02	0.00E+00	5.74E+00
Lead	5.36E+02	0.00E+00	5.36E+02	0.00E+00
Lead (+II)	9.52E+00	1.70E-01	0.00E+00	9.34E+00
Nickel	8.31E+01	0.00E+00	8.31E+01	0.00E+00
Nickel (+II)	3.28E+00	6.07E-02	0.00E+00	3.22E+00
Zinc	2.45E+04	0.00E+00	2.45E+04	0.00E+00
Zinc (+II)	2.49E+01	4.65E-01	0.00E+00	2.44E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	2.89E-04	2.54E-04	3.59E-09	3.48E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	5.01E-02	4.43E-04	3.25E-08	4.97E-02
Chromium	3.44E-03	3.26E-03	8.99E-06	1.73E-04
Chromium (+III)	7.94E-05	1.20E-05	2.31E-11	6.74E-05
Chromium (+VI)	2.25E-02	2.25E-02	0.00E+00	2.49E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	1.70E-02	1.61E-02	9.20E-08	9.03E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	9.04E-04	7.63E-04	2.42E-09	1.41E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.41E-03	6.46E-04	2.60E-06	2.76E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	6.15E-02	6.11E-02	9.98E-07	4.85E-04

Annex B. Selected LCI Emissions

Baseline (85% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.24E+02	2.60E+01	1.82E+00	9.63E+01
Arsenic (+V)	8.15E+00	1.50E+00	5.19E-07	6.64E+00
Cadmium	2.19E+01	3.50E+00	1.80E-01	1.82E+01
Cadmium (+II)	1.11E+00	3.10E-01	1.65E-07	8.01E-01
Chromium	2.25E+02	1.05E+02	7.22E+00	1.13E+02
Chromium (+III)	1.99E-01	2.03E-03	1.43E-09	1.97E-01
Chromium (+VI)	6.66E-01	2.50E-01	0.00E+00	4.16E-01
Copper	4.40E+02	3.50E+02	7.05E+01	1.95E+01
Copper (+II)	1.63E+01	6.65E-01	1.03E-06	1.57E+01
Lead	3.20E+02	1.58E+02	3.85E+01	1.24E+02
Lead (+II)	1.68E+02	4.71E+00	2.56E-06	1.64E+02
Molybdenum	8.23E+02	6.48E+02	1.53E+02	2.19E+01
Nickel	1.76E+02	3.18E+01	3.00E+00	1.41E+02
Nickel (+II)	4.48E+01	3.20E+00	9.63E-06	4.15E+01
Zinc	8.41E+03	6.38E+03	1.76E+03	2.80E+02
Zinc (+II)	6.66E+01	4.38E+00	2.80E-06	6.21E+01
Inorganic emissions to air				
Ammonia	1.78E+04	1.43E+03	1.04E-03	1.62E+04
Carbon dioxide	2.50E+09	7.19E+08	1.97E+08	1.58E+09
Hydrogen sulphide	1.74E+04	2.35E+03	1.82E-04	1.51E+04
Nitrogen dioxide	3.85E+01	3.60E+00	7.01E-15	3.46E+01
Nitrogen oxides	2.51E+06	5.19E+05	3.41E+04	1.95E+06
Phosphorus	1.72E+04	1.31E+04	3.35E+03	7.66E+02
Sulphur dioxide	4.12E+06	1.09E+06	7.59E-02	3.03E+06
Sulphur oxides	1.50E+06	2.57E+05	1.87E+04	1.23E+06
Organic emissions to air (group VOC)				
Group NMVOC to air	9.49E+05	1.04E+05	2.15E+04	8.22E+05
Hydrocarbons (unspecified)	1.35E+06	9.52E+03	0.00E+00	1.34E+06
Methane	5.36E+06	7.98E+05	1.71E+04	4.55E+06
VOC (unspecified)	9.35E+04	3.21E+04	1.81E-05	6.14E+04
Particles to air				
Dust (> PM10)	7.48E+03	2.34E+03	0.00E+00	5.13E+03
Dust (PM10)	1.18E+05	6.32E+04	2.47E+04	3.01E+04
Dust (PM2,5 - PM10)	9.22E+04	4.00E+03	0.00E+00	8.80E+04
Dust (PM2.5)	1.16E+05	3.94E+04	1.54E+04	6.10E+04
Dust (unspecified)	1.85E+05	9.27E+04	3.09E+04	6.09E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.11E+05	3.21E+04	1.86E-04	7.86E+04
Chemical oxygen demand (COD)	5.76E+05	8.29E+04	3.84E-03	4.93E+05
Heavy metals to fresh water				
Arsenic	3.00E+02	6.06E+01	1.59E+01	2.24E+02
Arsenic (+V)	4.11E+03	7.21E+01	7.33E-06	4.04E+03
Cadmium	1.88E+00	9.91E-05	1.88E+00	4.79E-04
Cadmium (+II)	1.73E+03	1.86E+01	4.44E-06	1.71E+03
Chromium	8.06E+03	2.80E+02	6.27E+01	7.71E+03
Chromium (+III)	3.79E+00	1.69E+00	4.62E-08	1.94E+00
Chromium (+VI)	5.00E+00	4.90E+00	7.81E-16	9.64E-02
Copper	5.68E+02	3.83E-01	5.68E+02	2.90E-03
Copper (+II)	2.13E+03	5.24E+01	1.59E-05	2.08E+03
Lead	3.10E+02	2.62E-01	3.09E+02	2.49E-03
Lead (+II)	1.53E+03	7.58E+01	4.26E-06	1.45E+03
Nickel	4.99E+01	1.74E+00	4.80E+01	1.98E-01
Nickel (+II)	2.53E+03	1.03E+02	5.34E-06	2.43E+03
Zinc	1.41E+04	1.22E+00	1.41E+04	1.33E-02
Zinc (+II)	4.88E+02	1.17E+02	2.80E-06	3.71E+02
Inorganic emissions to fresh water				
Ammonia	6.73E+03	2.24E+03	6.48E-08	4.48E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	3.42E+02	2.36E+02	1.33E-04	1.06E+02
Barium	1.90E+05	5.35E+04	2.33E+02	1.36E+05
Nitrate	1.13E+04	3.25E+03	1.81E-05	7.78E+03
Nitrogen organic bounded	2.19E+04	2.23E+03	6.09E-04	1.95E+04
Phosphate	4.31E+03	7.08E+02	4.75E-05	3.55E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	7.75E+02	5.42E-02	7.69E+02	5.76E+00
Anthracene	7.86E+02	1.06E-01	7.75E+02	1.08E+01
Benzene	1.39E+04	4.00E+02	1.84E-05	1.35E+04
Benzo{a}anthracene	7.61E+02	4.83E-03	7.61E+02	6.45E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	6.70E+02	4.71E+00	9.03E-06	6.65E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.87E+02	2.01E+00	4.06E-06	2.84E+02
Chromium	1.05E+03	7.36E+00	1.44E-05	1.04E+03
Chromium (+VI)	2.26E-03	2.26E-03	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.48E+02	1.78E+00	1.44E-05	2.46E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	2.03E+02	1.44E+00	2.86E-06	2.02E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.76E+02	2.66E+00	1.03E-05	3.73E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	1.12E+01	4.44E-01	2.57E-04	1.07E+01
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	1.47E+01	0.00E+00	1.47E+01	0.00E+00
Arsenic (+V)	1.14E-04	1.14E-04	0.00E+00	1.53E-08
Cadmium	1.88E+00	0.00E+00	1.88E+00	0.00E+00
Cadmium (+II)	4.88E-01	9.98E-02	0.00E+00	3.80E-01
Chromium	6.24E+01	7.70E-03	6.24E+01	-1.63E-02
Chromium (+III)	6.46E+00	1.40E-01	0.00E+00	6.31E+00
Copper	5.68E+02	0.00E+00	5.68E+02	0.00E+00
Copper (+II)	5.63E+00	1.05E-01	0.00E+00	5.52E+00
Lead	3.09E+02	0.00E+00	3.09E+02	0.00E+00
Lead (+II)	9.18E+00	1.95E-01	0.00E+00	8.98E+00
Nickel	4.80E+01	0.00E+00	4.80E+01	0.00E+00
Nickel (+II)	3.17E+00	6.97E-02	0.00E+00	3.09E+00
Zinc	1.41E+04	0.00E+00	1.41E+04	0.00E+00
Zinc (+II)	2.40E+01	5.34E-01	0.00E+00	2.35E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	3.25E-04	2.92E-04	2.07E-09	3.34E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.82E-02	5.09E-04	1.88E-08	4.77E-02
Chromium	3.91E-03	3.74E-03	5.19E-06	1.66E-04
Chromium (+III)	7.86E-05	1.38E-05	1.33E-11	6.48E-05
Chromium (+VI)	2.58E-02	2.58E-02	0.00E+00	2.40E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	1.94E-02	1.85E-02	5.31E-08	8.69E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.01E-03	8.76E-04	1.40E-09	1.36E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.40E-03	7.43E-04	1.50E-06	2.65E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	7.06E-02	7.01E-02	5.76E-07	4.66E-04

Annex B. Selected LCI Emissions

Extreme Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.16E+02	3.06E+01	0.00E+00	8.59E+01
Arsenic (+V)	8.05E+00	1.76E+00	0.00E+00	6.28E+00
Cadmium	2.04E+01	4.12E+00	0.00E+00	1.62E+01
Cadmium (+II)	1.12E+00	3.64E-01	0.00E+00	7.58E-01
Chromium	2.25E+02	1.24E+02	0.00E+00	1.01E+02
Chromium (+III)	1.88E-01	2.39E-03	0.00E+00	1.86E-01
Chromium (+VI)	6.89E-01	2.95E-01	0.00E+00	3.94E-01
Copper	4.29E+02	4.12E+02	0.00E+00	1.74E+01
Copper (+II)	1.56E+01	7.83E-01	0.00E+00	1.48E+01
Lead	2.96E+02	1.85E+02	0.00E+00	1.10E+02
Lead (+II)	1.60E+02	5.54E+00	0.00E+00	1.55E+02
Molybdenum	7.81E+02	7.62E+02	0.00E+00	1.97E+01
Nickel	1.63E+02	3.75E+01	0.00E+00	1.26E+02
Nickel (+II)	4.32E+01	3.77E+00	0.00E+00	3.94E+01
Zinc	7.75E+03	7.50E+03	0.00E+00	2.50E+02
Zinc (+II)	6.43E+01	5.15E+00	0.00E+00	5.90E+01
Inorganic emissions to air				
Ammonia	1.72E+04	1.68E+03	0.00E+00	1.54E+04
Carbon dioxide	2.30E+09	8.46E+08	0.00E+00	1.45E+09
Hydrogen sulphide	1.70E+04	2.76E+03	0.00E+00	1.43E+04
Nitrogen dioxide	3.72E+01	4.23E+00	0.00E+00	3.27E+01
Nitrogen oxides	2.43E+06	6.11E+05	0.00E+00	1.81E+06
Phosphorus	1.61E+04	1.54E+04	0.00E+00	6.83E+02
Sulphur dioxide	4.16E+06	1.29E+06	0.00E+00	2.87E+06
Sulphur oxides	1.40E+06	3.02E+05	0.00E+00	1.10E+06
Organic emissions to air (group VOC)				
Group NMVOC to air	8.99E+05	1.22E+05	0.00E+00	7.76E+05
Hydrocarbons (unspecified)	1.28E+06	1.12E+04	0.00E+00	1.27E+06
Methane	5.24E+06	9.38E+05	0.00E+00	4.30E+06
VOC (unspecified)	9.61E+04	3.78E+04	0.00E+00	5.83E+04
Particles to air				
Dust (> PM10)	7.61E+03	2.76E+03	0.00E+00	4.84E+03
Dust (PM10)	1.01E+05	7.44E+04	0.00E+00	2.68E+04
Dust (PM2,5 - PM10)	8.82E+04	4.71E+03	0.00E+00	8.33E+04
Dust (PM2.5)	1.04E+05	4.64E+04	0.00E+00	5.70E+04
Dust (unspecified)	1.64E+05	1.09E+05	0.00E+00	5.53E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.12E+05	3.78E+04	0.00E+00	7.45E+04
Chemical oxygen demand (COD)	5.64E+05	9.75E+04	0.00E+00	4.67E+05
Heavy metals to fresh water				
Arsenic	2.71E+02	7.13E+01	0.00E+00	2.00E+02
Arsenic (+V)	3.90E+03	8.48E+01	0.00E+00	3.81E+03
Cadmium	5.44E-04	1.17E-04	0.00E+00	4.28E-04
Cadmium (+II)	1.64E+03	2.19E+01	0.00E+00	1.61E+03
Chromium	7.61E+03	3.29E+02	0.00E+00	7.28E+03
Chromium (+III)	3.98E+00	1.99E+00	0.00E+00	1.83E+00
Chromium (+VI)	5.86E+00	5.77E+00	0.00E+00	9.13E-02
Copper	4.53E-01	4.51E-01	0.00E+00	2.58E-03
Copper (+II)	2.03E+03	6.17E+01	0.00E+00	1.97E+03
Lead	3.11E-01	3.09E-01	0.00E+00	2.22E-03
Lead (+II)	1.46E+03	8.91E+01	0.00E+00	1.37E+03
Nickel	2.22E+00	2.04E+00	0.00E+00	1.76E-01
Nickel (+II)	2.42E+03	1.21E+02	0.00E+00	2.29E+03
Zinc	1.45E+00	1.43E+00	0.00E+00	1.19E-02
Zinc (+II)	4.89E+02	1.37E+02	0.00E+00	3.51E+02
Inorganic emissions to fresh water				
Ammonia	6.90E+03	2.64E+03	0.00E+00	4.25E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	3.78E+02	2.77E+02	0.00E+00	1.00E+02
Barium	1.92E+05	6.29E+04	0.00E+00	1.29E+05
Nitrate	1.14E+04	3.83E+03	0.00E+00	7.35E+03
Nitrogen organic bounded	2.14E+04	2.62E+03	0.00E+00	1.85E+04
Phosphate	4.26E+03	8.32E+02	0.00E+00	3.38E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.51E+00	6.38E-02	0.00E+00	5.44E+00
Anthracene	1.04E+01	1.25E-01	0.00E+00	1.02E+01
Benzene	1.32E+04	4.70E+02	0.00E+00	1.28E+04
Benzo{a}anthracene	6.15E-01	5.68E-03	0.00E+00	6.09E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	6.34E+02	5.54E+00	0.00E+00	6.28E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.71E+02	2.37E+00	0.00E+00	2.69E+02
Chromium	9.91E+02	8.65E+00	0.00E+00	9.82E+02
Chromium (+VI)	2.66E-03	2.66E-03	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.35E+02	2.10E+00	0.00E+00	2.32E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.92E+02	1.69E+00	0.00E+00	1.90E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.56E+02	3.12E+00	0.00E+00	3.53E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	1.07E+01	5.23E-01	0.00E+00	1.01E+01
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.34E-04	1.34E-04	0.00E+00	1.44E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.85E-01	1.17E-01	0.00E+00	3.59E-01
Chromium	-6.34E-03	9.06E-03	0.00E+00	-1.54E-02
Chromium (+III)	6.13E+00	1.65E-01	0.00E+00	5.96E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	5.34E+00	1.24E-01	0.00E+00	5.21E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	8.71E+00	2.30E-01	0.00E+00	8.48E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.01E+00	8.20E-02	0.00E+00	2.92E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.28E+01	6.29E-01	0.00E+00	2.21E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	3.75E-04	3.43E-04	0.00E+00	3.16E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.57E-02	5.98E-04	0.00E+00	4.50E-02
Chromium	4.56E-03	4.40E-03	0.00E+00	1.57E-04
Chromium (+III)	7.75E-05	1.62E-05	0.00E+00	6.13E-05
Chromium (+VI)	3.04E-02	3.04E-02	0.00E+00	2.27E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.26E-02	2.18E-02	0.00E+00	8.22E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.16E-03	1.03E-03	0.00E+00	1.28E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.38E-03	8.74E-04	0.00E+00	2.51E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	8.30E-02	8.25E-02	0.00E+00	4.40E-04

Annex B. Selected LCI Emissions

Extreme Uncollected Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.67E+02	0.00E+00	1.21E+01	1.55E+02
Arsenic (+V)	8.70E+00	0.00E+00	3.46E-06	8.69E+00
Cadmium	3.05E+01	0.00E+00	1.20E+00	2.93E+01
Cadmium (+II)	1.04E+00	0.00E+00	1.10E-06	1.04E+00
Chromium	2.26E+02	0.00E+00	4.81E+01	1.78E+02
Chromium (+III)	2.59E-01	0.00E+00	9.55E-09	2.59E-01
Chromium (+VI)	5.38E-01	0.00E+00	0.00E+00	5.38E-01
Copper	5.01E+02	0.00E+00	4.70E+02	3.14E+01
Copper (+II)	2.05E+01	0.00E+00	6.88E-06	2.05E+01
Lead	4.56E+02	0.00E+00	2.57E+02	1.99E+02
Lead (+II)	2.15E+02	0.00E+00	1.71E-05	2.15E+02
Molybdenum	1.06E+03	0.00E+00	1.02E+03	3.45E+01
Nickel	2.47E+02	0.00E+00	2.00E+01	2.27E+02
Nickel (+II)	5.39E+01	0.00E+00	6.42E-05	5.38E+01
Zinc	1.22E+04	0.00E+00	1.17E+04	4.52E+02
Zinc (+II)	7.99E+01	0.00E+00	1.87E-05	7.97E+01
Inorganic emissions to air				
Ammonia	2.09E+04	0.00E+00	6.95E-03	2.08E+04
Carbon dioxide	3.63E+09	0.00E+00	1.31E+09	2.32E+09
Hydrogen sulphide	1.95E+04	0.00E+00	1.22E-03	1.95E+04
Nitrogen dioxide	4.58E+01	0.00E+00	4.67E-14	4.55E+01
Nitrogen oxides	2.97E+06	0.00E+00	2.27E+05	2.74E+06
Phosphorus	2.35E+04	0.00E+00	2.23E+04	1.23E+03
Sulphur dioxide	3.92E+06	0.00E+00	5.06E-01	3.92E+06
Sulphur oxides	2.11E+06	0.00E+00	1.25E+05	1.98E+06
Organic emissions to air (group VOC)				
Group NMVOC to air	1.23E+06	0.00E+00	1.44E+05	1.09E+06
Hydrocarbons (unspecified)	1.77E+06	0.00E+00	0.00E+00	1.77E+06
Methane	6.07E+06	0.00E+00	1.14E+05	5.95E+06
VOC (unspecified)	7.89E+04	0.00E+00	1.21E-04	7.89E+04
Particles to air				
Dust (> PM10)	6.76E+03	0.00E+00	0.00E+00	6.75E+03
Dust (PM10)	2.13E+05	0.00E+00	1.65E+05	4.84E+04
Dust (PM2,5 - PM10)	1.14E+05	0.00E+00	0.00E+00	1.14E+05
Dust (PM2.5)	1.87E+05	0.00E+00	1.03E+05	8.39E+04
Dust (unspecified)	2.98E+05	0.00E+00	2.06E+05	9.25E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.02E+05	0.00E+00	1.24E-03	1.02E+05
Chemical oxygen demand (COD)	6.46E+05	0.00E+00	2.56E-02	6.45E+05
Heavy metals to fresh water				
Arsenic	4.66E+02	0.00E+00	1.06E+02	3.60E+02
Arsenic (+V)	5.31E+03	0.00E+00	4.89E-05	5.31E+03
Cadmium	1.25E+01	0.00E+00	1.25E+01	7.72E-04
Cadmium (+II)	2.25E+03	0.00E+00	2.96E-05	2.25E+03
Chromium	1.06E+04	0.00E+00	4.18E+02	1.01E+04
Chromium (+III)	2.71E+00	0.00E+00	3.08E-07	2.56E+00
Chromium (+VI)	1.26E-01	0.00E+00	5.21E-15	1.26E-01
Copper	3.78E+03	0.00E+00	3.78E+03	4.67E-03
Copper (+II)	2.74E+03	0.00E+00	1.06E-04	2.74E+03
Lead	2.06E+03	0.00E+00	2.06E+03	4.01E-03
Lead (+II)	1.91E+03	0.00E+00	2.84E-05	1.91E+03
Nickel	3.20E+02	0.00E+00	3.20E+02	3.19E-01
Nickel (+II)	3.20E+03	0.00E+00	3.56E-05	3.19E+03
Zinc	9.42E+04	0.00E+00	9.42E+04	2.15E-02
Zinc (+II)	4.83E+02	0.00E+00	1.87E-05	4.83E+02
Inorganic emissions to fresh water				
Ammonia	5.77E+03	0.00E+00	4.32E-07	5.77E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	1.40E+02	0.00E+00	8.84E-04	1.40E+02
Barium	1.78E+05	0.00E+00	1.56E+03	1.76E+05
Nitrate	1.05E+04	0.00E+00	1.21E-04	1.02E+04
Nitrogen organic bounded	2.52E+04	0.00E+00	4.06E-03	2.50E+04
Phosphate	4.61E+03	0.00E+00	3.16E-04	4.56E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.13E+03	0.00E+00	5.13E+03	7.58E+00
Anthracene	5.18E+03	0.00E+00	5.16E+03	1.42E+01
Benzene	1.78E+04	0.00E+00	1.23E-04	1.77E+04
Benzo{a}anthracene	5.07E+03	0.00E+00	5.07E+03	8.49E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	8.75E+02	0.00E+00	6.02E-05	8.75E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	3.74E+02	0.00E+00	2.71E-05	3.74E+02
Chromium	1.37E+03	0.00E+00	9.60E-05	1.37E+03
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	3.24E+02	0.00E+00	9.59E-05	3.24E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	2.65E+02	0.00E+00	1.91E-05	2.65E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	4.92E+02	0.00E+00	6.87E-05	4.91E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	1.41E+01	0.00E+00	1.71E-03	1.41E+01
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	9.78E+01	0.00E+00	9.78E+01	0.00E+00
Arsenic (+V)	2.01E-08	0.00E+00	0.00E+00	2.01E-08
Cadmium	1.25E+01	0.00E+00	1.25E+01	0.00E+00
Cadmium (+II)	5.09E-01	0.00E+00	0.00E+00	5.00E-01
Chromium	4.16E+02	0.00E+00	4.16E+02	-2.14E-02
Chromium (+III)	8.31E+00	0.00E+00	0.00E+00	8.31E+00
Copper	3.78E+03	0.00E+00	3.78E+03	0.00E+00
Copper (+II)	7.26E+00	0.00E+00	0.00E+00	7.26E+00
Lead	2.06E+03	0.00E+00	2.06E+03	0.00E+00
Lead (+II)	1.18E+01	0.00E+00	0.00E+00	1.18E+01
Nickel	3.20E+02	0.00E+00	3.20E+02	0.00E+00
Nickel (+II)	4.07E+00	0.00E+00	0.00E+00	4.07E+00
Zinc	9.42E+04	0.00E+00	9.42E+04	0.00E+00
Zinc (+II)	3.09E+01	0.00E+00	0.00E+00	3.09E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	4.40E-05	0.00E+00	1.38E-08	4.39E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	6.28E-02	0.00E+00	1.25E-07	6.28E-02
Chromium	2.52E-04	0.00E+00	3.46E-05	2.17E-04
Chromium (+III)	8.49E-05	0.00E+00	8.88E-11	8.49E-05
Chromium (+VI)	3.11E-07	0.00E+00	0.00E+00	3.11E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	1.13E-03	0.00E+00	3.54E-07	1.13E-03
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.79E-04	0.00E+00	9.31E-09	1.78E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.49E-03	0.00E+00	9.99E-06	3.47E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	6.17E-04	0.00E+00	3.84E-06	6.13E-04

Annex B. Selected LCI Emissions

RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	6.78E+01	6.78E+01	0.00E+00	0.00E+00
Arsenic (+V)	6.05E+00	1.21E-01	0.00E+00	5.92E+00
Cadmium	6.70E+00	6.70E+00	0.00E+00	0.00E+00
Cadmium (+II)	7.53E-01	1.55E-02	0.00E+00	7.38E-01
Chromium	2.79E+02	2.68E+02	0.00E+00	1.14E+01
Chromium (+III)	1.71E-01	1.64E-03	0.00E+00	1.69E-01
Chromium (+VI)	4.09E-01	1.30E-02	0.00E+00	3.96E-01
Copper	2.62E+03	2.62E+03	0.00E+00	0.00E+00
Copper (+II)	1.42E+01	1.10E-01	0.00E+00	1.41E+01
Lead	1.43E+03	1.43E+03	0.00E+00	0.00E+00
Lead (+II)	1.43E+02	1.44E+00	0.00E+00	1.42E+02
Molybdenum	5.70E+03	5.70E+03	0.00E+00	2.42E+00
Nickel	1.12E+02	1.12E+02	0.00E+00	0.00E+00
Nickel (+II)	3.95E+01	4.90E-01	0.00E+00	3.89E+01
Zinc	6.52E+04	6.52E+04	0.00E+00	0.00E+00
Zinc (+II)	6.38E+01	2.52E+00	0.00E+00	6.11E+01
Inorganic emissions to air				
Ammonia	1.74E+04	1.13E+03	0.00E+00	1.61E+04
Carbon dioxide	2.09E+09	1.39E+09	0.00E+00	7.02E+08
Hydrogen sulphide	1.43E+04	2.15E+02	0.00E+00	1.41E+04
Nitrogen dioxide	3.37E+01	3.64E+00	0.00E+00	2.98E+01
Nitrogen oxides	2.09E+06	8.82E+05	0.00E+00	1.20E+06
Phosphorus	1.25E+05	1.25E+05	0.00E+00	0.00E+00
Sulphur dioxide	2.88E+06	2.29E+04	0.00E+00	2.86E+06
Sulphur oxides	9.74E+05	9.74E+05	0.00E+00	0.00E+00
Organic emissions to air (group VOC)				
Group NMVOC to air	8.71E+05	1.78E+05	0.00E+00	6.92E+05
Hydrocarbons (unspecified)	1.17E+06	1.07E+04	0.00E+00	1.16E+06
Methane	4.14E+06	8.84E+04	0.00E+00	4.05E+06
VOC (unspecified)	6.01E+04	1.80E+02	0.00E+00	5.99E+04
Particles to air				
Dust (> PM10)	4.49E+03	7.03E+01	0.00E+00	4.41E+03
Dust (PM10)	5.51E+05	5.51E+05	0.00E+00	5.46E+01
Dust (PM2,5 - PM10)	8.28E+04	1.28E+03	0.00E+00	8.13E+04
Dust (PM2.5)	3.89E+05	3.46E+05	0.00E+00	4.29E+04
Dust (unspecified)	7.00E+05	6.83E+05	0.00E+00	1.69E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	7.52E+04	3.05E+02	0.00E+00	7.49E+04
Chemical oxygen demand (COD)	4.43E+05	3.61E+03	0.00E+00	4.39E+05
Heavy metals to fresh water				
Arsenic	1.57E+02	1.57E+02	0.00E+00	0.00E+00
Arsenic (+V)	3.52E+03	3.19E+01	0.00E+00	3.48E+03
Cadmium	2.51E-04	2.51E-04	0.00E+00	0.00E+00
Cadmium (+II)	1.49E+03	1.38E+01	0.00E+00	1.47E+03
Chromium	6.77E+03	1.19E+02	0.00E+00	6.64E+03
Chromium (+III)	3.77E+00	1.94E+00	0.00E+00	1.67E+00
Chromium (+VI)	8.84E-02	1.18E-03	0.00E+00	8.72E-02
Copper	3.91E-01	3.91E-01	0.00E+00	0.00E+00
Copper (+II)	1.81E+03	1.74E+01	0.00E+00	1.80E+03
Lead	2.87E-02	2.87E-02	0.00E+00	0.00E+00
Lead (+II)	1.28E+03	1.90E+01	0.00E+00	1.26E+03
Nickel	3.78E-01	3.78E-01	0.00E+00	0.00E+00
Nickel (+II)	2.13E+03	2.69E+01	0.00E+00	2.10E+03
Zinc	3.10E+00	3.10E+00	0.00E+00	0.00E+00
Zinc (+II)	3.43E+02	2.29E+00	0.00E+00	3.41E+02
Inorganic emissions to fresh water				
Ammonia	4.37E+03	1.37E+01	0.00E+00	4.35E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	9.32E+01	1.44E+00	0.00E+00	9.17E+01
Barium	1.29E+05	5.74E+02	0.00E+00	1.29E+05
Nitrate	1.02E+04	3.25E+03	0.00E+00	6.69E+03
Nitrogen organic bounded	2.21E+04	2.56E+03	0.00E+00	1.93E+04
Phosphate	4.17E+03	6.12E+02	0.00E+00	3.51E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.01E+00	4.81E-02	0.00E+00	4.96E+00
Anthracene	9.41E+00	9.10E-02	0.00E+00	9.31E+00
Benzene	1.18E+04	1.06E+02	0.00E+00	1.17E+04
Benzo{a}anthracene	5.61E-01	5.20E-03	0.00E+00	5.55E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	5.78E+02	5.33E+00	0.00E+00	5.72E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.47E+02	2.28E+00	0.00E+00	2.45E+02
Chromium	9.03E+02	8.33E+00	0.00E+00	8.94E+02
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.14E+02	1.98E+00	0.00E+00	2.12E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.75E+02	1.62E+00	0.00E+00	1.73E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.25E+02	3.00E+00	0.00E+00	3.21E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	9.32E+00	8.69E-02	0.00E+00	9.22E+00
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.31E-08	3.76E-15	0.00E+00	1.31E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.44E-01	1.08E-01	0.00E+00	3.27E-01
Chromium	-1.43E-02	-2.32E-04	0.00E+00	-1.40E-02
Chromium (+III)	5.49E+00	5.48E-02	0.00E+00	5.43E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	4.80E+00	4.50E-02	0.00E+00	4.75E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	7.81E+00	7.66E-02	0.00E+00	7.72E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.69E+00	2.68E-02	0.00E+00	2.66E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.04E+01	1.98E-01	0.00E+00	2.02E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	2.95E-05	4.42E-07	0.00E+00	2.90E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.15E-02	4.03E-04	0.00E+00	4.10E-02
Chromium	1.49E-04	2.57E-06	0.00E+00	1.46E-04
Chromium (+III)	5.88E-05	1.21E-06	0.00E+00	5.76E-05
Chromium (+VI)	2.36E-07	8.49E-09	0.00E+00	2.27E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	8.14E-04	2.18E-05	0.00E+00	7.92E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.19E-04	1.84E-06	0.00E+00	1.17E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.39E-03	4.54E-05	0.00E+00	2.34E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	4.09E-04	5.42E-06	0.00E+00	4.03E-04

Annex B. Selected LCI Emissions

RFO LPC Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.35E+02	1.35E+02	0.00E+00	0.00E+00
Arsenic (+V)	6.05E+00	1.21E-01	0.00E+00	5.92E+00
Cadmium	1.33E+01	1.33E+01	0.00E+00	0.00E+00
Cadmium (+II)	7.53E-01	1.55E-02	0.00E+00	7.38E-01
Chromium	5.46E+02	5.35E+02	0.00E+00	1.14E+01
Chromium (+III)	1.71E-01	1.64E-03	0.00E+00	1.69E-01
Chromium (+VI)	4.09E-01	1.30E-02	0.00E+00	3.96E-01
Copper	5.22E+03	5.22E+03	0.00E+00	0.00E+00
Copper (+II)	1.42E+01	1.10E-01	0.00E+00	1.41E+01
Lead	2.85E+03	2.85E+03	0.00E+00	0.00E+00
Lead (+II)	1.43E+02	1.44E+00	0.00E+00	1.42E+02
Molybdenum	1.14E+04	1.14E+04	0.00E+00	2.42E+00
Nickel	2.22E+02	2.22E+02	0.00E+00	0.00E+00
Nickel (+II)	3.95E+01	4.90E-01	0.00E+00	3.89E+01
Zinc	1.30E+05	1.30E+05	0.00E+00	0.00E+00
Zinc (+II)	6.38E+01	2.52E+00	0.00E+00	6.11E+01
Inorganic emissions to air				
Ammonia	1.74E+04	1.13E+03	0.00E+00	1.61E+04
Carbon dioxide	2.09E+09	1.39E+09	0.00E+00	7.02E+08
Hydrogen sulphide	1.43E+04	2.15E+02	0.00E+00	1.41E+04
Nitrogen dioxide	3.37E+01	3.64E+00	0.00E+00	2.98E+01
Nitrogen oxides	3.87E+06	2.66E+06	0.00E+00	1.20E+06
Phosphorus	2.48E+05	2.48E+05	0.00E+00	0.00E+00
Sulphur dioxide	2.88E+06	2.29E+04	0.00E+00	2.86E+06
Sulphur oxides	1.39E+06	1.39E+06	0.00E+00	0.00E+00
Organic emissions to air (group VOC)				
Group NMVOC to air	2.30E+06	1.61E+06	0.00E+00	6.92E+05
Hydrocarbons (unspecified)	1.17E+06	1.07E+04	0.00E+00	1.16E+06
Methane	4.26E+06	2.05E+05	0.00E+00	4.05E+06
VOC (unspecified)	6.01E+04	1.80E+02	0.00E+00	5.99E+04
Particles to air				
Dust (> PM10)	4.49E+03	7.03E+01	0.00E+00	4.41E+03
Dust (PM10)	1.83E+06	1.83E+06	0.00E+00	5.46E+01
Dust (PM2,5 - PM10)	8.28E+04	1.28E+03	0.00E+00	8.13E+04
Dust (PM2.5)	1.19E+06	1.15E+06	0.00E+00	4.29E+04
Dust (unspecified)	2.31E+06	2.29E+06	0.00E+00	1.69E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	7.52E+04	3.05E+02	0.00E+00	7.49E+04
Chemical oxygen demand (COD)	4.43E+05	3.61E+03	0.00E+00	4.39E+05
Heavy metals to fresh water				
Arsenic	9.00E+01	9.00E+01	0.00E+00	0.00E+00
Arsenic (+V)	3.52E+03	3.19E+01	0.00E+00	3.48E+03
Cadmium	1.76E-04	1.76E-04	0.00E+00	0.00E+00
Cadmium (+II)	1.49E+03	1.38E+01	0.00E+00	1.47E+03
Chromium	6.75E+03	1.03E+02	0.00E+00	6.64E+03
Chromium (+III)	3.77E+00	1.94E+00	0.00E+00	1.67E+00
Chromium (+VI)	8.84E-02	1.18E-03	0.00E+00	8.72E-02
Copper	2.24E-01	2.24E-01	0.00E+00	0.00E+00
Copper (+II)	1.81E+03	1.74E+01	0.00E+00	1.80E+03
Lead	1.64E-02	1.64E-02	0.00E+00	0.00E+00
Lead (+II)	1.28E+03	1.90E+01	0.00E+00	1.26E+03
Nickel	3.11E-01	3.11E-01	0.00E+00	0.00E+00
Nickel (+II)	2.13E+03	2.69E+01	0.00E+00	2.10E+03
Zinc	1.77E+00	1.77E+00	0.00E+00	0.00E+00
Zinc (+II)	3.43E+02	2.29E+00	0.00E+00	3.41E+02
Inorganic emissions to fresh water				
Ammonia	4.37E+03	1.37E+01	0.00E+00	4.35E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	9.32E+01	1.44E+00	0.00E+00	9.17E+01
Barium	1.29E+05	5.74E+02	0.00E+00	1.29E+05
Nitrate	1.02E+04	3.25E+03	0.00E+00	6.69E+03
Nitrogen organic bounded	2.21E+04	2.56E+03	0.00E+00	1.93E+04
Phosphate	4.17E+03	6.12E+02	0.00E+00	3.51E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.01E+00	4.81E-02	0.00E+00	4.96E+00
Anthracene	9.41E+00	9.10E-02	0.00E+00	9.31E+00
Benzene	1.18E+04	1.06E+02	0.00E+00	1.17E+04
Benzo{a}anthracene	5.61E-01	5.20E-03	0.00E+00	5.55E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	5.78E+02	5.33E+00	0.00E+00	5.72E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.47E+02	2.28E+00	0.00E+00	2.45E+02
Chromium	9.03E+02	8.33E+00	0.00E+00	8.94E+02
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.14E+02	1.98E+00	0.00E+00	2.12E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.75E+02	1.62E+00	0.00E+00	1.73E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.25E+02	3.00E+00	0.00E+00	3.21E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	9.32E+00	8.69E-02	0.00E+00	9.22E+00
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.31E-08	3.76E-15	0.00E+00	1.31E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.44E-01	1.08E-01	0.00E+00	3.27E-01
Chromium	-1.43E-02	-2.32E-04	0.00E+00	-1.40E-02
Chromium (+III)	5.49E+00	5.48E-02	0.00E+00	5.43E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	4.80E+00	4.50E-02	0.00E+00	4.75E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	7.81E+00	7.66E-02	0.00E+00	7.72E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.69E+00	2.68E-02	0.00E+00	2.66E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.04E+01	1.98E-01	0.00E+00	2.02E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	2.95E-05	4.42E-07	0.00E+00	2.90E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.15E-02	4.03E-04	0.00E+00	4.10E-02
Chromium	1.49E-04	2.57E-06	0.00E+00	1.46E-04
Chromium (+III)	5.88E-05	1.21E-06	0.00E+00	5.76E-05
Chromium (+VI)	2.36E-07	8.49E-09	0.00E+00	2.27E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	8.14E-04	2.18E-05	0.00E+00	7.92E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.19E-04	1.84E-06	0.00E+00	1.17E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.39E-03	4.54E-05	0.00E+00	2.34E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	4.09E-04	5.42E-06	0.00E+00	4.03E-04

Annex B. Selected LCI Emissions

RFO HPC Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	4.48E-01	4.48E-01	0.00E+00	0.00E+00
Arsenic (+V)	6.05E+00	1.21E-01	0.00E+00	5.92E+00
Cadmium	4.61E-02	4.61E-02	0.00E+00	0.00E+00
Cadmium (+II)	7.53E-01	1.55E-02	0.00E+00	7.38E-01
Chromium	1.33E+01	1.93E+00	0.00E+00	1.14E+01
Chromium (+III)	1.71E-01	1.64E-03	0.00E+00	1.69E-01
Chromium (+VI)	4.09E-01	1.30E-02	0.00E+00	3.96E-01
Copper	1.74E+01	1.74E+01	0.00E+00	0.00E+00
Copper (+II)	1.42E+01	1.10E-01	0.00E+00	1.41E+01
Lead	9.52E+00	9.52E+00	0.00E+00	0.00E+00
Lead (+II)	1.43E+02	1.44E+00	0.00E+00	1.42E+02
Molybdenum	4.03E+01	3.79E+01	0.00E+00	2.42E+00
Nickel	7.43E-01	7.43E-01	0.00E+00	0.00E+00
Nickel (+II)	3.95E+01	4.90E-01	0.00E+00	3.89E+01
Zinc	4.33E+02	4.33E+02	0.00E+00	0.00E+00
Zinc (+II)	6.38E+01	2.52E+00	0.00E+00	6.11E+01
Inorganic emissions to air				
Ammonia	1.74E+04	1.13E+03	0.00E+00	1.61E+04
Carbon dioxide	2.09E+09	1.39E+09	0.00E+00	7.02E+08
Hydrogen sulphide	1.43E+04	2.15E+02	0.00E+00	1.41E+04
Nitrogen dioxide	3.37E+01	3.64E+00	0.00E+00	2.98E+01
Nitrogen oxides	1.43E+06	2.14E+05	0.00E+00	1.20E+06
Phosphorus	2.48E+03	2.48E+03	0.00E+00	0.00E+00
Sulphur dioxide	2.88E+06	2.29E+04	0.00E+00	2.86E+06
Sulphur oxides	5.65E+05	5.65E+05	0.00E+00	0.00E+00
Organic emissions to air (group VOC)				
Group NMVOC to air	7.11E+05	1.82E+04	0.00E+00	6.92E+05
Hydrocarbons (unspecified)	1.17E+06	1.07E+04	0.00E+00	1.16E+06
Methane	4.08E+06	3.15E+04	0.00E+00	4.05E+06
VOC (unspecified)	6.01E+04	1.80E+02	0.00E+00	5.99E+04
Particles to air				
Dust (> PM10)	4.49E+03	7.03E+01	0.00E+00	4.41E+03
Dust (PM10)	8.42E+03	8.29E+03	0.00E+00	5.46E+01
Dust (PM2,5 - PM10)	8.28E+04	1.28E+03	0.00E+00	8.13E+04
Dust (PM2.5)	4.99E+04	6.76E+03	0.00E+00	4.29E+04
Dust (unspecified)	2.45E+04	7.60E+03	0.00E+00	1.69E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	7.52E+04	3.05E+02	0.00E+00	7.49E+04
Chemical oxygen demand (COD)	4.43E+05	3.61E+03	0.00E+00	4.39E+05
Heavy metals to fresh water				
Arsenic	2.24E+02	2.24E+02	0.00E+00	0.00E+00
Arsenic (+V)	3.52E+03	3.19E+01	0.00E+00	3.48E+03
Cadmium	3.26E-04	3.26E-04	0.00E+00	0.00E+00
Cadmium (+II)	1.49E+03	1.38E+01	0.00E+00	1.47E+03
Chromium	6.78E+03	1.35E+02	0.00E+00	6.64E+03
Chromium (+III)	3.77E+00	1.94E+00	0.00E+00	1.67E+00
Chromium (+VI)	8.84E-02	1.18E-03	0.00E+00	8.72E-02
Copper	5.57E-01	5.57E-01	0.00E+00	0.00E+00
Copper (+II)	1.81E+03	1.74E+01	0.00E+00	1.80E+03
Lead	4.11E-02	4.11E-02	0.00E+00	0.00E+00
Lead (+II)	1.28E+03	1.90E+01	0.00E+00	1.26E+03
Nickel	4.45E-01	4.45E-01	0.00E+00	0.00E+00
Nickel (+II)	2.13E+03	2.69E+01	0.00E+00	2.10E+03
Zinc	4.44E+00	4.44E+00	0.00E+00	0.00E+00
Zinc (+II)	3.43E+02	2.29E+00	0.00E+00	3.41E+02
Inorganic emissions to fresh water				
Ammonia	4.37E+03	1.37E+01	0.00E+00	4.35E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	9.32E+01	1.44E+00	0.00E+00	9.17E+01
Barium	1.29E+05	5.74E+02	0.00E+00	1.29E+05
Nitrate	1.02E+04	3.25E+03	0.00E+00	6.69E+03
Nitrogen organic bounded	2.21E+04	2.56E+03	0.00E+00	1.93E+04
Phosphate	4.17E+03	6.12E+02	0.00E+00	3.51E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.01E+00	4.81E-02	0.00E+00	4.96E+00
Anthracene	9.41E+00	9.10E-02	0.00E+00	9.31E+00
Benzene	1.18E+04	1.06E+02	0.00E+00	1.17E+04
Benzo{a}anthracene	5.61E-01	5.20E-03	0.00E+00	5.55E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	5.78E+02	5.33E+00	0.00E+00	5.72E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.47E+02	2.28E+00	0.00E+00	2.45E+02
Chromium	9.03E+02	8.33E+00	0.00E+00	8.94E+02
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.14E+02	1.98E+00	0.00E+00	2.12E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.75E+02	1.62E+00	0.00E+00	1.73E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.25E+02	3.00E+00	0.00E+00	3.21E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	9.32E+00	8.69E-02	0.00E+00	9.22E+00
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.31E-08	3.76E-15	0.00E+00	1.31E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.44E-01	1.08E-01	0.00E+00	3.27E-01
Chromium	-1.43E-02	-2.32E-04	0.00E+00	-1.40E-02
Chromium (+III)	5.49E+00	5.48E-02	0.00E+00	5.43E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	4.80E+00	4.50E-02	0.00E+00	4.75E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	7.81E+00	7.66E-02	0.00E+00	7.72E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.69E+00	2.68E-02	0.00E+00	2.66E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.04E+01	1.98E-01	0.00E+00	2.02E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	2.95E-05	4.42E-07	0.00E+00	2.90E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.15E-02	4.03E-04	0.00E+00	4.10E-02
Chromium	1.49E-04	2.57E-06	0.00E+00	1.46E-04
Chromium (+III)	5.88E-05	1.21E-06	0.00E+00	5.76E-05
Chromium (+VI)	2.36E-07	8.49E-09	0.00E+00	2.27E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	8.14E-04	2.18E-05	0.00E+00	7.92E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.19E-04	1.84E-06	0.00E+00	1.17E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.39E-03	4.54E-05	0.00E+00	2.34E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	4.09E-04	5.42E-06	0.00E+00	4.03E-04

Annex B. Selected LCI Emissions

RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.42E+02	1.56E-01	0.00E+00	1.42E+02
Arsenic (+V)	7.65E+00	2.06E+00	0.00E+00	5.58E+00
Cadmium	2.77E+01	8.57E-01	0.00E+00	2.68E+01
Cadmium (+II)	1.02E+00	3.90E-01	0.00E+00	6.29E-01
Chromium	1.61E+02	2.67E+00	0.00E+00	1.58E+02
Chromium (+III)	1.80E-01	3.50E-03	0.00E+00	1.77E-01
Chromium (+VI)	6.49E-01	3.49E-01	0.00E+00	3.01E-01
Copper	2.93E+01	6.60E-01	0.00E+00	2.87E+01
Copper (+II)	1.33E+01	2.89E-01	0.00E+00	1.30E+01
Lead	1.82E+02	0.00E+00	0.00E+00	1.82E+02
Lead (+II)	1.51E+02	5.37E+00	0.00E+00	1.46E+02
Molybdenum	3.12E+01	8.86E-01	0.00E+00	3.03E+01
Nickel	2.09E+02	1.63E+00	0.00E+00	2.07E+02
Nickel (+II)	3.57E+01	3.73E+00	0.00E+00	3.20E+01
Zinc	4.35E+02	2.26E+01	0.00E+00	4.13E+02
Zinc (+II)	4.65E+01	3.21E+00	0.00E+00	4.31E+01
Inorganic emissions to air				
Ammonia	1.38E+04	2.61E+03	0.00E+00	1.10E+04
Carbon dioxide	2.08E+09	2.77E+08	0.00E+00	1.80E+09
Hydrogen sulphide	1.50E+04	3.47E+03	0.00E+00	1.15E+04
Nitrogen dioxide	3.64E+01	5.00E+00	0.00E+00	3.11E+01
Nitrogen oxides	2.38E+06	3.21E+05	0.00E+00	2.05E+06
Phosphorus	1.13E+03	0.00E+00	0.00E+00	1.13E+03
Sulphur dioxide	3.39E+06	1.09E+06	0.00E+00	2.29E+06
Sulphur oxides	2.16E+06	3.50E+05	0.00E+00	1.81E+06
Organic emissions to air (group VOC)				
Group NMVOC to air	8.02E+05	5.71E+04	0.00E+00	7.44E+05
Hydrocarbons (unspecified)	1.22E+06	1.23E+04	0.00E+00	1.21E+06
Methane	4.60E+06	7.80E+05	0.00E+00	3.82E+06
VOC (unspecified)	7.39E+04	3.09E+04	0.00E+00	4.30E+04
Particles to air				
Dust (> PM10)	5.08E+03	4.58E+02	0.00E+00	4.61E+03
Dust (PM10)	5.00E+04	5.71E+03	0.00E+00	4.43E+04
Dust (PM2,5 - PM10)	7.35E+04	3.55E+03	0.00E+00	6.98E+04
Dust (PM2.5)	6.34E+04	5.63E+03	0.00E+00	5.75E+04
Dust (unspecified)	1.03E+05	2.71E+04	0.00E+00	7.64E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	8.86E+04	3.03E+04	0.00E+00	5.83E+04
Chemical oxygen demand (COD)	4.75E+05	5.64E+04	0.00E+00	4.18E+05
Heavy metals to fresh water				
Arsenic	3.32E+02	2.25E+00	0.00E+00	3.30E+02
Arsenic (+V)	3.69E+03	7.47E+01	0.00E+00	3.61E+03
Cadmium	7.29E-04	2.25E-05	0.00E+00	7.06E-04
Cadmium (+II)	1.56E+03	2.27E+01	0.00E+00	1.53E+03
Chromium	7.51E+03	6.03E+02	0.00E+00	6.90E+03
Chromium (+III)	3.92E+00	2.03E+00	0.00E+00	1.74E+00
Chromium (+VI)	9.50E-01	8.71E-01	0.00E+00	7.93E-02
Copper	1.57E+00	1.57E+00	0.00E+00	4.27E-03
Copper (+II)	1.91E+03	5.03E+01	0.00E+00	1.86E+03
Lead	1.23E+00	1.23E+00	0.00E+00	3.67E-03
Lead (+II)	1.37E+03	8.09E+01	0.00E+00	1.29E+03
Nickel	8.21E+00	7.92E+00	0.00E+00	2.91E-01
Nickel (+II)	2.24E+03	6.16E+01	0.00E+00	2.17E+03
Zinc	4.36E+00	4.34E+00	0.00E+00	1.97E-02
Zinc (+II)	3.94E+02	9.61E+01	0.00E+00	2.97E+02
Inorganic emissions to fresh water				
Ammonia	5.33E+03	2.16E+03	0.00E+00	3.18E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	7.99E+02	7.04E+02	0.00E+00	9.48E+01
Barium	1.54E+05	5.15E+04	0.00E+00	1.02E+05
Nitrate	1.09E+04	3.67E+03	0.00E+00	7.00E+03
Nitrogen organic bounded	1.62E+04	2.65E+03	0.00E+00	1.33E+04
Phosphate	3.13E+03	6.29E+02	0.00E+00	2.45E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.29E+00	1.04E-01	0.00E+00	5.18E+00
Anthracene	9.95E+00	2.11E-01	0.00E+00	9.73E+00
Benzene	1.25E+04	4.24E+02	0.00E+00	1.20E+04
Benzo{a}anthracene	5.88E-01	6.93E-03	0.00E+00	5.80E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	6.04E+02	6.11E+00	0.00E+00	5.98E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.58E+02	2.62E+00	0.00E+00	2.56E+02
Chromium	9.45E+02	9.55E+00	0.00E+00	9.35E+02
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.24E+02	2.41E+00	0.00E+00	2.21E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.83E+02	1.88E+00	0.00E+00	1.81E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.40E+02	3.47E+00	0.00E+00	3.36E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	9.77E+00	1.26E-01	0.00E+00	9.64E+00
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.46E-08	8.79E-10	0.00E+00	1.37E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.76E-01	1.26E-01	0.00E+00	3.42E-01
Chromium	-1.65E-02	-1.84E-03	0.00E+00	-1.47E-02
Chromium (+III)	5.97E+00	2.91E-01	0.00E+00	5.68E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	5.17E+00	2.09E-01	0.00E+00	4.96E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	8.47E+00	3.96E-01	0.00E+00	8.07E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.93E+00	1.44E-01	0.00E+00	2.78E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.21E+01	9.96E-01	0.00E+00	2.11E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	3.56E-05	6.09E-06	0.00E+00	2.95E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.39E-02	9.94E-04	0.00E+00	4.29E-02
Chromium	2.17E-04	7.51E-05	0.00E+00	1.42E-04
Chromium (+III)	7.58E-05	2.11E-05	0.00E+00	5.47E-05
Chromium (+VI)	3.87E-07	2.13E-07	0.00E+00	1.74E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	1.19E-03	4.95E-04	0.00E+00	6.93E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.48E-04	2.73E-05	0.00E+00	1.21E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.02E-03	7.53E-04	0.00E+00	2.27E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	5.19E-04	1.04E-04	0.00E+00	4.15E-04

Annex B. Selected LCI Emissions

MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.09E+02	4.14E+01	0.00E+00	6.75E+01
Arsenic (+V)	8.20E+00	1.90E+00	0.00E+00	6.30E+00
Cadmium	1.83E+01	5.58E+00	0.00E+00	1.28E+01
Cadmium (+II)	1.18E+00	4.07E-01	0.00E+00	7.76E-01
Chromium	2.49E+02	1.67E+02	0.00E+00	8.21E+01
Chromium (+III)	1.84E-01	2.08E-03	0.00E+00	1.82E-01
Chromium (+VI)	7.40E-01	3.27E-01	0.00E+00	4.13E-01
Copper	2.20E+02	2.06E+02	0.00E+00	1.36E+01
Copper (+II)	1.51E+01	1.57E-01	0.00E+00	1.49E+01
Lead	1.28E+02	4.11E+01	0.00E+00	8.68E+01
Lead (+II)	1.55E+02	3.47E+00	0.00E+00	1.52E+02
Molybdenum	2.23E+02	2.07E+02	0.00E+00	1.61E+01
Nickel	1.43E+02	4.39E+01	0.00E+00	9.86E+01
Nickel (+II)	4.45E+01	3.92E+00	0.00E+00	4.05E+01
Zinc	3.37E+02	1.41E+02	0.00E+00	1.96E+02
Zinc (+II)	6.53E+01	2.72E+00	0.00E+00	6.24E+01
Inorganic emissions to air				
Ammonia	1.79E+04	1.35E+03	0.00E+00	1.64E+04
Carbon dioxide	2.41E+09	1.09E+09	0.00E+00	1.32E+09
Hydrogen sulphide	1.78E+04	3.02E+03	0.00E+00	1.47E+04
Nitrogen dioxide	3.63E+01	4.10E+00	0.00E+00	3.20E+01
Nitrogen oxides	2.44E+06	7.44E+05	0.00E+00	1.69E+06
Phosphorus	2.59E+03	2.05E+03	0.00E+00	5.37E+02
Sulphur dioxide	4.65E+06	1.68E+06	0.00E+00	2.97E+06
Sulphur oxides	1.05E+06	1.89E+05	0.00E+00	8.62E+05
Organic emissions to air (group VOC)				
Group NMVOC to air	9.12E+05	1.53E+05	0.00E+00	7.58E+05
Hydrocarbons (unspecified)	1.25E+06	1.09E+04	0.00E+00	1.24E+06
Methane	5.53E+06	1.22E+06	0.00E+00	4.31E+06
VOC (unspecified)	1.12E+05	5.02E+04	0.00E+00	6.16E+04
Particles to air				
Dust (> PM10)	4.99E+03	2.50E+02	0.00E+00	4.74E+03
Dust (PM10)	3.94E+04	1.82E+04	0.00E+00	2.11E+04
Dust (PM2,5 - PM10)	8.87E+04	3.55E+03	0.00E+00	8.50E+04
Dust (PM2.5)	6.45E+04	8.88E+03	0.00E+00	5.54E+04
Dust (unspecified)	9.09E+04	4.30E+04	0.00E+00	4.79E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.27E+05	4.93E+04	0.00E+00	7.76E+04
Chemical oxygen demand (COD)	5.52E+05	8.60E+04	0.00E+00	4.66E+05
Heavy metals to fresh water				
Arsenic	2.53E+02	9.60E+01	0.00E+00	1.57E+02
Arsenic (+V)	3.83E+03	9.45E+01	0.00E+00	3.73E+03
Cadmium	4.82E-04	1.46E-04	0.00E+00	3.36E-04
Cadmium (+II)	1.60E+03	2.31E+01	0.00E+00	1.58E+03
Chromium	7.41E+03	2.75E+02	0.00E+00	7.13E+03
Chromium (+III)	3.93E+00	1.99E+00	0.00E+00	1.80E+00
Chromium (+VI)	1.44E-01	5.19E-02	0.00E+00	9.20E-02
Copper	3.27E-02	3.07E-02	0.00E+00	2.03E-03
Copper (+II)	1.99E+03	6.02E+01	0.00E+00	1.93E+03
Lead	2.57E-03	8.25E-04	0.00E+00	1.74E-03
Lead (+II)	1.46E+03	1.10E+02	0.00E+00	1.35E+03
Nickel	2.00E-01	6.14E-02	0.00E+00	1.39E-01
Nickel (+II)	2.33E+03	7.67E+01	0.00E+00	2.25E+03
Zinc	1.60E-02	6.68E-03	0.00E+00	9.35E-03
Zinc (+II)	5.08E+02	1.50E+02	0.00E+00	3.57E+02
Inorganic emissions to fresh water				
Ammonia	7.99E+03	3.51E+03	0.00E+00	4.48E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	1.87E+02	8.84E+01	0.00E+00	9.83E+01
Barium	2.17E+05	8.34E+04	0.00E+00	1.34E+05
Nitrate	1.08E+04	3.41E+03	0.00E+00	7.18E+03
Nitrogen organic bounded	2.25E+04	2.58E+03	0.00E+00	1.97E+04
Phosphate	4.25E+03	6.17E+02	0.00E+00	3.58E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.38E+00	5.14E-02	0.00E+00	5.32E+00
Anthracene	1.01E+01	9.82E-02	0.00E+00	9.99E+00
Benzene	1.31E+04	5.81E+02	0.00E+00	1.25E+04
Benzo{a}anthracene	6.02E-01	5.29E-03	0.00E+00	5.96E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	6.20E+02	5.36E+00	0.00E+00	6.14E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.65E+02	2.29E+00	0.00E+00	2.63E+02
Chromium	9.69E+02	8.38E+00	0.00E+00	9.60E+02
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.30E+02	2.00E+00	0.00E+00	2.27E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.88E+02	1.63E+00	0.00E+00	1.86E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.48E+02	3.01E+00	0.00E+00	3.45E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	1.00E+01	8.92E-02	0.00E+00	9.90E+00
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.47E-08	5.61E-10	0.00E+00	1.41E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.74E-01	1.15E-01	0.00E+00	3.51E-01
Chromium	-1.59E-02	-8.16E-04	0.00E+00	-1.51E-02
Chromium (+III)	5.98E+00	1.47E-01	0.00E+00	5.83E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	5.21E+00	1.12E-01	0.00E+00	5.10E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	8.50E+00	2.03E-01	0.00E+00	8.29E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.93E+00	7.26E-02	0.00E+00	2.86E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.22E+01	5.15E-01	0.00E+00	2.17E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	3.47E-05	3.54E-06	0.00E+00	3.11E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.45E-02	4.48E-04	0.00E+00	4.40E-02
Chromium	1.90E-04	3.42E-05	0.00E+00	1.56E-04
Chromium (+III)	7.90E-05	1.76E-05	0.00E+00	6.13E-05
Chromium (+VI)	4.26E-07	1.88E-07	0.00E+00	2.38E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	1.25E-03	4.09E-04	0.00E+00	8.38E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.38E-04	1.22E-05	0.00E+00	1.26E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.09E-03	5.91E-04	0.00E+00	2.49E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	4.65E-04	3.30E-05	0.00E+00	4.32E-04

Annex B. Selected LCI Emissions

VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to air				
Heavy metals to air				
Arsenic	1.49E+02	0.00E+00	0.00E+00	1.49E+02
Arsenic (+V)	6.33E+00	1.44E-01	0.00E+00	6.19E+00
Cadmium	2.81E+01	0.00E+00	0.00E+00	2.81E+01
Cadmium (+II)	1.04E+00	2.76E-01	0.00E+00	7.59E-01
Chromium	1.67E+02	4.63E-01	0.00E+00	1.66E+02
Chromium (+III)	1.80E-01	1.66E-03	0.00E+00	1.79E-01
Chromium (+VI)	4.13E-01	7.42E-03	0.00E+00	4.05E-01
Copper	3.01E+01	0.00E+00	0.00E+00	3.01E+01
Copper (+II)	1.46E+01	1.11E-01	0.00E+00	1.45E+01
Lead	1.91E+02	0.00E+00	0.00E+00	1.91E+02
Lead (+II)	1.51E+02	1.53E+00	0.00E+00	1.49E+02
Molybdenum	3.25E+01	2.17E-02	0.00E+00	3.25E+01
Nickel	2.18E+02	0.00E+00	0.00E+00	2.18E+02
Nickel (+II)	4.03E+01	1.11E+00	0.00E+00	3.92E+01
Zinc	4.33E+02	0.00E+00	0.00E+00	4.33E+02
Zinc (+II)	6.23E+01	2.52E+00	0.00E+00	5.95E+01
Inorganic emissions to air				
Ammonia	1.69E+04	1.14E+03	0.00E+00	1.56E+04
Carbon dioxide	2.12E+09	1.12E+08	0.00E+00	2.01E+09
Hydrogen sulphide	1.44E+04	8.51E+01	0.00E+00	1.43E+04
Nitrogen dioxide	3.54E+01	3.64E+00	0.00E+00	3.15E+01
Nitrogen oxides	2.44E+06	2.78E+05	0.00E+00	2.16E+06
Phosphorus	1.18E+03	0.00E+00	0.00E+00	1.18E+03
Sulphur dioxide	3.16E+06	2.87E+05	0.00E+00	2.87E+06
Sulphur oxides	1.95E+06	5.04E+04	0.00E+00	1.90E+06
Organic emissions to air (group VOC)				
Group NMVOC to air	7.91E+05	2.40E+04	0.00E+00	7.66E+05
Hydrocarbons (unspecified)	1.23E+06	1.07E+04	0.00E+00	1.22E+06
Methane	4.43E+06	1.89E+05	0.00E+00	4.24E+06
VOC (unspecified)	7.08E+04	1.17E+04	0.00E+00	5.91E+04
Particles to air				
Dust (> PM10)	4.74E+03	7.05E+01	0.00E+00	4.66E+03
Dust (PM10)	5.00E+04	3.48E+03	0.00E+00	4.65E+04
Dust (PM2,5 - PM10)	8.56E+04	3.10E+03	0.00E+00	8.23E+04
Dust (PM2.5)	7.05E+04	3.45E+03	0.00E+00	6.69E+04
Dust (unspecified)	8.60E+04	2.02E+03	0.00E+00	8.40E+04
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	8.38E+04	9.00E+03	0.00E+00	7.48E+04
Chemical oxygen demand (COD)	4.74E+05	1.81E+04	0.00E+00	4.55E+05
Heavy metals to fresh water				
Arsenic	3.46E+02	0.00E+00	0.00E+00	3.46E+02
Arsenic (+V)	3.72E+03	4.27E+01	0.00E+00	3.67E+03
Cadmium	7.42E-04	0.00E+00	0.00E+00	7.42E-04
Cadmium (+II)	1.57E+03	1.54E+01	0.00E+00	1.55E+03
Chromium	7.14E+03	1.03E+02	0.00E+00	7.03E+03
Chromium (+III)	3.86E+00	1.94E+00	0.00E+00	1.77E+00
Chromium (+VI)	2.55E-01	1.65E-01	0.00E+00	8.99E-02
Copper	4.48E-03	0.00E+00	0.00E+00	4.48E-03
Copper (+II)	1.92E+03	2.45E+01	0.00E+00	1.89E+03
Lead	3.85E-03	0.00E+00	0.00E+00	3.85E-03
Lead (+II)	1.36E+03	3.46E+01	0.00E+00	1.33E+03
Nickel	3.06E-01	0.00E+00	0.00E+00	3.06E-01
Nickel (+II)	2.25E+03	3.57E+01	0.00E+00	2.21E+03
Zinc	2.06E-02	0.00E+00	0.00E+00	2.06E-02
Zinc (+II)	3.75E+02	2.77E+01	0.00E+00	3.47E+02
Inorganic emissions to fresh water				
Ammonia	4.92E+03	6.17E+02	0.00E+00	4.31E+03

Annex B. Selected LCI Emissions

Ammonium / ammonia	1.47E+02	4.97E+01	0.00E+00	9.67E+01
Barium	1.44E+05	1.48E+04	0.00E+00	1.29E+05
Nitrate	1.08E+04	3.51E+03	0.00E+00	7.07E+03
Nitrogen organic bounded	2.16E+04	2.59E+03	0.00E+00	1.88E+04
Phosphate	4.07E+03	6.12E+02	0.00E+00	3.41E+03
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	5.29E+00	4.81E-02	0.00E+00	5.24E+00
Anthracene	9.94E+00	9.10E-02	0.00E+00	9.84E+00
Benzene	1.25E+04	1.88E+02	0.00E+00	1.23E+04
Benzo{a}anthracene	5.92E-01	5.20E-03	0.00E+00	5.87E-01
Emissions to sea water				
Heavy metals to sea water				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	6.10E+02	5.33E+00	0.00E+00	6.04E+02
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	2.61E+02	2.28E+00	0.00E+00	2.58E+02
Chromium	9.54E+02	8.32E+00	0.00E+00	9.45E+02
Chromium (+VI)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	2.26E+02	1.98E+00	0.00E+00	2.24E+02
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.85E+02	1.62E+00	0.00E+00	1.83E+02
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	3.43E+02	3.00E+00	0.00E+00	3.40E+02
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	9.84E+00	8.69E-02	0.00E+00	9.75E+00
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	1.39E-08	3.76E-15	0.00E+00	1.39E-08
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.62E-01	1.08E-01	0.00E+00	3.46E-01
Chromium	-1.51E-02	-2.32E-04	0.00E+00	-1.48E-02
Chromium (+III)	5.80E+00	5.52E-02	0.00E+00	5.74E+00
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	5.07E+00	4.54E-02	0.00E+00	5.02E+00
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	8.24E+00	7.72E-02	0.00E+00	8.16E+00
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.84E+00	2.70E-02	0.00E+00	2.81E+00
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	2.15E+01	2.00E-01	0.00E+00	2.13E+01
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic (+V)	3.10E-05	3.38E-07	0.00E+00	3.06E-05
Cadmium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium (+II)	4.38E-02	4.04E-04	0.00E+00	4.34E-02
Chromium	1.55E-04	1.31E-06	0.00E+00	1.54E-04
Chromium (+III)	6.09E-05	4.74E-07	0.00E+00	6.03E-05
Chromium (+VI)	2.34E-07	5.37E-11	0.00E+00	2.34E-07
Copper	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper (+II)	8.34E-04	9.71E-06	0.00E+00	8.24E-04
Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead (+II)	1.26E-04	1.65E-06	0.00E+00	1.24E-04
Nickel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel (+II)	2.48E-03	2.16E-05	0.00E+00	2.46E-03
Zinc	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc (+II)	4.30E-04	4.63E-06	0.00E+00	4.25E-04

Annex C. Percentage Contribution to Impact Categories

kg SO2-Equiv.

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**7.57E+06**	**1.51E+06**	**7.38E+04**	**5.99E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.5%	0.0%	0.0%	0.4%
Carbon dioxide				
Hydrogen sulphide	0.4%	0.1%	0.0%	0.4%
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	23.8%	4.2%	0.5%	19.0%
Phosphorus				
Sulphur dioxide	54.1%	12.6%	0.0%	41.5%
Sulphur oxides	20.9%	2.9%	0.4%	17.5%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.2%	0.0%	0.0%	0.1%
Ammonium / ammonia	0.0%	0.0%	0.0%	0.0%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**7.48E+06**	**1.73E+06**	**4.26E+04**	**5.70E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.4%	0.0%	0.0%	0.4%
Carbon dioxide				
Hydrogen sulphide	0.4%	0.1%	0.0%	0.4%
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	23.5%	4.9%	0.3%	18.3%
Phosphorus				
Sulphur dioxide	55.1%	14.6%	0.0%	40.5%
Sulphur oxides	20.1%	3.4%	0.3%	16.4%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.2%	0.1%	0.0%	0.1%
Ammonium / ammonia	0.0%	0.0%	0.0%	0.0%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**5.40E+06**	**1.62E+06**		**3.77E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.6%	0.0%		0.6%
Carbon dioxide				
Hydrogen sulphide	0.5%	0.0%		0.5%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	27.1%	11.4%		15.6%
Phosphorus				
Sulphur dioxide	53.4%	0.4%		52.9%
Sulphur oxides	18.1%	18.1%		
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.2%	0.0%		0.2%
Ammonium / ammonia	0.0%	0.0%		0.0%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**7.51E+06**	**2.41E+06**		**5.09E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.4%	0.0%		0.4%
Carbon dioxide				
Hydrogen sulphide	0.4%	0.1%		0.4%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides				
Phosphorus				
Sulphur dioxide	62.0%	22.4%		39.6%
Sulphur oxides	14.0%	2.5%		11.5%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.2%	0.1%		0.1%
Ammonium / ammonia	0.0%	0.0%		0.0%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**6.90E+06**	**5.36E+05**		**6.36E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.5%	0.0%		0.4%
Carbon dioxide				
Hydrogen sulphide	0.4%	0.0%		0.4%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	24.8%	2.8%		21.9%
Phosphorus				
Sulphur dioxide	45.8%	4.2%		41.6%
Sulphur oxides	28.3%	0.7%		27.6%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.1%	0.0%		0.1%
Ammonium / ammonia	0.0%	0.0%		0.0%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**7.30E+06**	**1.69E+06**		**5.60E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.4%	0.1%		0.3%
Carbon dioxide				
Hydrogen sulphide	0.4%	0.1%		0.3%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	22.9%	3.1%		19.7%
Phosphorus				
Sulphur dioxide	46.4%	15.0%		31.4%
Sulphur oxides	29.6%	4.8%		24.8%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.1%	0.1%		0.1%
Ammonium / ammonia	0.0%	0.0%		0.0%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**8.21E+06**		**2.84E+05**	**7.92E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.5%		0.0%	0.5%
Carbon dioxide				
Hydrogen sulphide	0.4%		0.0%	0.4%
Nitrogen dioxide	0.0%		0.0%	0.0%
Nitrogen oxides	25.3%		1.9%	23.3%
Phosphorus				
Sulphur dioxide	47.8%		0.0%	47.8%
Sulphur oxides	25.7%		1.5%	24.1%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.1%		0.0%	0.1%
Ammonium / ammonia	0.0%		0.0%	0.0%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Acidification Potential	**7.35E+06**	**2.03E+06**		**5.31E+06**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.4%	0.0%		0.4%
Carbon dioxide				
Hydrogen sulphide	0.4%	0.1%		0.4%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	23.2%	5.8%		17.3%
Phosphorus				
Sulphur dioxide	56.6%	17.5%		39.0%
Sulphur oxides	19.0%	4.1%		14.9%
Emissions to fresh water				
Inorganic emissions to fresh water				
Ammonia	0.2%	0.1%		0.1%
Ammonium / ammonia	0.0%	0.0%		0.0%

Annex C. Percentage Contribution to Impact Categories

CTUe

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**4.36E+09**	**2.56E+08**	**3.34E+09**	**7.66E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%	0.0%	0.0%	0.0%
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.2%	0.2%	0.1%	0.0%
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Molybdenum	0.0%	0.0%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc	3.4%	2.1%	1.2%	0.1%
Zinc (+II)	0.0%	0.0%	0.0%	0.0%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%	0.0%	0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	0.3%	0.0%	0.0%	0.2%
Arsenic (+V)	4.0%	0.1%	0.0%	3.9%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.4%	0.0%	0.0%	0.4%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%	0.0%	0.0%
Copper	1.2%	0.0%	1.2%	0.0%
Copper (+II)	2.8%	0.1%	0.0%	2.7%
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.9%	0.0%	0.0%	0.9%
Zinc	21.7%	0.0%	21.7%	0.0%
Zinc (+II)	0.4%	0.1%	0.0%	0.3%
Inorganic emissions to fresh water				
Barium	6.6%	1.6%	0.0%	4.9%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.1%	0.0%	0.1%	0.0%
Anthracene	8.1%	0.0%	8.1%	0.1%
Benzene	0.0%	0.0%	0.0%	0.0%
Benzo{a}anthracene	24.0%	0.0%	24.0%	0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%

Annex C. Percentage Contribution to Impact Categories

CTUe

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.0%		0.0%	
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper	0.7%		0.7%	
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%		0.0%	
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%		0.0%	
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	11.9%		11.9%	
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**2.96E+09**	**2.94E+08**	**1.92E+09**	**7.36E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%	0.0%	0.0%	0.1%
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.3%	0.3%	0.1%	0.0%
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Molybdenum	0.0%	0.0%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc	4.8%	3.6%	1.0%	0.2%
Zinc (+II)	0.0%	0.0%	0.0%	0.0%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%	0.0%	0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	0.4%	0.1%	0.0%	0.3%
Arsenic (+V)	5.6%	0.1%	0.0%	5.5%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.6%	0.0%	0.0%	0.6%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%	0.0%	0.0%
Copper	1.1%	0.0%	1.1%	0.0%
Copper (+II)	4.0%	0.1%	0.0%	3.9%
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	1.3%	0.1%	0.0%	1.2%
Zinc	18.5%	0.0%	18.4%	0.0%
Zinc (+II)	0.6%	0.2%	0.0%	0.5%
Inorganic emissions to fresh water				
Barium	9.8%	2.8%	0.0%	7.0%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.1%	0.0%	0.1%	0.0%
Anthracene	7.0%	0.0%	6.9%	0.1%
Benzene	0.0%	0.0%	0.0%	0.0%
Benzo{a}anthracene	20.4%	0.0%	20.4%	0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.0%		0.0%	
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper	0.6%		0.6%	
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%		0.0%	
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%		0.0%	
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	10.1%		10.1%	
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**1.84E+09**	**1.18E+09**		**6.54E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%	0.1%		
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	3.3%	3.3%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	59.6%	59.6%		
Zinc (+II)	0.1%	0.0%		0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	0.3%	0.3%		
Arsenic (+V)	7.7%	0.1%		7.7%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.8%	0.0%		0.8%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	5.5%	0.1%		5.4%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	1.7%	0.0%		1.7%
Zinc	0.0%	0.0%		
Zinc (+II)	0.7%	0.0%		0.7%
Inorganic emissions to fresh water				
Barium	10.8%	0.0%		10.7%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.1%	0.0%		0.1%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene	0.0%	0.0%		0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO HPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**6.83E+08**	**2.89E+07**		**6.54E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.0%	0.0%		
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.1%	0.1%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	1.1%	1.1%		
Zinc (+II)	0.2%	0.0%		0.2%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	1.3%	1.3%		
Arsenic (+V)	20.8%	0.2%		20.6%
Cadmium	0.0%	0.0%		
Cadmium (+II)	2.1%	0.0%		2.1%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	14.7%	0.1%		14.5%
Lead	0.0%	0.0%		
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		
Nickel (+II)	4.6%	0.1%		4.6%
Zinc	0.0%	0.0%		
Zinc (+II)	1.9%	0.0%		1.9%
Inorganic emissions to fresh water				
Barium	28.9%	0.1%		28.8%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.4%	0.0%		0.4%
Benzene	0.1%	0.0%		0.1%
Benzo{a}anthracene	0.1%	0.0%		0.1%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO HPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.1%	0.0%		0.1%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO LPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**3.16E+09**	**2.51E+09**		**6.54E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%	0.1%		
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	3.8%	3.8%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	69.0%	69.0%		
Zinc (+II)	0.0%	0.0%		0.0%
Organic emissions to air (group VOC)				
Group NMVOC to air	2.2%	2.2%		0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	0.1%	0.1%		
Arsenic (+V)	4.5%	0.0%		4.4%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.5%	0.0%		0.5%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	3.2%	0.0%		3.1%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	1.0%	0.0%		1.0%
Zinc	0.0%	0.0%		
Zinc (+II)	0.4%	0.0%		0.4%
Inorganic emissions to fresh water				
Barium	6.2%	0.0%		6.2%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.1%	0.0%		0.1%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene	0.0%	0.0%		0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO LPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**9.74E+08**	**2.73E+08**		**7.01E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.2%	0.1%		0.1%
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.5%	0.5%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.1%	0.0%		0.1%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.6%	0.2%		0.3%
Zinc (+II)	0.1%	0.0%		0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.1%	0.0%		0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	1.0%	0.4%		0.7%
Arsenic (+V)	15.9%	0.4%		15.5%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	1.6%	0.0%		1.6%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	11.3%	0.3%		10.9%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	3.6%	0.1%		3.4%
Zinc	0.0%	0.0%		0.0%
Zinc (+II)	2.0%	0.6%		1.4%
Inorganic emissions to fresh water				
Barium	34.0%	13.1%		20.9%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.3%	0.0%		0.3%
Benzene	0.1%	0.0%		0.1%
Benzo{a}anthracene	0.0%	0.0%		0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**7.47E+08**	**4.80E+07**		**6.99E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.3%			0.3%
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%			0.0%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.1%			0.1%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%			0.0%
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.2%			0.2%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	1.0%			1.0%
Zinc (+II)	0.1%	0.0%		0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	1.9%			1.9%
Arsenic (+V)	20.1%	0.2%		19.9%
Cadmium	0.0%			0.0%
Cadmium (+II)	2.0%	0.0%		2.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%			0.0%
Copper (+II)	14.2%	0.2%		14.0%
Lead	0.0%			0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%			0.0%
Nickel (+II)	4.5%	0.1%		4.4%
Zinc	0.0%			0.0%
Zinc (+II)	1.9%	0.1%		1.8%
Inorganic emissions to fresh water				
Barium	29.4%	3.0%		26.4%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.3%	0.0%		0.3%
Benzene	0.1%	0.0%		0.1%
Benzo{a}anthracene	0.1%	0.0%		0.1%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.1%	0.0%		0.1%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**7.72E+08**	**1.61E+08**		**6.11E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.3%	0.0%		0.3%
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.1%	0.0%		0.1%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%			0.0%
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.2%	0.0%		0.2%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.9%	0.0%		0.9%
Zinc (+II)	0.1%	0.0%		0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Emissions to fresh water	74.0%	11.6%		62.3%
Heavy metals to fresh water	4.31E-01	1.45E-02		4.16E-01
Arsenic	1.7%	0.0%		1.7%
Arsenic (+V)	19.3%	0.4%		18.9%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	2.0%	0.0%		1.9%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	13.7%	0.4%		13.3%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	4.3%	0.1%		4.2%
Zinc	0.0%	0.0%		0.0%
Zinc (+II)	2.0%	0.5%		1.5%
Inorganic emissions to fresh water	3.04E-01	1.02E-01		2.02E-01
Barium	30.4%	10.2%		20.2%
Organic emissions to fresh water	5.07E-03	1.16E-04		4.96E-03
Hydrocarbons to fresh water	5.07E-03	1.16E-04		4.96E-03
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.3%	0.0%		0.3%
Benzene	0.1%	0.0%		0.1%
Benzo{a}anthracene	0.1%	0.0%		0.1%
Emissions to sea water	0.0%	0.0%		0.0%
Heavy metals to sea water	2.94E-22	3.11E-24		2.91E-22
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil	0.1%	0.0%		0.1%
Heavy metals to agricultural soil	8.40E-04	3.78E-05		8.02E-04
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.1%	0.0%		0.1%
Emissions to industrial soil	0.0%	0.0%		0.0%
Heavy metals to industrial soil	3.71E-07	3.56E-08		3.35E-07
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**1.38E+10**		**1.28E+10**	**9.65E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.0%		0.0%	0.0%
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium	0.0%		0.0%	0.0%
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)	0.0%		0.0%	0.0%
Chromium (+VI)	0.0%			0.0%
Copper	0.1%		0.1%	0.0%
Copper (+II)	0.0%		0.0%	0.0%
Lead	0.0%		0.0%	0.0%
Lead (+II)	0.0%		0.0%	0.0%
Molybdenum	0.0%		0.0%	0.0%
Nickel	0.0%		0.0%	0.0%
Nickel (+II)	0.0%		0.0%	0.0%
Zinc	1.5%		1.4%	0.1%
Zinc (+II)	0.0%		0.0%	0.0%
Group NMVOC to air	0.0%		0.0%	0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	0.1%		0.0%	0.1%
Arsenic (+V)	1.6%		0.0%	1.6%
Cadmium	0.0%		0.0%	0.0%
Cadmium (+II)	0.2%		0.0%	0.2%
Chromium				
Chromium (+III)	0.0%		0.0%	0.0%
Chromium (+VI)	0.0%		0.0%	0.0%
Copper	1.5%		1.5%	0.0%
Copper (+II)	1.1%		0.0%	1.1%
Lead	0.0%		0.0%	0.0%
Lead (+II)	0.0%		0.0%	0.0%
Nickel	0.0%		0.0%	0.0%
Nickel (+II)	0.3%		0.0%	0.3%
Zinc	26.3%		26.3%	0.0%
Zinc (+II)	0.1%		0.0%	0.1%
Inorganic emissions to fresh water				
Barium	2.0%		0.0%	1.9%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.2%		0.2%	0.0%
Anthracene	9.8%		9.8%	0.0%
Benzene	0.0%		0.0%	0.0%
Benzo{a}anthracene	29.2%		29.2%	0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)	0.0%		0.0%	0.0%
Lead				
Lead (+II)	0.0%		0.0%	0.0%
Nickel				
Nickel (+II)	0.0%		0.0%	0.0%
Zinc				
Zinc (+II)	0.0%		0.0%	0.0%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.0%		0.0%	
Arsenic (+V)	0.0%			0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%			0.0%
Chromium				
Chromium (+III)	0.0%			0.0%
Copper	0.8%		0.8%	
Copper (+II)	0.0%			0.0%
Lead	0.0%		0.0%	
Lead (+II)	0.0%			0.0%
Nickel	0.0%		0.0%	
Nickel (+II)	0.0%			0.0%
Zinc	14.4%		14.4%	
Zinc (+II)	0.0%			0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)	0.0%		0.0%	0.0%
Chromium (+VI)	0.0%			0.0%
Copper				
Copper (+II)	0.0%		0.0%	0.0%
Lead				
Lead (+II)	0.0%		0.0%	0.0%
Nickel				
Nickel (+II)	0.0%		0.0%	0.0%
Zinc				
Zinc (+II)	0.0%		0.0%	0.0%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ecotoxicity	**1.04E+09**	**3.46E+08**		**6.96E+08**
Emissions to air				
Heavy metals to air				
Arsenic	0.2%	0.0%		0.1%
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	1.0%	0.9%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.0%	0.0%		0.0%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.1%	0.0%		0.1%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	12.5%	12.1%		0.4%
Zinc (+II)	0.1%	0.0%		0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	1.0%	0.3%		0.8%
Arsenic (+V)	15.1%	0.3%		14.8%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	1.5%	0.0%		1.5%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.1%	0.1%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	10.8%	0.3%		10.4%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.1%	0.0%		0.0%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	3.5%	0.2%		3.3%
Zinc	0.0%	0.0%		0.0%
Zinc (+II)	1.8%	0.5%		1.3%
Inorganic emissions to fresh water				
Barium	28.1%	9.2%		18.9%
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.3%	0.0%		0.3%
Benzene	0.1%	0.0%		0.1%
Benzo{a}anthracene	0.0%	0.0%		0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Annex C. Percentage Contribution to Impact Categories

kg N-Equiv.

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**4.49E+05**	**4.94E+04**	**2.39E+05**	**1.61E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.5%	0.0%	0.0%	0.4%
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	25.4%	4.5%	0.6%	20.3%
Phosphorus	4.5%	2.8%	1.4%	0.2%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.2%	0.3%	0.0%	0.9%
Chemical oxygen demand (COD)	6.5%	0.8%	0.0%	5.7%
Inorganic emissions to fresh water				
Ammonia	1.1%	0.3%	0.0%	0.8%
Ammonium / ammonia	0.1%	0.0%	0.0%	0.0%
Barium				
Nitrate	0.6%	0.1%	0.0%	0.4%
Nitrogen organic bounded	4.9%	0.4%	0.0%	4.4%
Phosphate	2.3%	0.3%	0.0%	2.0%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**3.49E+05**	**5.67E+04**	**1.38E+05**	**1.54E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.6%	0.0%	0.0%	0.6%
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	31.9%	6.6%	0.4%	24.8%
Phosphorus	5.5%	4.2%	1.1%	0.2%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.6%	0.5%	0.0%	1.1%
Chemical oxygen demand (COD)	8.3%	1.2%	0.0%	7.1%
Inorganic emissions to fresh water				
Ammonia	1.5%	0.5%	0.0%	1.0%
Ammonium / ammonia	0.1%	0.1%	0.0%	0.0%
Barium				
Nitrate	0.8%	0.2%	0.0%	0.5%
Nitrogen organic bounded	6.2%	0.6%	0.0%	5.5%
Phosphate	2.9%	0.5%	0.0%	2.4%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**3.01E+05**	**1.85E+05**		**1.16E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.7%	0.0%		0.6%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	30.8%	13.0%		17.7%
Phosphorus	46.6%	46.6%		
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	1.2%	0.0%		1.2%
Chemical oxygen demand (COD)	7.4%	0.1%		7.3%
Inorganic emissions to fresh water				
Ammonia	1.1%	0.0%		1.1%
Ammonium / ammonia	0.0%	0.0%		0.0%
Barium				
Nitrate	0.8%	0.3%		0.5%
Nitrogen organic bounded	7.2%	0.8%		6.3%
Phosphate	3.3%	0.5%		2.8%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**1.91E+05**	**4.99E+04**		**1.40E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	1.1%	0.1%		1.0%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides				
Phosphorus	1.5%	1.2%		0.3%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	3.3%	1.3%		2.0%
Chemical oxygen demand (COD)	14.5%	2.3%		12.2%
Inorganic emissions to fresh water				
Ammonia	3.3%	1.4%		1.8%
Ammonium / ammonia	0.1%	0.0%		0.0%
Barium				
Nitrate	1.3%	0.4%		0.9%
Nitrogen organic bounded	11.6%	1.3%		10.2%
Phosphate	5.3%	0.8%		4.5%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**1.79E+05**	**1.94E+04**		**1.59E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	1.1%	0.1%		1.0%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	60.3%	6.9%		53.2%
Phosphorus	0.7%			0.7%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	2.3%	0.3%		2.1%
Chemical oxygen demand (COD)	13.2%	0.5%		12.7%
Inorganic emissions to fresh water				
Ammonia	2.1%	0.3%		1.9%
Ammonium / ammonia	0.1%	0.0%		0.0%
Barium				
Nitrate	1.4%	0.5%		0.9%
Nitrogen organic bounded	11.8%	1.4%		10.3%
Phosphate	5.4%	0.8%		4.5%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**1.70E+05**	**2.66E+04**		**1.43E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	1.0%	0.2%		0.8%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	62.0%	8.4%		53.4%
Phosphorus	0.7%			0.7%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	2.6%	0.9%		1.7%
Chemical oxygen demand (COD)	14.0%	1.7%		12.3%
Inorganic emissions to fresh water				
Ammonia	2.4%	1.0%		1.5%
Ammonium / ammonia	0.4%	0.3%		0.0%
Barium				
Nitrate	1.5%	0.5%		1.0%
Nitrogen organic bounded	9.4%	1.5%		7.7%
Phosphate	4.4%	0.9%		3.4%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**1.13E+06**		**9.18E+05**	**2.08E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%		0.0%	0.2%
Nitrogen dioxide	0.0%		0.0%	0.0%
Nitrogen oxides	11.7%		0.9%	10.8%
Phosphorus	2.3%		2.2%	0.1%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	0.5%		0.0%	0.5%
Chemical oxygen demand (COD)	2.9%		0.0%	2.9%
Inorganic emissions to fresh water				
Ammonia	0.4%		0.0%	0.4%
Ammonium / ammonia	0.0%		0.0%	0.0%
Barium				
Nitrate	0.2%		0.0%	0.2%
Nitrogen organic bounded	2.2%		0.0%	2.2%
Phosphate	1.0%		0.0%	1.0%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Eutrophication	**2.11E+05**	**6.67E+04**		**1.44E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	1.0%	0.1%		0.9%
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	51.0%	12.8%		38.0%
Phosphorus	8.5%	8.1%		0.4%
Emissions to fresh water				
Analytical measures to fresh water				
Biological oxygen demand (BOD)	2.7%	0.9%		1.8%
Chemical oxygen demand (COD)	13.3%	2.3%		11.0%
Inorganic emissions to fresh water				
Ammonia	2.5%	1.0%		1.6%
Ammonium / ammonia	0.1%	0.1%		0.0%
Barium				
Nitrate	1.3%	0.4%		0.8%
Nitrogen organic bounded	10.0%	1.2%		8.6%
Phosphate	4.8%	0.9%		3.8%

Annex C. Percentage Contribution to Impact Categories

kg CO2-Equiv.

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.79E+09**	**6.44E+08**	**3.44E+08**	**1.80E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	94.8%	22.4%	12.2%	60.1%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%	0.0%	0.0%
Hydrocarbons (unspecified)				
Methane	4.9%	0.6%	0.0%	4.2%
VOC (unspecified)				

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.64E+09**	**7.40E+08**	**1.98E+08**	**1.70E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	94.7%	27.2%	7.5%	59.9%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%	0.0%	0.0%
Hydrocarbons (unspecified)				
Methane	5.1%	0.8%	0.0%	4.3%
VOC (unspecified)				

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.20E+09**	**1.39E+09**		**8.05E+08**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	95.0%	63.0%		31.9%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane	4.7%	0.1%		4.6%
VOC (unspecified)				

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.56E+09**	**1.12E+09**		**1.43E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	94.3%	42.6%		51.6%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air				
Hydrocarbons (unspecified)				
Methane	5.4%	1.2%		4.2%
VOC (unspecified)				

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.24E+09**	**1.17E+08**		**2.12E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	94.8%	5.0%		89.7%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane	4.9%	0.2%		4.7%
VOC (unspecified)				

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.20E+09**	**2.97E+08**		**1.90E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	94.5%	12.6%		81.8%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane	5.2%	0.9%		4.3%
VOC (unspecified)				

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**3.80E+09**		**1.32E+09**	**2.47E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	95.7%		34.6%	61.0%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%		0.0%	0.0%
Hydrocarbons (unspecified)				
Methane	4.0%		0.1%	3.9%
VOC (unspecified)				

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Global Warming Air	**2.44E+09**	**8.71E+08**		**1.57E+09**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide	94.4%	34.7%		59.6%
Hydrogen sulphide				
Nitrogen dioxide				
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane	5.4%	1.0%		4.4%
VOC (unspecified)				

Annex C. Percentage Contribution to Impact Categories

kg PM2,5-Equiv.

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**5.68E+05**	**1.31E+05**	**4.92E+04**	**3.87E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%	0.0%	0.0%	0.2%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	3.3%	0.6%	0.1%	2.6%
Phosphorus				
Sulphur dioxide	44.1%	10.2%	0.0%	33.8%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.3%	0.1%		0.2%
Dust (PM10)	5.2%	2.2%	1.7%	1.3%
Dust (PM2,5 - PM10)	16.7%	0.6%		16.1%
Dust (PM2.5)	22.1%	6.0%	4.7%	11.3%
Dust (unspecified)	8.0%	3.2%	2.1%	2.6%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**5.51E+05**	**1.50E+05**	**2.84E+04**	**3.71E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%	0.0%	0.0%	0.2%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	3.3%	0.7%	0.0%	2.6%
Phosphorus				
Sulphur dioxide	45.8%	12.1%	0.0%	33.6%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.3%	0.1%		0.2%
Dust (PM10)	4.9%	2.6%	1.0%	1.2%
Dust (PM2,5 - PM10)	16.7%	0.7%		16.0%
Dust (PM2.5)	21.1%	7.2%	2.8%	11.1%
Dust (unspecified)	7.6%	3.8%	1.3%	2.5%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**9.50E+05**	**6.36E+05**		**3.14E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.1%	0.0%		0.1%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	1.6%	0.7%		0.9%
Phosphorus				
Sulphur dioxide	18.5%	0.1%		18.4%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.1%	0.0%		0.1%
Dust (PM10)	13.2%	13.2%		0.0%
Dust (PM2,5 - PM10)	8.7%	0.1%		8.6%
Dust (PM2.5)	40.9%	36.4%		4.5%
Dust (unspecified)	16.8%	16.4%		0.4%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**4.87E+05**	**1.35E+05**		**3.52E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%	0.0%		0.2%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides				
Phosphorus				
Sulphur dioxide	58.3%	21.1%		37.2%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.2%	0.0%		0.2%
Dust (PM10)				
Dust (PM2,5 - PM10)				
Dust (PM2.5)	13.2%	1.8%		11.4%
Dust (unspecified)	4.3%	2.0%		2.2%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**4.01E+05**	**2.75E+04**		**3.72E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.3%	0.0%		0.3%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	4.4%	0.5%		3.9%
Phosphorus				
Sulphur dioxide	48.2%	4.4%		43.8%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.3%	0.0%		0.3%
Dust (PM10)	2.8%	0.2%		2.6%
Dust (PM2,5 - PM10)	21.4%	0.8%		20.6%
Dust (PM2.5)	17.6%	0.9%		16.7%
Dust (unspecified)	4.9%	0.1%		4.8%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**3.98E+05**	**8.62E+04**		**3.12E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%	0.0%		0.2%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	4.3%	0.6%		3.7%
Phosphorus				
Sulphur dioxide	51.9%	16.8%		35.1%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.3%	0.0%		0.3%
Dust (PM10)	2.9%	0.3%		2.5%
Dust (PM2,5 - PM10)	18.4%	0.9%		17.5%
Dust (PM2.5)	15.9%	1.4%		14.4%
Dust (unspecified)	5.9%	1.6%		4.4%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**6.83E+05**		**1.89E+05**	**4.93E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%		0.0%	0.2%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%		0.0%	0.0%
Nitrogen oxides	3.1%		0.2%	2.9%
Phosphorus				
Sulphur dioxide	35.1%		0.0%	35.1%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.2%			0.2%
Dust (PM10)	7.1%		5.5%	1.6%
Dust (PM2,5 - PM10)	16.8%			16.7%
Dust (PM2.5)	27.4%		15.1%	12.3%
Dust (unspecified)	10.0%		6.9%	3.1%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human Health Particulate Air	**5.27E+05**	**1.77E+05**		**3.50E+05**
Emissions to air				
Inorganic emissions to air				
Ammonia	0.2%	0.0%		0.2%
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	3.3%	0.8%		2.5%
Phosphorus				
Sulphur dioxide	48.2%	14.9%		33.3%
Sulphur oxides				
Particles to air				
Dust (> PM10)	0.3%	0.1%		0.2%
Dust (PM10)	4.4%	3.2%		1.2%
Dust (PM2,5 - PM10)	16.7%	0.9%		15.8%
Dust (PM2.5)	19.6%	8.8%		10.8%
Dust (unspecified)	7.1%	4.7%		2.4%

Annex C. Percentage Contribution to Impact Categories

CTUh

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**2.78E+00**	**3.43E-01**	**5.04E-01**	**1.94E+00**
Emissions to air				
Heavy metals to air				
Arsenic	1.6%	0.3%	0.0%	1.2%
Arsenic (+V)	0.1%	0.0%	0.0%	0.1%
Cadmium	0.2%	0.0%	0.0%	0.2%
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.3%	0.1%	0.1%	0.1%
Lead (+II)	0.2%	0.0%	0.0%	0.2%
Molybdenum				
Nickel	0.3%	0.1%	0.0%	0.3%
Nickel (+II)	0.1%	0.0%	0.0%	0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	5.4%	2.5%	1.3%	1.5%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	4.3%	0.7%	0.4%	3.2%
Arsenic (+V)	56.5%	0.8%	0.0%	55.6%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.1%	0.0%	0.0%	0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	1.7%	1.6%	0.0%	0.0%
Copper				
Copper (+II)				
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel	0.1%	0.0%	0.1%	0.0%
Nickel (+II)	3.6%	0.1%	0.0%	3.5%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.1%	0.0%	0.0%	0.1%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.8%	0.0%	0.0%	0.8%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.1%	0.0%	0.0%	0.1%
Zinc				

Annex C. Percentage Contribution to Impact Categories

CTUh

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.4%		0.4%	
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.1%		0.1%	
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead	1.5%		1.5%	
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.3%		0.3%	
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)				

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**2.54E+00**	**3.94E-01**	**2.91E-01**	**1.85E+00**
Emissions to air				
Heavy metals to air				
Arsenic	1.6%	0.3%	0.0%	1.3%
Arsenic (+V)	0.1%	0.0%	0.0%	0.1%
Cadmium	0.2%	0.0%	0.0%	0.2%
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.3%	0.2%	0.0%	0.1%
Lead (+II)	0.2%	0.0%	0.0%	0.2%
Molybdenum				
Nickel	0.4%	0.1%	0.0%	0.3%
Nickel (+II)	0.1%	0.0%	0.0%	0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	5.6%	3.1%	0.8%	1.6%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	4.4%	0.9%	0.2%	3.3%
Arsenic (+V)	59.7%	1.0%	0.0%	58.6%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.1%	0.0%	0.0%	0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	2.1%	2.1%	0.0%	0.0%
Copper				
Copper (+II)				
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel	0.1%	0.0%	0.1%	0.0%
Nickel (+II)	3.8%	0.2%	0.0%	3.7%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.1%	0.0%	0.0%	0.1%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.8%	0.0%	0.0%	0.8%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.1%	0.0%	0.0%	0.1%
Zinc				

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.2%		0.2%	
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead	0.9%		0.9%	
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.2%		0.2%	
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)				

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**1.77E+00**	**3.35E-01**		**1.44E+00**
Emissions to air				
Heavy metals to air				
Arsenic	1.3%	1.3%		
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.1%	0.1%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	2.2%	2.2%		
Lead (+II)	0.2%	0.0%		0.2%
Molybdenum				
Nickel	0.3%	0.3%		
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	10.9%	10.2%		0.7%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	3.3%	3.3%		
Arsenic (+V)	73.2%	0.7%		72.4%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.1%	0.0%		0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	4.6%	0.1%		4.5%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.2%	0.0%		0.2%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	1.0%	0.0%		1.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				

Extreme RFO HPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**1.54E+00**	**1.02E-01**		**1.44E+00**
Emissions to air				
Heavy metals to air				
Arsenic	0.0%	0.0%		
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.0%	0.0%		
Lead (+II)	0.3%	0.0%		0.2%
Molybdenum				
Nickel	0.0%	0.0%		
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	1.1%	0.3%		0.8%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	5.4%	5.4%		
Arsenic (+V)	84.2%	0.8%		83.4%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.2%	0.0%		0.2%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	5.3%	0.1%		5.2%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.2%	0.0%		0.2%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	1.1%	0.0%		1.1%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				

Extreme RFO HPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				

Extreme RFO LPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**4.80E+00**	**3.36E+00**		**1.44E+00**
Emissions to air				
Heavy metals to air				
Arsenic	0.9%	0.9%		
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.1%	0.1%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead	1.6%	1.6%		
Lead (+II)	0.1%	0.0%		0.1%
Molybdenum				
Nickel	0.2%	0.2%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	33.2%	33.0%		0.3%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	0.7%	0.7%		
Arsenic (+V)	27.0%	0.2%		26.8%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	1.7%	0.0%		1.7%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.1%	0.0%		0.1%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.4%	0.0%		0.4%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				

Extreme RFO LPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**1.91E+00**	**2.33E-01**		**1.67E+00**
Emissions to air				
Heavy metals to air				
Arsenic	1.9%	0.7%		1.2%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.2%	0.1%		0.1%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.2%	0.1%		0.1%
Copper				
Copper (+II)				
Lead	0.2%	0.1%		0.1%
Lead (+II)	0.2%	0.0%		0.2%
Molybdenum				
Nickel	0.4%	0.1%		0.3%
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	8.1%	6.4%		1.7%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	4.9%	1.9%		3.0%
Arsenic (+V)	74.1%	1.8%		72.2%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.1%	0.0%		0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	4.7%	0.2%		4.5%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.2%	0.0%		0.2%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	1.0%	0.0%		1.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**1.84E+00**	**2.90E-02**		**1.81E+00**
Emissions to air				
Heavy metals to air				
Arsenic	2.7%			2.7%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.3%			0.3%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.0%		0.1%
Copper				
Copper (+II)				
Lead	0.3%			0.3%
Lead (+II)	0.2%	0.0%		0.2%
Molybdenum				
Nickel	0.6%			0.6%
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	3.4%	0.5%		3.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	6.9%			6.9%
Arsenic (+V)	74.5%	0.9%		73.6%
Cadmium	0.0%			0.0%
Cadmium (+II)	0.1%	0.0%		0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.1%		0.1%
Copper				
Copper (+II)				
Lead	0.0%			0.0%
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%			0.0%
Nickel (+II)	4.7%	0.1%		4.6%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.2%	0.0%		0.2%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	1.0%	0.0%		1.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**1.88E+00**	**1.18E-01**		**1.76E+00**
Emissions to air				
Heavy metals to air				
Arsenic	2.5%	0.0%		2.5%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.3%	0.0%		0.3%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.2%	0.1%		0.1%
Copper				
Copper (+II)				
Lead	0.3%			0.3%
Lead (+II)	0.2%	0.0%		0.2%
Molybdenum				
Nickel	0.6%	0.0%		0.6%
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	3.8%	1.1%		2.7%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water	84.2%	2.2%		82.0%
Heavy metals to fresh water	8.41E-01	2.15E-02		8.19E-01
Arsenic	6.5%	0.0%		6.5%
Arsenic (+V)	72.3%	1.5%		70.8%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.1%	0.0%		0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.5%	0.5%		0.0%
Copper				
Copper (+II)				
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	4.5%	0.1%		4.4%
Zinc				
Zinc (+II)				
Organic emissions to fresh water	1.60E-03	5.45E-05		1.55E-03
Hydrocarbons to fresh water	1.60E-03	5.45E-05		1.55E-03
Acenaphthene				
Anthracene				
Benzene	0.2%	0.0%		0.2%
Benzo{a}anthracene				
Emissions to sea water	1.1%	0.0%		1.0%
Heavy metals to sea water	1.05E-02	1.07E-04		1.04E-02
Arsenic				
Arsenic (+V)	1.0%	0.0%		1.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.1%	0.0%		0.1%
Zinc				

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil	0.1%	0.0%		0.1%
Heavy metals to agricultural soil	6.26E-04	5.62E-05		5.67E-04
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil	0.0%	0.0%		0.0%
Heavy metals to industrial soil	1.14E-05	3.00E-07		1.11E-05
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)				

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**4.43E+00**		**1.94E+00**	**2.49E+00**
Emissions to air				
Heavy metals to air				
Arsenic	1.3%		0.1%	1.2%
Arsenic (+V)	0.1%		0.0%	0.1%
Cadmium	0.1%		0.0%	0.1%
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%			0.1%
Copper				
Copper (+II)				
Lead	0.3%		0.2%	0.1%
Lead (+II)	0.1%		0.0%	0.1%
Molybdenum				
Nickel	0.3%		0.0%	0.3%
Nickel (+II)	0.1%		0.0%	0.1%
Zinc				
Zinc (+II)				
Group NMVOC to air	4.6%		3.2%	1.4%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	3.9%		0.9%	3.0%
Arsenic (+V)	44.2%		0.0%	44.2%
Cadmium	0.0%		0.0%	0.0%
Cadmium (+II)	0.1%		0.0%	0.1%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%		0.0%	0.0%
Copper				
Copper (+II)				
Lead	0.0%		0.0%	0.0%
Lead (+II)	0.0%		0.0%	0.0%
Nickel	0.3%		0.3%	0.0%
Nickel (+II)	2.8%		0.0%	2.8%
Zinc				
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				
Anthracene				
Benzene	0.1%		0.0%	0.1%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.6%		0.0%	0.6%
Cadmium				
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+VI)				
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%		0.0%	0.0%
Nickel				
Nickel (+II)	0.0%		0.0%	0.0%
Zinc				

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.9%		0.9%	
Arsenic (+V)	0.0%			0.0%
Cadmium	0.1%		0.1%	
Cadmium (+II)	0.0%			0.0%
Chromium				
Chromium (+III)				
Copper				
Copper (+II)				
Lead	3.5%		3.5%	
Lead (+II)	0.0%			0.0%
Nickel	0.8%		0.8%	
Nickel (+II)	0.0%			0.0%
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%			0.0%
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%		0.0%	0.0%
Nickel				
Nickel (+II)	0.0%		0.0%	0.0%
Zinc				
Zinc (+II)				

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, cancer	**2.21E+00**	**4.64E-01**		**1.74E+00**
Emissions to air				
Heavy metals to air				
Arsenic	1.8%	0.5%		1.3%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.2%	0.0%		0.2%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)				
Chromium (+VI)	0.1%	0.1%		0.1%
Copper				
Copper (+II)				
Lead	0.4%	0.2%		0.1%
Lead (+II)	0.2%	0.0%		0.2%
Molybdenum				0.3%
Nickel	0.4%	0.1%		0.1%
Nickel (+II)	0.1%	0.0%		
Zinc				
Zinc (+II)				
Organic emissions to air (group VOC)				
Group NMVOC to air	5.9%	4.2%		
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Heavy metals to fresh water				
Arsenic	4.5%	1.2%		
Arsenic (+V)	65.2%	1.4%		
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.1%	0.0%		0.0%
Chromium				0.0%
Chromium (+III)				4.0%
Chromium (+VI)	2.8%	2.8%		
Copper				
Copper (+II)				0.9%
Lead	0.0%	0.0%		0.9%
Lead (+II)	0.0%	0.0%		
Nickel	0.0%	0.0%		0.9%
Nickel (+II)	4.2%	0.2%		
Zinc				0.0%
Zinc (+II)				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene				0.1%
Anthracene				0.1%
Benzene	0.1%	0.0%		
Benzo{a}anthracene				0.0%
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.9%	0.0%		
Cadmium				
Cadmium (+II)	0.0%	0.0%		
Chromium				
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)				0.0%
Lead				
Lead (+II)	0.0%	0.0%		
Nickel				0.0%
Nickel (+II)	0.1%	0.0%		0.0%
Zinc				

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Zinc (+II)				0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		
Cadmium				0.0%
Cadmium (+II)	0.0%	0.0%		
Chromium				
Chromium (+III)				
Copper				0.0%
Copper (+II)				
Lead				0.0%
Lead (+II)	0.0%	0.0%		
Nickel				
Nickel (+II)	0.0%	0.0%		
Zinc				
Zinc (+II)				
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		
Cadmium				
Cadmium (+II)	0.0%	0.0%		
Chromium				
Chromium (+III)				
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)				
Lead				
Lead (+II)	0.0%	0.0%		
Nickel				
Nickel (+II)	0.0%	0.0%		
Zinc				
Zinc (+II)				

Annex C. Percentage Contribution to Impact Categories

CTUh

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**1.44E+03**	**9.89E+01**	**1.18E+03**	**1.61E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.2%	0.0%	0.0%	0.1%
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium	0.1%	0.0%	0.0%	0.1%
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%	0.0%	0.0%
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead	0.2%	0.1%	0.0%	0.1%
Lead (+II)	0.1%	0.0%	0.0%	0.1%
Molybdenum	0.1%	0.1%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc	9.6%	6.0%	3.3%	0.3%
Zinc (+II)	0.1%	0.0%	0.0%	0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%	0.0%	0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	0.6%	0.1%	0.1%	0.5%
Arsenic (+V)	8.1%	0.1%	0.0%	8.0%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.1%	0.0%	0.0%	0.1%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%	0.0%	0.0%
Copper	0.0%	0.0%	0.0%	0.0%
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc	2.2%	0.0%	2.2%	0.0%
Zinc (+II)	0.0%	0.0%	0.0%	0.0%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	1.3%	0.3%	0.0%	1.0%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%	0.0%	0.0%
Anthracene	0.0%	0.0%	0.0%	0.0%
Benzene	0.0%	0.0%	0.0%	0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.1%	0.0%	0.0%	0.1%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				

Annex C. Percentage Contribution to Impact Categories

CTUh

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.1%		0.1%	
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper	0.0%		0.0%	
Copper (+II)	0.0%	0.0%		0.0%
Lead	1.0%		1.0%	
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%		0.0%	
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	74.0%		74.0%	
Zinc (+II)	0.1%	0.0%		0.1%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**9.48E+02**	**1.14E+02**	**6.81E+02**	**1.54E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.2%	0.0%	0.0%	0.2%
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium	0.1%	0.0%	0.0%	0.1%
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%	0.0%	0.0%
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead	0.3%	0.2%	0.0%	0.1%
Lead (+II)	0.2%	0.0%	0.0%	0.2%
Molybdenum	0.1%	0.1%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc	13.8%	10.5%	2.9%	0.5%
Zinc (+II)	0.1%	0.0%	0.0%	0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%	0.0%	0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	0.9%	0.2%	0.0%	0.6%
Arsenic (+V)	11.8%	0.2%	0.0%	11.6%
Cadmium	0.0%	0.0%	0.0%	0.0%
Cadmium (+II)	0.1%	0.0%	0.0%	0.1%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%	0.0%	0.0%
Copper	0.0%	0.0%	0.0%	0.0%
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead	0.0%	0.0%	0.0%	0.0%
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel	0.0%	0.0%	0.0%	0.0%
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc	1.9%	0.0%	1.9%	0.0%
Zinc (+II)	0.1%	0.0%	0.0%	0.1%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	2.0%	0.6%	0.0%	1.4%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%	0.0%	0.0%
Anthracene	0.0%	0.0%	0.0%	0.0%
Benzene	0.0%	0.0%	0.0%	0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.2%	0.0%	0.0%	0.2%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.0%		0.0%	
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper	0.0%		0.0%	
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.9%		0.9%	
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%		0.0%	
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	64.9%		64.9%	
Zinc (+II)	0.1%	0.0%		0.1%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%	0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%	0.0%	0.0%
Chromium				
Chromium (+III)	0.0%	0.0%	0.0%	0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%	0.0%	0.0%
Lead				
Lead (+II)	0.0%	0.0%	0.0%	0.0%
Nickel				
Nickel (+II)	0.0%	0.0%	0.0%	0.0%
Zinc				
Zinc (+II)	0.0%	0.0%	0.0%	0.0%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**1.17E+03**	**1.05E+03**		**1.18E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%	0.1%		
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	1.2%	1.2%		
Lead (+II)	0.1%	0.0%		0.1%
Molybdenum	0.8%	0.8%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	87.1%	87.1%		
Zinc (+II)	0.1%	0.0%		0.1%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	0.4%	0.4%		
Arsenic (+V)	8.2%	0.1%		8.1%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.1%	0.0%		0.1%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%	0.0%		
Zinc (+II)	0.0%	0.0%		0.0%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	1.1%	0.0%		1.1%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.1%	0.0%		0.1%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO HPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**1.34E+02**	**1.58E+01**		**1.18E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.0%	0.0%		
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.1%	0.1%		
Lead (+II)	1.0%	0.0%		1.0%
Molybdenum	0.1%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	5.1%	5.1%		
Zinc (+II)	0.7%	0.0%		0.7%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	4.6%	4.6%		
Arsenic (+V)	71.8%	0.7%		71.1%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.5%	0.0%		0.5%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%	0.0%		
Zinc (+II)	0.3%	0.0%		0.3%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	9.5%	0.0%		9.5%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	1.0%	0.0%		1.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme RFO HPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.2%	0.0%		0.2%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.7%	0.0%		0.7%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RFO LPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**2.20E+03**	**2.09E+03**		**1.18E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%	0.1%		
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	1.2%	1.2%		
Lead (+II)	0.1%	0.0%		0.1%
Molybdenum	0.9%	0.9%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	92.0%	92.0%		
Zinc (+II)	0.0%	0.0%		0.0%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	0.1%	0.1%		
Arsenic (+V)	4.4%	0.0%		4.3%
Cadmium	0.0%	0.0%		
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		
Lead (+II)	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%	0.0%		
Zinc (+II)	0.0%	0.0%		0.0%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	0.6%	0.0%		0.6%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme RFO LPC	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**1.59E+02**	**2.00E+01**		**1.39E+02**
Emissions to air				
Heavy metals to air				
Arsenic	1.1%	0.4%		0.7%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.5%	0.2%		0.4%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.8%	0.2%		0.5%
Lead (+II)	0.9%	0.0%		0.9%
Molybdenum	0.2%	0.2%		0.0%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	3.3%	1.4%		1.9%
Zinc (+II)	0.6%	0.0%		0.6%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	4.3%	1.6%		2.7%
Arsenic (+V)	65.7%	1.6%		64.0%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.4%	0.0%		0.4%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%	0.0%		0.0%
Zinc (+II)	0.4%	0.1%		0.3%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	13.4%	5.1%		8.2%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.9%	0.0%		0.9%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.1%	0.0%		0.1%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.6%	0.0%		0.6%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**1.56E+02**	**2.89E+00**		**1.53E+02**
Emissions to air				
Heavy metals to air				
Arsenic	1.6%			1.6%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.8%			0.8%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%			0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	1.2%			1.2%
Lead (+II)	0.9%	0.0%		0.9%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.0%			0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	4.3%			4.3%
Zinc (+II)	0.6%	0.0%		0.6%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	6.0%			6.0%
Arsenic (+V)	65.0%	0.7%		64.2%
Cadmium	0.0%			0.0%
Cadmium (+II)	0.4%	0.0%		0.4%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%			0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%			0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%			0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%			0.0%
Zinc (+II)	0.3%	0.0%		0.3%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	9.0%	0.9%		8.1%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.9%	0.0%		0.9%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.1%	0.0%		0.1%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.6%	0.0%		0.6%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**1.55E+02**	**8.67E+00**		**1.46E+02**
Emissions to air				
Heavy metals to air				
Arsenic	1.5%	0.0%		1.5%
Arsenic (+V)	0.1%	0.0%		0.1%
Cadmium	0.8%	0.0%		0.8%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	1.1%			1.1%
Lead (+II)	0.9%	0.0%		0.9%
Molybdenum	0.0%	0.0%		0.0%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	4.4%	0.2%		4.2%
Zinc (+II)	0.5%	0.0%		0.4%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water	81.5%	4.7%		76.7%
Chemical oxygen demand (COD)				
Heavy metals to fresh water	7.17E-01	1.45E-02		7.02E-01
Arsenic	5.8%	0.0%		5.8%
Arsenic (+V)	65.0%	1.3%		63.7%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.4%	0.0%		0.4%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%	0.0%		0.0%
Zinc (+II)	0.3%	0.1%		0.2%
Inorganic emissions to fresh water	9.73E-02	3.26E-02		6.47E-02
Ammonia				
Ammonium / ammonia				
Barium	9.7%	3.3%		6.5%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water	4.95E-06	1.68E-07		4.78E-06
Hydrocarbons to fresh water	4.95E-06	1.68E-07		4.78E-06
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water	0.9%	0.0%		0.9%
Heavy metals to sea water	9.15E-03	9.26E-05		9.05E-03
Arsenic				
Arsenic (+V)	0.9%	0.0%		0.9%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil	0.8%	0.0%		0.8%
Heavy metals to agricultural soil	8.05E-03	4.52E-04		7.58E-03
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.1%	0.0%		0.1%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.6%	0.0%		0.6%
Emissions to industrial soil	0.0%	0.0%		0.0%
Heavy metals to industrial soil	3.68E-05	8.64E-07		3.59E-05
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**4.75E+03**		**4.54E+03**	**2.08E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.1%		0.0%	0.1%
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium	0.0%		0.0%	0.0%
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)	0.0%		0.0%	0.0%
Chromium (+VI)	0.0%			0.0%
Copper	0.0%		0.0%	0.0%
Copper (+II)	0.0%		0.0%	0.0%
Lead	0.1%		0.1%	0.0%
Lead (+II)	0.0%		0.0%	0.0%
Molybdenum	0.0%		0.0%	0.0%
Nickel	0.0%		0.0%	0.0%
Nickel (+II)	0.0%		0.0%	0.0%
Zinc	4.0%		3.8%	0.1%
Zinc (+II)	0.0%		0.0%	0.0%
Group NMVOC to air	0.0%		0.0%	0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	0.3%		0.1%	0.2%
Arsenic (+V)	3.1%		0.0%	3.1%
Cadmium	0.0%		0.0%	0.0%
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)	0.0%		0.0%	0.0%
Chromium (+VI)	0.0%		0.0%	0.0%
Copper	0.0%		0.0%	0.0%
Copper (+II)	0.0%		0.0%	0.0%
Lead	0.0%		0.0%	0.0%
Lead (+II)	0.0%		0.0%	0.0%
Nickel	0.0%		0.0%	0.0%
Nickel (+II)	0.0%		0.0%	0.0%
Zinc	2.5%		2.5%	0.0%
Zinc (+II)	0.0%		0.0%	0.0%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	0.4%		0.0%	0.4%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%		0.0%	0.0%
Anthracene	0.0%		0.0%	0.0%
Benzene	0.0%		0.0%	0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)				
Copper				
Copper (+II)	0.0%		0.0%	0.0%
Lead				
Lead (+II)	0.0%		0.0%	0.0%
Nickel				
Nickel (+II)	0.0%		0.0%	0.0%
Zinc				
Zinc (+II)	0.0%		0.0%	0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic	0.1%		0.1%	
Arsenic (+V)	0.0%			0.0%
Cadmium	0.0%		0.0%	
Cadmium (+II)	0.0%			0.0%
Chromium				
Chromium (+III)	0.0%			0.0%
Copper	0.0%		0.0%	
Copper (+II)	0.0%			0.0%
Lead	1.2%		1.2%	
Lead (+II)	0.0%			0.0%
Nickel	0.0%		0.0%	
Nickel (+II)	0.0%			0.0%
Zinc	86.4%		86.4%	
Zinc (+II)	0.0%			0.0%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%		0.0%	0.0%
Cadmium				
Cadmium (+II)	0.0%		0.0%	0.0%
Chromium				
Chromium (+III)	0.0%		0.0%	0.0%
Chromium (+VI)	0.0%			0.0%
Copper				
Copper (+II)	0.0%		0.0%	0.0%
Lead				
Lead (+II)	0.0%		0.0%	0.0%
Nickel				
Nickel (+II)	0.0%		0.0%	0.0%
Zinc				
Zinc (+II)	0.0%		0.0%	0.0%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Human toxicity, non-cancer	**2.78E+02**	**1.34E+02**		**1.45E+02**
Emissions to air				
Heavy metals to air				
Arsenic	0.7%	0.2%		0.5%
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium	0.3%	0.1%		0.3%
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	1.0%	0.6%		0.4%
Lead (+II)	0.5%	0.0%		0.5%
Molybdenum	0.5%	0.5%		0.0%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	43.4%	42.0%		1.4%
Zinc (+II)	0.4%	0.0%		0.3%
Organic emissions to air (group VOC)				
Group NMVOC to air	0.0%	0.0%		0.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				
Emissions to fresh water				
Chemical oxygen demand (COD)				
Heavy metals to fresh water				
Arsenic	2.7%	0.7%		2.0%
Arsenic (+V)	38.3%	0.8%		37.4%
Cadmium	0.0%	0.0%		0.0%
Cadmium (+II)	0.3%	0.0%		0.2%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper	0.0%	0.0%		0.0%
Copper (+II)	0.0%	0.0%		0.0%
Lead	0.0%	0.0%		0.0%
Lead (+II)	0.1%	0.0%		0.1%
Nickel	0.0%	0.0%		0.0%
Nickel (+II)	0.0%	0.0%		0.0%
Zinc	0.0%	0.0%		0.0%
Zinc (+II)	0.2%	0.1%		0.2%
Inorganic emissions to fresh water				
Ammonia				
Ammonium / ammonia				
Barium	6.8%	2.2%		4.6%
Nitrate				
Nitrogen organic bounded				
Phosphate				
Organic emissions to fresh water				
Hydrocarbons to fresh water				
Acenaphthene	0.0%	0.0%		0.0%
Anthracene	0.0%	0.0%		0.0%
Benzene	0.0%	0.0%		0.0%
Benzo{a}anthracene				
Emissions to sea water				
Heavy metals to sea water				
Arsenic				
Arsenic (+V)	0.5%	0.0%		0.5%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Chromium (+VI)	0.0%	0.0%		
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%
Emissions to agricultural soil				
Heavy metals to agricultural soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.1%	0.0%		0.1%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.4%	0.0%		0.3%
Emissions to industrial soil				
Heavy metals to industrial soil				
Arsenic				
Arsenic (+V)	0.0%	0.0%		0.0%
Cadmium				
Cadmium (+II)	0.0%	0.0%		0.0%
Chromium				
Chromium (+III)	0.0%	0.0%		0.0%
Chromium (+VI)	0.0%	0.0%		0.0%
Copper				
Copper (+II)	0.0%	0.0%		0.0%
Lead				
Lead (+II)	0.0%	0.0%		0.0%
Nickel				
Nickel (+II)	0.0%	0.0%		0.0%
Zinc				
Zinc (+II)	0.0%	0.0%		0.0%

Annex C. Percentage Contribution to Impact Categories

kg CFC 11-Equiv.

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**3.75E-02**	**2.25E-02**	**6.53E-07**	**1.49E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	43.0%	3.8%	0.0%	39.2%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**4.02E-02**	**2.59E-02**	**3.77E-07**	**1.43E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	39.2%	4.1%	0.0%	35.0%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**1.26E-02**	**2.10E-04**		**1.24E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	98.3%	1.6%		96.5%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**1.44E-02**	**1.10E-03**		**1.33E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	97.4%	6.6%		90.7%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**1.33E-02**	**1.99E-04**		**1.31E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	98.3%	1.4%		96.8%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**1.41E-02**	**1.32E-03**		**1.28E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	97.9%	8.5%		89.4%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**1.88E-02**		**2.51E-06**	**1.88E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	98.5%		0.0%	98.4%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Ozone Depletion Air	**4.40E-02**	**3.05E-02**		**1.35E-02**
Emissions to air				
Organic emissions to air (group VOC)				
Group NMVOC to air	34.7%	4.4%		30.3%
Hydrocarbons (unspecified)				
Methane				
VOC (unspecified)				

Annex C. Percentage Contribution to Impact Categories

kg O3-Equiv.

Baseline (74% Collection) Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**6.59E+07**	**1.17E+07**	**1.68E+06**	**5.23E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	96.8%	17.0%	2.2%	77.3%
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	2.3%	0.5%	0.2%	1.6%
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%	0.0%	0.1%
VOC (unspecified)	0.5%	0.2%	0.0%	0.3%

85% Collection Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**6.44E+07**	**1.34E+07**	**9.69E+05**	**4.98E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%	0.0%	0.0%
Nitrogen oxides	96.9%	20.0%	1.3%	75.3%
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	2.3%	0.6%	0.1%	1.6%
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%	0.0%	0.1%
VOC (unspecified)	0.5%	0.2%	0.0%	0.3%

Extreme RFO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**5.37E+07**	**2.26E+07**		**3.09E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	96.6%	40.7%		55.5%
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	2.8%	1.3%		1.5%
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%		0.1%
VOC (unspecified)	0.4%	0.0%		0.4%

Extreme MDO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**6.26E+07**	**1.92E+07**		**4.31E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides				
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air				
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%		0.1%
VOC (unspecified)	0.6%	0.3%		0.4%

Extreme VGO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**6.20E+07**	**7.01E+06**		**5.48E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	97.7%	11.1%		86.2%
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	1.7%	0.1%		1.6%
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%		0.1%
VOC (unspecified)	0.4%	0.1%		0.3%

Extreme RRBO Scenario	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**6.06E+07**	**8.32E+06**		**5.21E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		0.0%
Nitrogen oxides	97.5%	13.2%		84.0%
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	1.9%	0.4%		1.5%
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%		0.1%
VOC (unspecified)	0.4%	0.2%		0.3%

Extreme uncollected scenario (0% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**7.63E+07**		**6.46E+06**	**6.96E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%		0.0%	0.0%
Nitrogen oxides	96.6%		7.4%	88.9%
Phosphorus				
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	2.5%		0.7%	1.8%
Hydrocarbons (unspecified)				
Methane	0.1%		0.0%	0.1%
VOC (unspecified)	0.4%		0.0%	0.4%

Extreme collected (100% collection)	TOTAL	Formal Management	Informal Management	Virgin Product top-up
Smog Air	**6.23E+07**	**1.58E+07**		**4.63E+07**
Emissions to air				
Inorganic emissions to air				
Ammonia				
Carbon dioxide				
Hydrogen sulphide				
Nitrogen dioxide	0.0%	0.0%		
Nitrogen oxides	97.0%	24.3%		0.0%
Phosphorus				0.0%
Sulphur dioxide				
Sulphur oxides				
Organic emissions to air (group VOC)				
Group NMVOC to air	2.3%	0.7%		
Hydrocarbons (unspecified)				
Methane	0.1%	0.0%		
VOC (unspecified)	0.6%	0.2%		

GROUPE AGÉCO

FINAL CRITICAL REVIEW REPORT

LIFE CYCLE ASSESSMENT OF USED OIL MANAGEMENT

Prepared for

energy API®

AMERICAN PETROLEUM INSTITUTE

December 5, 2016

CRITICAL REVIEW PROCESS INFORMATION	
Title and version of the study	Life Cycle Assessment of Used Oil management- Final draft – November 2016
Authors of the study	Environmental Resources Management (ERM)
Commissioner of the study	American Petroleum Institute
Review committee	François Charron Doucet, Scientific Director, Groupe AGÉCO (Chairman) francois.charron@groupeageco.ca Christopher Loreti, Principal, The Loreti Group Keith A. Weitz, Environmental Scientist, RTI International Richard P. Zink, Chief Process Engineer, Process Engineering Associates, LCC
Client contact	David H. Lax, Sr Environmental Scientist, API (lax@api.org)

1 Introduction

This document constitutes the final critical review of the *Life Cycle Assessment of Used Oil* management report. Commissioned by the American Petroleum Institute (API), the study was conducted by Environmental Resources Management (ERM). It is presented as Phase II of the study commissioned by CalRecycle in the context of Senate Bill 546 (Lowenthal) and was carried out by the Donald Bren School of Environmental Science and Management at the University of California Santa Barbara (UCSB) (Phase I LCA study). The objective of the Phase II LCA study was to address several limitations identified in the Phase I model and report.

This study complies with ISO 14040 and 14044 standards. Because the study is expected to be made available to third parties, a critical review by a panel of independent experts was conducted.

The final conclusions and verdict of this critical review report apply to the November 2016 (final draft) version of the report.

2 Scope of the critical review

The aim of this critical review is to ensure that the LCA report complies with the requirements of the ISO 14044 standard, which stipulates that:

- the methods used to carry out the LCA are consistent with this international standard;
- 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 interpretations reflect the limitations identified and the goal of the study, and;
- the study report is transparent and consistent.

The critical review process was performed concurrently with the LCA study and is based on the ISO 14044 standard - section 6.3. The critical review process did not include a thorough review

of the LCA model developed with GaBi software or an analysis of individual datasets. Still, the overall plausibility of the results was assessed.

Description of the review process

The critical review panel was chaired by François Charron-Doucet, scientific director at Groupe AGÉCO (formerly Quantis Canada). The panel was made up of three experts in the petroleum industry, used oil management industry and/or life cycle assessment field:

- Christopher Loreti, Principal, The Loreti Group
- Keith A. Weitz, Environmental Scientist, RTI International
- Richard P. Zink, Chief Process Engineer, Process Engineering Associates, LCC

The review process got underway in July 2014 with the presentation and review of the first version of the goal and scope. The process was stopped for a period of time after the discussion on the goal and scope document (refer to the preliminary review report (July 16, 2014) for the discussions held prior to 2016).

On August 11, 2016, a final draft report was provided to the review committee. The document was significantly different from the methodology proposed in 2014.

On September 19, 2016, a meeting was held between the members of the review panel, ERM and API. Prior to the meeting, the review committee had provided their comments to the authors (see *Intermediate critical review report* – September 26, 2016).

On November 7, ERM submitted an updated version of the report (final draft). This report and the authors' responses to the reviewers' comments were deemed satisfactory by the review committee, but additional comments for non-critical improvements were provided on November 25.

On December 2, the final version of the document was delivered by ERM.

3 Conclusions of the critical review and verdict

The critical review committee recognizes the high quality of the report and the robustness of the scientific approach used in this study. The report is well written, clear and transparent. The authors have demonstrated an excellent understanding of the LCA methodology and the tools used in this study, including the GaBi software and the life cycle impact assessment (LCIA) methods. The results and conclusions are deemed robust and are used in a manner consistent with the goals of the study.

The committee is of the opinion that the objectives of the study, which are to address a number of the limitations, improve transparency and increase the utility of the model developed in the Phase I LCA study, have been achieved. Used in conjunction with the Phase I report, the Phase II report will help better respond to the used oil management issues posed by the SB546 (Lowenthal) legislation in California.

Critical review verdict

The critical review committee confirms that the *Life Cycle Assessment of Used Oil management* – November 2016 study complies with the requirements of the ISO 14044 standard.

François Charron-Doucet, Eng. MScA

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4 List of comments

Detailed list of the reviewers' comments on the first draft and final draft of the reports:

Initials - #	Section /Paragraph /figure/table	Type1	Comments	Proposed changed	Author's answer	Status
CL-1	2.1.3/P5	TE	If the claim is that most RFO is being used in asphalt, the basis of this information is unclear. Unclear where reference is ("reported1"?). Text should note it is being used for combustion rather than as a raw material.	Clarify whether RFO is being burned at the asphalt plant or incorporated into the asphalt. Include reference.	DOE Reference, which cites it being combusted, has been added. 'used as a fuel' added as well as the correct footer.	Closed
CL-2	2.1.6/P5	GE	Seems inappropriate to speculate on the results here.	Qualify or delete paragraph.	Paragraph deleted.	Closed
CL-3	2.3.11/P1	GE	This paragraph needs further explanation. Are there data to suggest that the exported oil is handled in the same way as if it were not exported?	Explain what the implications are of assuming exported oil from CA is handled the same way as the oil handled in state.	Text added to this section.	Closed
CL-4	4.1.2/P6	TE	The derivation of energy and product quantities deserves	For example, describe where heating value	Added clarification.	Closed

			further explanation. Explanation is OK, but it still is not clear where the values came from—who came up with these equivalencies and how?	(presumably LHV) for oil came from, as well as mass of other products.	The derivation if market is essentially arbitrary as long as the number cannot be exceeded by used oil management. We cut it fine by making the market just big enough eg for 'energy' the total volume of dry used oil x 43MJ, for 'VGO', 'RRBO' products etc we multiplied total volume of dry used oil by the baseline yield in the inventory uplifted by 10% (eg for VGO 0.8x 1.1x 4.35E8). In this way we could accommodate sensitivities around yield whilst minimising the influence of the virgin market.	
CL-5	4.1.3/T4.4	ED	WECC 2010 grid mix seems consistent with other sources (e.g., EPA eGRID) but no source is listed.	Provide citation for data (for this and other tables in report).	Added reference.	Closed
CL-6	4.7.5/T4.5	TE	Figures on informal management for MSW disposal and formal management to hazardous	Clarify T10.1 and T4.5 to make them consistent. Provide citation for split of informal disposal	Tables clarified to make more consistent and to distinguish between informal and formal	Closed

			waste in T4.5 seem inconsistent with T10.1 description, which seems to confuse informal and formal management. Citation for 87% of informal management going to improper disposal needed. OK, but T4.5 should cite where the baseline numbers actually come from instead of just saying the Phase 1 report. (What if the reader doesn't have that report?)	routes.	management. See section 4. 2 and 5.1 of the Phase 1 report. No aggregated table is provided. Section 5.1 'The base year as reported in all other analyses assumes that 4% of informally managed oil is landfilled, and the remaining quantity is split 90/10 between dumping and onsite combustion, which equates to an 87/9/4 dumping/onsite combustion/landfill split.' We have added note to Table 4.5 referring sections in Phase I	
CL-7	5.1.3/P2	TE	It seems very unlikely that oil is being disposed of at hazardous waste landfills in underground deposits, especially if it is in liquid form. Is this allowed	Add discussion on the form of the oil (liquid, absorbed, etc.), cite a source for this disposal method and the amount and describe the	According to Phase I, this is based on manifest records of used oil hauling within the state of California. Additional comments were added	Closed

			anywhere in California? While the used oil may be shipped or hauled to hazardous waste landfills, it is very unlikely that it is disposed of by landfilling. Unless the manifest data actually says that is the disposal method, I would suggest saying disposal by landfill was assumed lacking any better data.	applicability of the ecoinvent v3.2 data.	to this section. The use of ecoinvent data, although a limitation, is considered reasonable in light of the scale of the flow (0.7% of formally managed used oil). 'In the absence of better data' has been added.	
CL-8	5.1.3/last P	TE	What are the implications of using a generic wastewater treatment process to represent the used oil load? What mix of oil and water was assumed?	Add discussion and data.	Additional text added.	Closed
CL-9	5.1.5/P3	TE	Assumption that VGO impacts are the same as heavy fuel oil should be explained. What is meant by "heavy fuel oil"? If it is residual from atmospheric distillation then, unlike VGO, the vacuum distillation step is not used.	Add explanation.	Explanation added.	Closed
CL-10	5.1.7/P1	TE	How much sediment is generated when reprocessing to RFO? What are the implications of ignoring it?	Add discussion.	Additional text added.	Closed

CL-11	5.1.8/last P	TE	There are only 3 hazardous waste landfills in CA. 10 km seems much too short a transportation distance from anything.	Revise as necessary.	This was a copy and paste error and it is modelled as a municipal landfill. The text is adjusted here to reflect that. As such, the distance is set at 10 km.	Closed
CL-12	5.1.10/T5.9	ED	Should the reference be EPA AP 42?	Correct as needed.	Adjusted.	Closed
CL-13	5.1.10/T5.10	TE	Are the percentages in this table by volume, heat content or something else?	Add explanation.	Adjusted.	Closed
CL-14	5.1.11T5.14	TE	Combustion emissions for some pollutants (e.g. NOx) can vary greatly from one type of device to another. What device or devices are these emission factors for?		High, low and default emission factors, unless otherwise stated, were as used in Phase I, which reflects performance across technologies for each fuel reported in the MACT database.	Closed
CL-15	6.4.1/F6.3	ED	Y-axis of figure is not labelled.	Add label.	This is a dimensionless value, a relative comparison. Note added to title.	Closed
CL-16	6.4.2/3rd P after T6.3	TE	R-114 is very rarely used and was phased out by the Montreal Protocol. Thus it is unclear why it is included in the impact results.	Provide explanation for R-114 inclusion.	Comment added to explain. Although manufacturing is banned, emissions are still occurring from industrial activity	Closed
CL-17	6.4.3 and F6.13	TE	Is it realistic to assume that	Add explanation.	The premise is that the	Closed

			MDO can substitute for coal or NG? If so, the applications where this might occur should be described.		distillation process is producing a liquid fuel that may serve a multitude of energy needs and may not be limited to marine applications. In the marine sector, natural gas is being used in marine engines.	
CL-18	7.1/next to last bullet	TE	Explain where CO2-equivalent figure for the disposal of uncollected used oil comes from. What is the emission source? OK, but this bullet would be clearer if it simply referred to "informal disposal of used oil" and noted that degradation of the oil contributes to the CO2e. (Then, begin the last bullet with "if the used oil collection rate…")	Add explanation.	This is the GWP contribution from informal management. The source is therefore the impact from improper disposal and dumping and from degradation of the oil itself over time. Text amended.	?
CL-19	7.1.3/T7.8	TE	It is not clear where the greater ozone depletion from coal is coming from.	Add explanation.	This is due to 1,1,1-Trichloroethane emissions when combusting coal.	Closed
FCD-1	p.15 – Table 2.2	ED	Definition of the PAO acronym is missing.	Add and consider including an acronym table.	Added definition.	Closed

FCD-2	p.19 – first paragraph	GE	Issue with global parameters: This is quite surprising. Are you sure that you did not have the same problem during your own study?		To summarize our conversation during the call on September 19, we circumvented the issue by closing off the results module in the software after each individual run of results. Combined with sense-checking and recalculating the results manually, we found the results to be stable.	Closed
FCD-3	p.19 section 2.3.1	TE	System expansion instead of avoided burden: Although this choice is appropriate and well justified, it would be important to underline that comparative results will not be modified by this choice.	Clarify this point.	Clarification added.	Closed
FCD-4	Sections 2.3.2 to 2.3.4	GE	Although the model is well explained in other sections (e.g. section 5), it would be beneficial to mention in these sections whether the issues are actually addressed by the phase II model.	Add clarification and make reference to other section if applicable.	Additional text added.	Closed
FCD-5	p. 24 – section 2.3.12	GE	The three resources methods: It is worth mentioning that methods 1 and 3 cover the same type	Add clarification.	Added clarification. Text added to clarify.	Closed

			of resources (fossil fuel only), while method 2 covers a totally different type of resources (mineral). For the same reason, it would be interesting to indicate in the conclusion whether or not methods 1 or 3 make any difference on the results, such as relative contribution between life cycle stages. The description for method 2 (abiotic depletion, elements) includes "fuel", which could be true for uranium but not apply to fossil fuels. There is a slight risk of confusion.			
FCD-6	p. 31 – figure 4-1	GE	For the sake of completeness, some life cycle stages or processes could be added, such as waste management (could be explicitly included with Other Product Systems for example). Also, some coproducts such as light fuel oil from VGO process are considered in the constant output market calculation	Consider completing the figure or provide explanations if simplifications or aggregations were made.	Added a comment.	Closed

			but cannot be seen on this figure.			
FCD-7	Table 4.5 – note below the table	GE	What do the percentages for RRBO and RFO between parentheses refer to?	Add clarifications.	Added a comment to the table.	Closed
FCD-8	Table 4.6 – and other results tables	ED	Suggestion: select units that facilitate the reading of these tables. For example, in Table 4-6, using tons instead of kg would help.	Consider a review of the choice of units.	We considered. The kg minimizes the risk of units being misinterpreted (tons, tonnes etc.).	Closed
FCD-9	Table 5.5	GE	Provide definition for acronyms Mm and Tpy.	Also consider adding an acronym table.	Changed the units in the tables.	Closed
FCD-10	Table 5.6	GE	Is there a mass balance issue with this process? The quantity of output appears high relative to the amount of input.	Check the mass balance.	This was corrected. The data was erroneously reported in the report.	Closed
FCD-11	Table 5.8	GE	Is this a partial inventory? We would assume other emissions (besides natural gas combustion), inputs and waste.	Add clarifications.	Yes, this is partial inventory. The full inventories are in GaBi. Clarification has been added.	Closed
FCD-12	Section 6.1	TE	ISO requirement: Add the following statement: “LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks” in this section or another relevant section.	Add statement.	Added.	Closed

FCD-13	Figure 6.5	GE	I am not sure I understand why the scenario 100% gas is more impacting that 100% coal for ecotoxicity.	Add clarifications.	This is due to barium and silver in the NG extraction inventory.	Closed
FCD-14	P.146 – section 8.1	GE	Although some elements are already proposed in this discussion, it could be more explicitly suggested to move from an attributional modelling approach to a consequential approach.	Consider this suggestion.	We are not aware of data to support an alternative consequential approach and do not feel in a position to make this recommendation.	Closed
FCD-15	General suggestion	GE	In order to fully achieve the goal of informing policy makers, there would be a very large number of comparisons and sensitivity analyses that should/could be done with these results. Have you considered the idea of building a dynamic report that would allow readers to select scenarios for comparison and change key parameters?	Suggestion only.	This is an excellent suggestion and would indeed make the report even more useful for policy makers. We have included it as a recommendation in the report. Unfortunately, we cannot make this change within the scope of this current project.	Closed
KAW-1	Cover	GE	If the system expansion approach is kept, perhaps consider changing the title to reflect that the LCA covers the entire petroleum products market in CA.	For consideration.	Further text has been added to explain the system expansion approach. The LCA does not appraise the whole of the market but only	Closed

			Something perhaps along the lines of "…the role of used oil in the petroleum products market … " or maybe just "LCA of the petroleum products market in CA", though the latter may not meet the legislative requirement.		the proportion that may be affected by used oil management.	
KAW-2	2/1 - p.6	GE	Is there, or will there be, an economic analysis performed to accompany the LCA, as required by SB546? If so, how will the LCA and economic analysis be linked?	Add information on the economic component of the analysis.	An economic analysis was not undertaken. Text added.	Closed
KAW-3	2/Figure 2.1 – p.8	GE	Given the current market for crude with historically low prices, does the market demand concept still hold? That is, with cheap crude is there less of a market for used oil?	Add clarification as needed.	Economic considerations have not been addressed in this report. Text to this effect has been added.	Closed
KAW-4	2.1.2/2 – p.10	GE	Losses of oil also occur in the virgin crude oil pathway so, if included for the used oil pathway, they should also be addressed in the crude oil pathway.	Add clarification as needed.	Losses during use are not considered. This is mentioned in 2.1.2./P3	Closed
KAW-5	2.1.3/5 – p.11	GE	Typo in the first sentence. "use" should read "user".	Please correct.	Corrected.	Closed

KAW-6	2.1.3/10 – p.12	GE	The paragraph includes a statement that not all the used oil will be suitable for recovery, though the scenarios modeled assume 100% suitability. Are there data to quantify the fraction of used oil that is non-suitable, rather than saying "some"?	Add clarification if possible.	There is no data although the haz waste fraction may provide an indication of the used oil that is unsuitable.	Closed
KAW-7	2.1.4/4-5 – p.12	TE	Per used oil generation, how do improvements (or lack thereof) of the useful life of petroleum products impact the generation of used oil? Many motors oils, for example, now say change every 5000 vs. 3000 miles. Another example may be industrial filtration/reuse systems that extent the usable life of oil.	For consideration.	Added a comment to 2.1.4./P3, where this is already partially covered.	Closed
KAW-8	2.1.8/4 – p.17	TE	Closed vs. open loop recycling discussion states "…where products of reprocessing or re-refining do not exceed market demand…" Does this imply that there is a benefit when market demand is not met?	Add clarification as needed.	The study assumes there is always a demand.	Closed
KAW-9	2.2/2 – p.18	TE	Do data and information from re-refiners and pre-	Add clarification as needed.	No addition made.	Closed

			processors support the no difference between open and closed loop recycling statement?			
KAW-10	2.2/5 – p.18	GE	Per the bullet listing, is there any sense of how results might vary if another LCA database was used? Also, in the second bullet, can you elaborate on how the modelling was modified? Were specific data values tossed out, etc.?	Add clarification as needed.	There were a number of updates and improvements to the GaBi databases in the intervening years and it would be extremely difficult to identify each change. The changes obviously can cause a massive variation when taking an avoided burden approach. The same would be true when selecting other databases. This is one of the reasons why the system expansion approach provides greater confidence in light of the context it provides.	Closed
KAW-11	2.3.1/1 – p.19	TE	In moving to the system expansion (versus displacement) model approach, have the [directional] results/conclusions changed significantly? This may be	Add clarification as needed.	The net results are not dissimilar. However the interpretation and presentation of results are different.	Closed

			difficult to discern given the GaBi update and subsequent impact on results.			
KAW-12	2.3.4/1 – p.21	GE	Something is wrong in the second sentence. The second "released to air" should either read "…directly released to air" or "released to water/soil".	Please correct as needed.	Amended.	Closed
KAW-13	2.3.4/3-4 – p.21	GE	It may be useful to include a table listing all of the processes, issues, LCI data consistency and impact (and significance of impact) on results.	For consideration.	This would require significant resources and co-operation to fully document.	Closed
KAW-14	2.3.10 – p.24	GE	Does the uncollected used oil include oil contained in used oil filters, etc.?	Add clarification as needed.	Oil filters are captured in the MSW flow according to Phase I, section 4.21.	Closed
KAW-15	2.3.11 – p.24	GE	It may be of interest to state the key export markets and percentage of used oil that is exported from CA, if known.	Add clarification as needed.	Added a comment on export rate.	Closed
KAW-16	4.1.3/3 – p.31	TE	The constant market output approach assumes that the volume of used oil will have a direct and equivalent reduction in the volume of virgin petroleum. Does this follow in reality? That is, with current low virgin	Add clarification as needed.	No economic analysis has been undertaken.	Closed

			petroleum prices is the used oil market stagnant and less going into make new petroleum product? Has the used oil market rebounded since 2011?			
KAW-17	4.1.3/1 – p.33	GE	Is ”informal” landfill disposal of used oil illegal in CA? Or are small amounts acceptable for disposal in Subtitle D landfills?	Add clarification as needed.	Used oil is considered a hazardous waste and should not be dumped in garbage cans or drains.	Closed
KAW-18	4.1.3/1 – p.33	GE	Are informal management considerations included in the virgin crude pathway as well? Seems likely there may be ‘waste oil’ in the crude pathway as well. Has there been any discussion of this?	Add clarification as needed.	We have not been made aware of any addition of waste oil into crude feedstocks.	Closed
KAW-19	4.1.3/4 – p.35	GE	Is there any coal used in CA? I thought given the air regs, that coal was a non-starter? But this paragraph and Table 4.4 show coal as almost 30% of the grid mix. This is because the WECC mix is not CA-specific. Should a CA-specific grid mix be used since the study is CA-specific?	For discussion.	This is from Phase I: The 10-Year Regional Transmission Plan for the Western Electricity Coordination Council (WECC) was used to determine future electricity grid mixes for California. California grid is connected with other western states and is a net importer of electricity. Changes that	Closed

					occur in other states will likely have an effect on the emissions intensity of California electricity use and therefore future WECC mixes are used.	
KAW-20	4.1.3/1 – p.36	GE	Please include source for electricity mix and emissions by fuel type. Also, has the grid mix changed significantly since 2010? Perhaps include that information and how results, if year 2015 or 2016 were used as the base year, might be impacted.	Add source information and other clarification as needed.	Included the source from Phase I, and a comment about CA mix.	Closed
KAW-21	4.1.6/bullet list (end) – p.41	TE	With a general 50%/50% split of illegal dumping to water/land, how may a significant change in the assumed split impact LCIA results? Or perhaps illegal dumping in not significant when one considers the entire petroleum products system?	Add clarification as needed.	Most impact categories are unaffected by such a change. As would be expected changing the split only affects eutrophication and the toxicity impact categories. Illegal dumping is shown to be a significant consideration and area of concern.	Closed
KAW-22	5.1.3/2 – p.50	GE	Per hazardous waste incineration (and disposal), why was ecoinvent data used instead of GaBi? I	Add clarification as needed.	The appropriate inventories were not available in GaBi, therefore ecoinvent was	Closed

			assume those modules aren't available in GaBi or is there another reason?		chosen, as in Phase I.	
KAW-23	5.1.5 – p.55	TE	Is there any indication for how consistent (or not) the data are per the reprocessing technologies? For example, on this page do the data for VGO and MDO (cited to different authors) have the same scope, boundaries, and data completeness? In the MDO and RFO cases, there are no emissions listed in Tables 5.6 or 5.7?	Add clarification as needed.	There are no additional emissions included for RFO and MDO beyond those associated with energy consumption.	Closed
KAW-24	Figure 6.1 – p.80	GE	It would be useful to include the tonnage of crude going into virgin refinery production for 'top up'. This comment applies to all scenario system diagrams in this section.	Please add.	All scenario results show the fossil fuel consumption associated with virgin top up.	Closed
KAW-25	Table 6.2 – p.81	GE	It is obvious that the virgin 'top up' drives many of the results for the baseline and alternative scenarios. Has there been analysis/discussion of differences in results when using the avoided burden versus system expansion	Topic for discussion.	By comparison, the net results would be the same.	Closed

			approach?			
KAW-26	Last paragraph – p.83	GE	The last sentence points to avoided zinc and organic emissions as the primary source of ecotoxicity benefits as used oil collection increases. Is this benefit real or more because there are zinc / organics data for virgin petroleum products but no comparable data for used oil reprocessing?	Add clarification as needed.	This benefit is a result of avoiding illegal dumping and the release of these substances to the environment.	Closed
KAW-27	Figure 6.3 – p.84	GE	It would be useful to keep y-axis units the same on the bars charts where appropriate to do so (e.g., show Fig 6.3 y-axis with 1.0 increment similar to Figs 6-4 and 6-5).	Make change where appropriate.	Adjusted for figure 6.3.	Closed
KAW-28	7/1-3 – p.120	GE	The stated goal of the LCA is to assess the *used oil* management system in CA. Moving to the system expansion approach that includes the entire petroleum products market may make it difficult to convey the used oil aspects as they are now quite diluted by the full petroleum market scope. If the	Topic for discussion.	Text added up front to explain approach. Only a small proportion of the virgin market is considered (i.e. the proportion that would be affected by UO management).	Closed

			avoided burden approach is used could negative values be displayed as [positive] savings to facilitate their interpretation?			
KAW-29	7 – p.120	GE	Somewhere in Section 7, it would be good to include a chart that shows the fractions of used oil and top up assumed to make up the total petroleum product demand for each scenario. This may help stakeholders understand the role of used oil in the total petroleum products market. Tabular values are provided in an earlier section but a summary chart may be useful in this Interpretation section.	For consideration.	Figures 6.1, 6.6, 6.10 6.14 and 6.17 do this. Repetition is not seen as necessary.	Closed
KAW-30	– p.138	GE	Suggest the multiple tables be combined into one table for RFO and one for RRBO to improve readability?	Suggestion for consideration.	Change made.	Closed
KAW-31	8/3 – p.143	GE	Should a discussion be added about potential variability in the GaBi, etc. data sets used for this LCA? The impact on results from Phase 1 after the GaBi updates was surprisingly	Topic for discussion.	This is an issue with the avoided burden approach where variation appears large.	Closed

			large.			
RPZ-1	2.1, 3rd PP	Typo	"In the context of this LCA, it instructive…"	"In the context of this LCA, it is instructive…"	Changed.	Closed
RPZ-2	2.1, 5th PP	Not Needed	Delete the second sentence starting with "Market demand… through including Figure 2.1."	Stop the thought with the first sentence, which says it all the rest is in contrast to this sentence	This text was seen as desirable.	Closed
RPZ-3	2.1, 9th PP	Addition	Add at the end of the PP starting with "It is important to remember …"	Technologically advanced lubricants derived from used oil can require equipment upgrades in order to meet more stringent product specifications.	Not changed since we address this in the limitations and recommendations section (i.e. "This work has not considered the technical issues and barriers to use of re-refined base oil and any potential impacts on formulation and additive packages required or constraints on adoption of new and changed mixes of base oils."	Closed
RPZ-4	2.1.2, page 11	Incorrectly stated guidance	Sentence starting with "Some used oils may have become contaminated…": This PP misses the real world of UO recycling where plants must constantly deal with varying compositions of oil from many different sources.	Large scale UO recycling must always contend with a wide range of collected fluids that collectively are called UO but, in fact, contain a wide range of discarded fluids.	Added clarification to this sentence. We are referring to the mixing of waste and not contaminants in the oil stream as a result of their application.	Closed

RPZ-5	3 – Goal Second bullet	Consistency	… through re-refining, reprocessed fuel oil (RFO), VGO and / or Marine Distillate Oil (MDO)?	… through re-refined base oil (RRBO), reprocessed fuel oil (RFO), vacuum gas oil (VGO) and / or marine distillate oil (MDO)?	Changed.	Closed
RPZ-6	4.1, 1st PP	Consistency	… as well as re-refining of used oil to base oil, RRBO and various types of reprocessing of used oil to RFO, MDO and vacuum gas oil (VGO). Contains a mix of acronyms in parenthesis and not	… as well as re-refining of used oil to base oil (RRBO) and various types of reprocessing of used oil to reprocessed fuel oil (RFO), marine diesel oil (MDO) and vacuum gas oil (VGO).	Amended.	Closed
RPZ-7	4.1.1, top page 29	Typo	… (see Table 4.1) he work …	… (see Table 4.1) the work	Adjusted.	Closed
RPZ-8	4.1.3. Figure 4.1	Typo	rFO is used in all of these Figures, but elsewhere in the document it is always referred to as RFO	Change rFO to RFO	Amended.	Closed
RPZ-9	4.1.4, top page 38	Important model piece missing	The PP starting with ”Of these, a reader should note that infrastructure and capital goods…” can be clarified once the proposed change (adjacent) is implemented	The model should include a formal management variable input section to allow for the permitted installed total capacity for processing RFO, RRBO, VGO and MDO to be inputted. Then when the model is used and new values for the fraction of	This is a good suggestion. Recommendation included within report and the limitation was documented.	Closed

				UO now going to RFO, RRBO, VGO and MDO if any of these increase beyond the input value, an exception should can be noted. This model now predicts UO flowing in excess of permitted, installed capacity for (RFO, RRBO, VGO, MDO), whichever is exceeded. Each state will have these permitted, installed capacities for each of these four recycle routes.		
RPZ-10	4.1.5, top page 39	Typo	PP beginning with "Step two involved…" (i.e. no collection at all with all, with all …).	(i.e. no collection at all, with all…)	Adjusted.	Closed
RPZ-11	Table 4.6	Column Spacing	Extreme MDO column spacing incorrect.	Fix to eliminate number wrapping.	Fixed.	Closed
RPZ-12	4.1.6, bottom bullet	Assumption	50 % disposal to land and 50% disposal to freshwater.	50% disposal to freshwater seems excessive and would come to the attention of authorities: 5 to 10 % seems more reasonable	As a dispersed source it is very small and could go unnoticed or be masked by other flows. It amounts to 7g per capita per day. Daily use of cooking oils is reported to be 30g per capita day. A sensitivity analysis has been added.	Closed

RPZ-13	Table 4.8	Typo	Process Engineering Associates LCC	Process Engineering Associates, LLC	Changed.	Closed
RPZ-14	5.1.4	Formatting	Bullets are used for the five mentioned techniques and Table 5.1 references these by number.	Change the bullets to numbers (1 – 5).	The IFEU paper describes the techniques but doesn't reveal which of the inventories matches with which technique, to keep the data confidential. So therefore we haven't numbered the list of techniques.	Closed
RPZ-15	Tables 5.5, 5.6, 5.7	Mixed Units, Normalized Data	Tables 5.5, 5.6 and 5.7 contain mixed units and the data is not normalized.	Use consistent units and normalize the data.	Adjusted.	Closed
RPZ-16	5.1.9, 2nd PP	Typo	"…any individual product from through used oil…"	"…any individual product from used oil…"	Adjusted.	Closed
RPZ-17	Table 5.8	Typo?	I"nputs and Outputs with production of 1 kg of virgin product amount of – e.g. Crude oil needed – for Group II BO 1.08 kg."	I find it hard to believe that 1 kg of Group II BO can be derived from 1.08 kg of crude oil! BO will be a minor fraction of the crude oil and will take many more kgs of crude oil to make a kg of BO	Refineries are extremely efficient at converting crude to a range of products and the data reflects that a refinery produces more than just lube from a kg of crude. Very little of the input crude is wasted or consumed.	Closed
RPZ-18	6.4.2, pg 95 2nd to last PP	Addition	Assuming the model has been updated to include a variable input for the	If the model is used to predict a new RFO production rate, this rate	The need to consider available capacity is highlighted in the report	Closed

			installed permitted capacity to produce RFO – this section can make some reference to this.	should be at or below the permitted installed base of RFO production or new capacity is needed and this will require regulatory steps and capital investment	and recommendations made.	
RPZ-19	6.4.3	Addition	Similar to comment above for RFO – a PP should be added to discuss MDO processing in excess of permitted installed capacity	Similar to comment made for RFO.	The need to consider available capacity is highlighted in the report and recommendations made.	Closed
RPZ-20	6.4.4	Additions	Similar to comment above for RFO – for VGO in excess.	Similar to comment above for RFO.	The need to consider available capacity is highlighted in the report and recommendations made.	Closed
RPZ-21	6.4.5	Additions	Similar to comment above for RFO – for RRBO in excess.	Similar to comment above for RFO.	The need to consider available capacity is highlighted in the report and recommendations made.	Closed
RPZ-22	7.1.3	Additions	A paragraph should be added discussing the use of the model and predictions of processing in excess of permitted installed capacity.	Add a PP.	The need to consider available capacity is highlighted in the report and recommendations are made.	Closed
RPZ-23	8 Conclusions	Addition	No mention of model predictions for processing in excess of permitted installed capacity	Care must be taken when using the model to re-route UO to a specific recycle route (RRBO,	The need to consider available capacity is highlighted in the report and recommendations	Closed

				RFO, VGO, and MDO). The volume of re-routed UO should not exceed the permitted installed capacity for the route in question.	made.	

5 ISO compliance grid

Specifications	Verdict
General reporting requirements and considerations	
Are the results and conclusions of the LCA completely and accurately reported without bias to the intended audience?	Requirement fulfilled
Are the results, data, methods, assumptions, and limitations transparent and presented in sufficient details to allow the reader to comprehend the complexities and trade-offs inherent to LCA?	Requirement fulfilled.
Does the report allow the results and interpretation to be used in a manner consistent with the goals of the study?	Requirement fulfilled.
LCA commissioner, LCA practitioner (internal or external)	Requirement fulfilled
Date of report	Requirement fulfilled
Statement that the study has been conducted according to the requirements of ISO 14040 and 14044	Requirement fulfilled
Goal of the study	
Reasons for carrying out the study	Requirement fulfilled
Intended applications	Requirement fulfilled
Target audiences	Requirement fulfilled
Statement whether the study intends to support comparative assertions intended to be disclosed to the public	Requirement fulfilled
Scope of the study	
→ ***Function***	
Definition	Requirement fulfilled
Statement of performance characteristics	Requirement fulfilled
Any omission of additional functions in comparisons	Requirement fulfilled
→ ***Functional unit***	
Definition	Requirement fulfilled
Consistency with goal and scope	Requirement fulfilled
Results of performance measurement	Requirement fulfilled
→ ***System boundary***	
Definition	Requirement fulfilled

Omissions of life cycle stages, processes or data needs. Quantification of energy and material inputs and outputs.	Requirement fulfilled
Assumptions about electricity production	Requirement fulfilled.
→ ***Cut-off criteria for initial inclusion of inputs and outputs***	
Description of cut-off criteria and assumptions	Requirement fulfilled
Effect of selection on results	Requirement fulfilled
Inclusion of mass, energy and environmental cut-off criteria	Requirement fulfilled
Life cycle inventory analysis	
Data collection procedures	Requirement fulfilled
Qualitative and quantitative description of unit processes	Requirement fulfilled
Sources of published literature	Requirement fulfilled
Calculation procedures	Requirement fulfilled
Data quality analysis	Requirement fulfilled
Treatment of missing data	Requirement fulfilled
Sensitivity analyses to refine the system boundaries	Requirement fulfilled
Documentation and justification of allocation procedures	Requirement fulfilled
Uniform application of allocation procedures	Requirement fulfilled
Life cycle impact assessment	
LCIA procedures, calculations and results of the study	Requirement fulfilled
Limitations of the LCIA results relative to the defined goal and	Requirement fulfilled

scope of the LCA	
Relationship of LCIA results to the defined goal and scope	Requirement fulfilled
Relationship of the LCIA results to the LCI results	Requirement fulfilled
Impact categories and category indicators considered, including a rationale for their selection and a reference to their source	Requirement fulfilled
Descriptions of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations	Requirement fulfilled
Descriptions of or reference to all value-choices used in relation to impact categories, characterization models & factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations	Requirement fulfilled
A statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks	Requirement fulfilled
When applicable:	
Description and justification of the definition and description of any new impact categories, category indicators or characterization models used for the LCIA	N/A
Statement and justification of any grouping of the impact categories	N/A
Any further procedures that transform the indicator results and a justification of the selected references, weighting factors, etc.	Requirement fulfilled
Any analysis of the indicator results, for example, sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results	Requirement fulfilled
Data and indicator results reached prior to any normalization, grouping or weighting shall be made available together with the normalized, grouped or weighted results	Requirement fulfilled
Life cycle interpretation	
Results	Requirement fulfilled
Assumptions and limitations associated with the interpretation of results, both methodology and data related	Requirement fulfilled
Data quality analysis	Requirement fulfilled
Full transparency in terms of value-choices, rationales and expert judgments	Requirement fulfilled
Additional requirements for comparative assertions intended for public disclosure	
Analysis of material and energy flows to justify their inclusion or	Requirement fulfilled

exclusion	
Assessment of the precision, completeness and representativeness of data used	Requirement fulfilled
Description of the equivalence of the systems being compared	Requirement fulfilled
Description of the critical review process	Requirement fulfilled
Evaluation of the completeness of the LCIA	Requirement fulfilled
Statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use	Requirement fulfilled
Explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study	Requirement fulfilled
Results of the uncertainty and sensitivity analyses	Requirement fulfilled
Evaluation of the significance of the differences found	Requirement fulfilled
Critical review	
Name and affiliation of reviewers	Requirement fulfilled
Critical review reports	Requirement fulfilled
Responses to recommendations	Requirement fulfilled

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