Environmental Assessment of Used Oil Management Methods

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The 1 billion gal of used oil generated in the U.S. each year are managed in three primary ways: refined into base oil for reuse, distilled into marine diesel oil fuel, and marketed as untreated fuel oil. Management of used oil has local, regional and global impacts. Because of the globally distributed nature of fuel markets, used oil as fuel has localized and regional impacts in many areas. In this paper, the human health and environmental tradeoffs of the management options are quantified and characterized. The goal of this study was to assess and compare the environmental impacts and benefits of each management method in a product end-of-life scenario using a life-cycle assessment (LCA) approach. A life-cycle inventory showed that 800 mg of zinc and 30 mg of lead air emissions may result from the combustion of 1 L of used oil as fuel (50–100 times that of crude-derived fuel oils). As an example, up to 136 Mg of zinc and 5 Mg of lead air emissions may be generated from combustion of over 50 M gal of California-generated used oil each year. While occurring elsewhere, these levels are significant (of the same magnitude as reported total stationary source emissions in California). An impact assessment showed that heavy metals-related toxicity dominates the comparison of management methods. Zinc and lead emissions were the primary contributors to the terrestrial and human toxicity impact potentials that were calculated to be 150 and 5 times higher, respectively, for used oil combusted as fuel than for rerefining or distillation. Low profits and weak markets increasingly drive the used oil management method selection toward the untreated fuel oil market. Instead, both the rerefining and distillation methods and associated product markets should be strongly supported because they are environmentally preferable to the combustion of unprocessed used oil as fuel.

Introduction

Used oil is generated from a broad variety of sources within the transportation, construction, and industrial sectors and consists of lubricating oils (motor and transmission oils) and industrial oils (hydraulic and cutting oils). Used oils are collected from decentralized stocks and ultimately aggregated at permitted treatment, storage and disposal facilities (TSDF). The 1 billion gal of used oil collected in the U.S. each year are managed in three primary ways: 14% is rerefined, 11% is used for space heating fuel, and 75% is marketed as fuel oil for a variety of industrial consumers (*1*). The focus of this paper is to quantify and characterize the human health and environmental tradeoffs of three management options that are representative of U.S. practices. The goal of this study was to assess and compare the environmental impacts and benefits in a product end-of-life scenario. The assumption that collection and management of used oil is environmentally preferred was made; hence, other management methods, such as for dust control or the impacts of dumping used oil in the environment, were not studied. California was chosen to study because accurate volume and process information was available for each management option.

The 92 million gal distilled, rerefined, and marketed as fuel oil by California recycling facilities in 2002 are the focus of this paper (*2*). Table 1 presents the volumes for each management method and the resulting product and waste volumes for 2002. The majority of used lubricating oil was blended, marketed as fuel oil cutter stock, and shipped out of state and overseas for use as fuel. Only ~3 million gal/year of used oil fuels were consumed within California because of strict air pollution requirements and the relatively poor quality of used oil as fuel (generally high sulfur and ash content). About 32 million gal of lubricating and industrial oils were processed by distillation to produce marine diesel oil fuel (MDO) and an asphalt-flux. Approximately 11 million gal of used lubricating oil are rerefined in California annually. The rerefining process recovers an asphalt tar product and a lubricating oil base stock that can be formulated into new motor oil or other finished lubricant products. The rerefined lubricant base oil, MDO, and asphalt products compete with California crude oil refinery products in the open market.

Used Oil Fuel Combustion with Energy Recovery. Used oil that is certified to meet the recycled oil standard (pursuant to California Health and Safety Code 25250.1 (*3*)) and consumed as fuel outside of the U.S. was considered to be the current state of practice for this study. The recycled oil standard limits the levels of certain heavy metals, total halogens and halogenated compounds as contaminants pursuant to California and Federal laws (40 CFR, part 279). Used oils contain significantly higher concentrations of heavy metals, sulfur, phosphorus, and total halogens compared to low-sulfur crude-based heavy fuel oils (*4*). Because of a generally low quality as fuel, used oil is commonly blended with other fuel oils before use (*5*). With blending, the specific level of contaminants in the finished fuel is lowered to an acceptable level for equipment specifications and temporal emission limits for any given user. Combustion of a blended fuel is assumed to not affect the net release of emissions with time; that is, from a life-cycle perspective, the net emissions per unit of used oil consumed remain the same regardless of dilution.

Currently, used oil marketed as fuel constitutes <0.5% of the total fuel oil market in California (*6*). Because this amount is relatively small, it is assumed that there is no significant displacement in crude refining capacity or in the fuel oil market.

Rerefining. The rerefining process includes flash evaporation to remove light ends and water, a defueling step to

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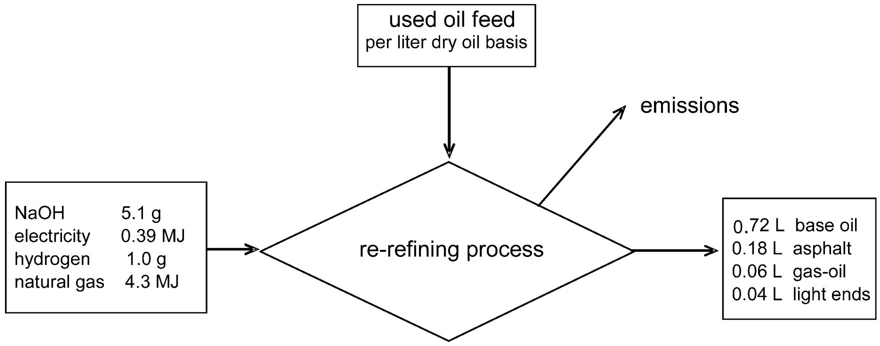

FIGURE 1. Rerefining process model (liter of dry used oil basis).

TABLE 1. In-State Management Methods for California-Generated Used Oils[a]

management method	net product distribution	wastes
48.9 M gal; fuel oil	49.5[b] M gal fuel oil (cutter stock)	
31.7 M gal; distillation	15.8 M gal asphalt flux	1.3 M gal wastewater
	13.3 M gal MDO fuel	1.3 M gal hazardous waste
11.4 M gal; rerefined[b]	7.9 M gal lube base stock	0.5 M gal wastewater
	1.9 M gal asphalt extender	0.5 M gal hazardous waste

[a] 92 M gal in 2002. [b] Note: 0.6 M gal of gas-oil from rerefining are added to cutter stock.

separate gas oils, lube distillate separation from heavy residual, and a hydrofinishing step (*7, 8*). These steps require energy and material inputs, such as natural gas for heating, electricity for pressurization and pumping, and hydrogen for hydrofinishing. The hydrofinishing step also requires the use of a catalyst. Sodium hydroxide is used in several process steps (including wastewater treatment).

The rerefining plant capacity in California is 12 million gal of used oil feed per year at 4−5% water content. The rerefining process model shown in Figure 1 is based on 1 L of dry used oil input. The data for this paper were collected from the facility operator (*8*, *9*). The product distribution shown in Figure 1 is the average over a 2-year operating period (2001−2002). The process inputs are based on daily or monthly averages, with the exception of the catalyst that is replaced biannually. A cost allocation method was used to evaluate the significance of the catalyst use to the study. The cost of the catalyst constitutes ∼0.6% of the base oil product value per gallon, and spent catalyst disposal ∼0.1%. Because the catalyst consumption per unit of used oil processed is exceedingly small (<0.02 wt %), the catalyst was excluded in the study.

Rerefining results in recovery of a high-purity lubricating base oil which displaces virgin lube base oil. However, the rerefined base oil currently constitutes only 2.5% of California's base oil production capacity and 0.3% of U.S. capacity (*10*). Hence, rerefining is considered to not affect the overall lubricating oil market. The heavy metals and other contaminants in used oil are concentrated in the asphalt byproduct of the rerefining process. This material can be used as a roofing tar, asphalt concrete additive, or for other traditional asphalt bitumen uses. Uses of the asphalt product could result in some risk due to leaching of heavy metals; however, leaching tests (California WET and Federal TCLP) show that the heavy metals are bound within the tar matrix and insignificant leaching occurs. (These results are contained in California Department of Toxic Substances Control lab reports.)

Distillation. The process employed to produce MDO and asphalt flux involves distillation to remove light ends and water and the final separation of a heavy fuel oil (distillate) from contaminants (bottoms). The distillation process requires energy and material inputs, such as natural gas for heating and electricity for pressurization and pumping. The distillation plant capacity in California is ∼40 million gal of used oil feed per year (at 5% water content). However, the facility has commonly operated at 75% capacity due to a weak market for the byproduct flux. The simplified distillation process model shown in Figure 2 is based on 1 L of dry used oil input. The process inputs are based on daily averages and were collected from the facility operator (*5*). The product distribution shown is the average for 2002.

Distillation results in recovery of a high-quality marine diesel oil (very low ash and sulfur content) and asphalt flux residual. The MDO fuel volume is a minor fraction of the total market (*6*). Via distillation, the heavy metals and other contaminants of the used oil concentrate in the asphalt flux byproduct. Flux may be used as an extender for virgin asphalt materials, asphalt concrete additive, or for other traditional asphalt bitumen uses. Uses of the asphalt product could result in some risk due to leaching of heavy metals; however, leach-

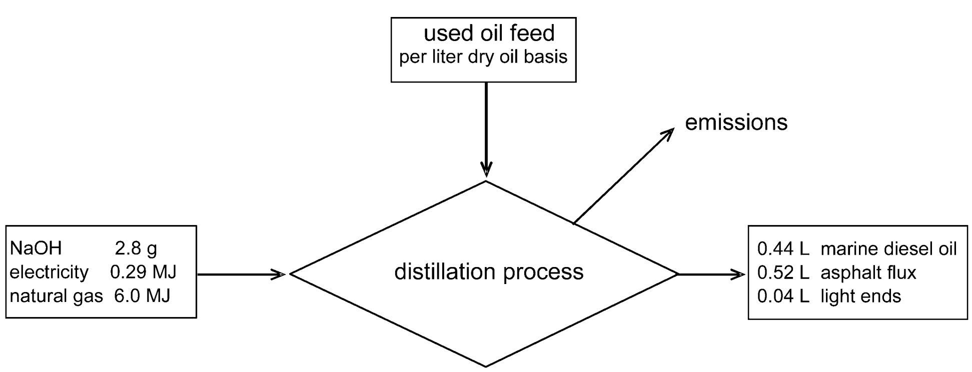

FIGURE 2. Distillation process model (liter of dry used oil basis).

ing tests (California WET and Federal TCLP) show that the heavy metals are bound within the tar matrix and insignificant leaching occurs. (These results are contained in California Department of Toxic Substances Control lab reports.)

Methodology

Life-cycle assessment (LCA) methodology was used to compare California used-oil management methods based on accepted methods and protocols (*11*, *12*) and using the GaBi 3 Software System for Life-Cycle Engineering (*13*). The goal of this study was to assess and compare the environmental impacts and benefits of each management method. The combustion of used oil as fuel with energy recovery was compared to two alternative management methods:

(i) rerefining of used oil to produce lube oil base stock and other products, and

(ii) distillation of used oil to produce MDO and an asphalt flux byproduct.

Life-cycle boundary and functional units were devised, and applicable data were acquired as described in this section. An inventory of relevant energy and material inputs and environmental releases for each method was compiled. The potential environmental impacts associated with those inputs and releases were then evaluated and compared.

Life-Cycle Boundary. This paper focuses on the end-of-life phase and the impacts associated directly with the management method chosen, because the choice of method is assumed to not affect the prior phases of the life-cycle (manufacturing and use). The study boundary begins with the delivery of used oil at a recycling facility followed by blending to produce a fuel oil or processing by rerefining or by distillation. Dewatering steps for oily water were considered as pretreatment and excluded. The combustion of used oil as fuel and the production of rerefining or distillation products close the boundary for the cases.

Used oil collection- and transportation-related impacts are considered equivalent among all methods and are excluded, as are the impacts associated with the transportation of the final products. The origin of the materials needed to manufacture lubricating oil and the manufacturing of the finished motor oils are also considered to be the same for each case and are not included. Similarly, the impacts from use of lubricating oil (losses during driving) are excluded as these will also be equivalent for each case. Removal of these life-cycle phases from consideration is consistent with the principle of excluding identical activities for comparative assessments (*12*, *14*).

For both distillation and rerefining, the discrete process steps were aggregated because the goal of this study was not to assess the impacts from each step and explore possible process improvements, but to compare the overall impacts of rerefining or distillation compared to used oil combustion. The life-cycle impacts from constructing and maintaining the rerefining and distillation plants were excluded considering the hundreds of millions of gallons processed in these plants over an average of 30-year facility lifetime. In addition, comparable tankage and truck off-pumping/piping systems are present in all used oil recycling facilities and were excluded for each case. It was assumed for this study that there are no environmental differences between the use of the rerefined and distillation products and byproducts, such as asphalt and asphalt flux versus crude oil-based products.

The process wastewater recovered from used oil rerefining and distillation is treated on site before discharge to a public sewer system. The treatment chemicals and energy required are accounted for in the model input values. No impacts from wastewater treatment in publicly owned treatment works (POTW) were included in the study, because the total discharged volume is exceedingly small (8000 gal/day for the rerefining process and 5000 gal/day for the distillation process) as compared to the overall municipal sewage volumes treated at the specific POTW. The discharged wastewater contains minimal COD and no heavy metals. Onsite wastewater treatment produces a minimal amount of oily water sent to disposal, or treatment on site, which was also excluded in this study.

Functional Unit. The management methods studied result in either energy or resource recovery. Combustion of used oil as fuel recovers the energy content of the used oil. Distillation and rerefining each result in the recovery of valuable materials (at the expense of some energy resources and chemical inputs). Functional units for this paper consist of equivalent amounts of products and recovered energy from one liter of dry used oil following the SETAC “code of practice” (*15*) and the technological “whole system method” approach (*14*). Specifically, the impacts of rerefining or distillation processes were added to the impacts from the manufacture and combustion of heavy fuel oil from crude-oil resources (to produce an equivalent amount of recovered energy). To provide an equivalent system for comparison, the impacts from manufacture of lubricating base oil, asphalt tar, and gas-oil from crude oil resources were added to the impacts of combustion of used oil as fuel with energy recovery. For the distillation case, the impacts from the manufacture of MDO and asphalt flux from crude oil resources were added to the impacts of combustion of used oil as fuel for energy recovery. This method provided for the two processes to be compared to used oil as fuel on an equal products and energy recovery functional unit basis.

Data Sources. The production impacts for all input and product materials (such as sodium hydroxide or lubricating base oil) are taken directly from the process databases in ref *13*. The databases chosen for electricity and natural gas production and combustion are based on U.S. data. However, the asphalt, lubricating base oil, and fuel oil production steps are based on German refining facility process data. German and U.S. rerefining facilities are considered to be equivalent for this study. Inconsistency between U.S. and German processes is tempered by the methodology used in this paper because each case is credited for the recovered resources in a consistent manner. No data were available for local or regional effects and sensitivities in California or the U.S.

A study of heavy metals and acid gas emissions from the combustion of used oil as space heating fuel in Vermont (*16*) shows the concentration of sulfur, chlorides and heavy metals in used oil (Table 2) consistent with levels reported by the U.S. Environmental Protection Agency (EPA) and others (*4*). The Vermont study showed that the mass flux of contaminants correlated very closely between the air emissions and the used oil fuel feed. This is reasonable due to the lack of emission controls on the small combustion units studied. Although no waste oil furnaces are in use in California, the Vermont study emission data were considered to represent used oil fuel combustion with minimal emission controls. Although there are combustion unit configurations which lead to condensation of metals and lower net emissions, it was assumed for this paper that the majority of used oil fuel is combusted in units with limited or no emission controls. No data were available to show that other emissions except for heavy metals are significantly different from virgin fuel oil combustion levels (*17*, *18*).

Data for California used oil characteristics were gathered from two major recyclers in California representing over 75% of the collected used oils. The range and average values for California presented in Table 2 are characteristic of consolidated used oil rather than generator derived samples of used oils. Recycling facility operators consider the ranges as representative of used oil fuels on the basis of thousands of

TABLE 2. Constituent Concentrations in Used Oil

element	VT samples ($n = 21$) av (ppm)	VT samples ($n = 21$) range	CA recycled oil[a] av (ppm)	CA recycled oil[a] range	no. 4 fuel oil (*16*) av (ppm)
Ba	2.9	<1−7	18	12−26	<1
Pb	49.2	<20−146	33	18−38	<10
Cd	1.65	<0.25−6.6	1	<1−2	<0.25
Cr	3.33	<2−6.8	1.4	<1−2	<2
Cu	36	<30−50	40	28−64	na
Ni	1.5	1−3	1	<1−1.7	8.3
Zn	1152	568−2370	822	600−877	9
Cl	100	<100−439	100		<200
P[b]			790	690−840	na
S[c]	3015	1200−4140	3200	2930−3375	1860
ash	0.52 wt %	0.32−0.87 wt %	0.8 wt %	0.7−1 wt %	0.56 wt %

[a] Industry consensus average values and ranges derived from bulked oil prior to shipping as certified fuel oil, (*5*, *9*) [b] Converted to PO_4 emissions to water and soil for modeling [c] Converted to SO_2 emissions to air for modeling

used oil fuel shipments each year. California data were also available for additional constituents such as phosphorus, a significant additive component in lubricating oils. To model used oil fuel combustion with energy recovery, emissions inventory data (*13*) for heavy fuel oil combusted in a power plant were adjusted with the California averages presented in Table 2 for lead, barium, cadmium, copper, chromium, nickel, zinc, chlorides, phosphate, and sulfur dioxide emissions. Compared to fuels made from crude oil, fuels derived from used oil contain high levels of heavy metals as well as phosphate- and sulfur-based additive chemicals. These contaminants contribute to air emissions, some several orders of magnitude higher than those produced from crude-based heavy fuel oils (*13*, *17*).

Rerefining process data were collected from the Evergreen Oil facility located in Newark, California and from facility volume reports (filed quarterly with the California Integrated Waste Management Board). Distillation process data were collected from the DeMenno/Kerdoon facility located in Compton, California, and also from facility volume reports (quarterly reports to the California Integrated Waste Management Board).

Temporal and Geographical Considerations. The characteristics of bulked used oils received at recycling facilities are well documented (recycling facility certified laboratory reports and California Department of Toxic Substances Control laboratory reports) and do not vary significantly with time or location in terms of water content, contaminant levels, heating value, etc. This is a result of the distributed generation of used oils and the dispersed waste oil collection and management system. Typically, used oils are collected from many sources and are combined during collection and again at bulking or transfer stations. Used oils are then blended to meet fuel oil specifications or to produce a consistent rerefining or distillation process feedstock. Therefore, it was assumed that there are no temporal and geographical differences in used oil composition to consider.

Other geographical differences between the cases may be significant. The fact that the majority of used oil is shipped overseas for use as fuel will lead to transportation impacts for the used oil fuel case. Used oil rerefining and distillation occur at discrete sites in California. The rerefining and distillation products regionally compete with California crude oil refinery products. Most of the regional impacts from the rerefining and distillation facilities studied are assumed to balance with offsets from crude refining facilities located in relative proximity. Because local sensitivity data were not available, internationally accepted characterization factors were used (*13*).

Results

Databases from ref *13* were used to compile the output inventory for each management method based on equivalent functional units and the assumptions described above. According to accepted LCA protocol, a systematic procedure for classifying and characterizing the types of environmental effects of each constituent was then followed, and the potential environmental and human health impacts were assessed.

Inventory. Heavy metal emissions were found to dominate the inventory, as presented in Table 3. Other emissions to air and water and solid wastes are comparable for each case or are very small and have very little influence on the conclusions of the study.

On an equivalent functional unit basis, used oil combustion results in several orders of magnitude higher emissions of several heavy metals compared to the processing options. Zinc (from zinc dialkyl dithiophosphate additive in finished motor oil in the range of 10 wt %) is the principal contributor to the total heavy metal emissions on a mass basis for used oil combustion; however, lead, cadmium, and copper emissions are significant as well. Phosphate emissions are also important for used oil combustion also due to the presence of dialkyl dithiophosphate additives in motor oils.

Applying these emission values to the total volume of California generated used oil combusted as fuel (assuming no emission control) leads to emissions of up to 136 Mg of zinc, 5.2 Mg of lead, 6.5 Mg of copper, and 0.164 Mg of cadmium each year. This level of environmental loading can be put into context by comparison to statewide emissions of heavy metals. The EPA's Toxics Release Inventory contains air emissions data from major stationary sources in California (*18*) and cites totals of 19.9, 16.1, 6.9, and 0.007 Mg of zinc, lead, copper, and cadmium compounds, respectively, for 2001. A comparison to the California toxics inventory, which

TABLE 3. Inventory of Key Heavy Metal Air Emissions Based on Equivalent Functional Units[a]

heavy metal	rerefining case: used oil as fuel and equiv products	rerefining case: rerefining and equiv energy	rerefining case: ratio	distillation case: used oil as fuel and equiv products	distillation case: distillation and equiv energy	distillation case: ratio
Zn	729	1.2	600	729	1.2	600
Cu	35	0.017	2100	35	0.015	2300
Pb	29	1.6	18	29	1.6	18
Cr	1.2	0.48	2.6	1.2	0.48	2.6
Cd	0.89	0.011	80	0.89	0.010	88

[a] mg of air emissions per L of fuel. Assuming no air pollution control.

TABLE 4. Impact Factors for Heavy Metal Air Emissions[a]

heavy metal	terrestrial ecotoxicity potential [kg DCB equiv]	human toxicity potential [kg DCB equiv]	aquatic ecotoxicity potential [kg DCB equiv]
Zn	660 000	0.63	2.6
Cu	910 000	350	2.9
Pb	11 000	67 000	1.2
Cr	220 000	490 000	2.5
Cd	130 000 000	23 000	130

[a] On a 1-kg basis (*13*).

TABLE 5. Ratios of Impact Characteristics for Used Oil Combustion Compared to Rerefining and Distillation[a]

environmental impact category	ratio of used oil fuel to rerefining	ratio of used oil fuel to distillation
terrestrial ecotoxicity potential [kg DCB equiv]	150	150
human toxicity potential [kg DCB equiv]	5.7	5.7
eutrophication potential [kg phosphate equiv]	3.2	3.1
aquatic ecotoxicity potential [kg DCB equiv]	2	2
ozone depletion potential [kg R11 equiv]	1.1	1.1
photochemical oxidant potential [kg ethane equiv]	1.1	1.1
global warming potential (100 yr) [kg CO_2 equiv]	0.9	0.9
acidification potential [kg SO_2 equiv]	0.5	0.5

[a] based on equivalent functional units of product and energy recovery assuming no air pollution control.

includes more sources than the TRI, gives 58, 14.7, and 3.9 Mg per year of zinc, lead, and cadmium compounds, respectively, from stationary sources for 1996 (*19*).

Impact Assessment. Mass of emissions alone does not convey a degree of significance to human health or the environment. Because each elemental and chemical species has different specific impacts, a weighting method was used to evaluate and compare the cases. Comparisons were carried out after characterization of the individual loadings relative to potential impact categories. Table 4 shows that the impact factors for the heavy metal air emissions in this study may differ by orders of magnitude (e.g., cadmium in almost all categories).

The results for each case are presented in Table 5 as a ratio of potential impacts from used oil combustion with no emission control to the alternative processing options based on equivalent functional units. The ratios of each case are near unity for many characteristics, however are especially high for the terrestrial and human toxicity potentials (principally due to heavy metal air emissions). Consuming used oil as fuel results in terrestrial ecotoxicity impact potential 150 times and human toxicity impact potential of over 5 times that of rerefining or distillation. The human toxicity potential is driven by lead and chromium emissions (71 and 22%, respectively), while zinc and cadmium contribute the majority of the terrestrial ecotoxicity potential (76 and 18%, respectively). The eutrophication impact potential is three times higher for used oil combustion due to the significant phosphorus content of used oil.

Discussion of Results

On the basis of potential human health and environmental impacts, used oil rerefining and distillation are significantly better management practices than combustion of used oil as fuel. The results of this end-of-life impact assessment showed that heavy metal air emissions dominate the comparison of the three used oil management methods studied. The results were not sensitive to rerefining or distillation process yields, energy input rates, or chemical (e.g., NaOH and H_2) consumption rates. The conclusions were also not affected by the range of concentration of contaminants, including the key heavy metals in the used oil.

Management of California-generated used oils has local, regional, and global impacts. Combustion of used oil as fuel has localized and regional impacts in many areas because the majority of the used oil derived fuels are shipped overseas and are combusted for energy recovery at many locations or used as ship fuel. Many rerefining and distillation facility impacts are recognized as local and regional impacts, however, the effects from the rerefining and distillation processes are relatively small (compared to the use as fuel), and those effects are offset to some degree by crude oil refineries nearby.

The results of the Vermont study showed that the metals emission and fuel feed mass fluxes matched closely for small space heating systems with no emission controls. However, the assumption that there are no heavy metal emission controls during used oil fuel combustion is conservative. Emissions of lead and chromium are probably overstated for large oil-fired boiler systems. Hence, the human toxicity potential ratio is overstated to some degree. The human toxicity impact for used oil combusted as fuel may also be overstated because some used oil fuel is consumed away from significant populations (e.g., as ship fuel on the high seas and at remote electricity generating stations). However, no information was available to quantify the level of emission controls or locations of used oil-based fuel use.

The range of heavy metal concentrations (Table 2) in aggregated used oils at recycling facilities is relatively small. Using the lowest range values for the heavy metals in Table 2 lowers the terrestrial ecotoxicity impact potential ratios by 30%, which would not significantly influence the conclusions of the study.

Recommendations. About one-half of California-generated used oil is consumed as fuel without treatment each year (50 million gal). Additionally, ∼10 million gal of California-generated used oils were transported to out-of-state TSDFs in 2001 and 2002. The bulk of that oil was destined for fuel use as well, but was not included in this study. Because of population growth and increased collection of used oil from the public, collected used oil volumes have increased ∼4 million gal each year for the last 5 years and are expected to continue to do so (*2*). Following waste management principles, source reduction and returning used oil to its original intended use are preferred over its use as a fuel. Source reduction should be considered as a way of reducing the generation (e.g., better oil filter designs that would lead to longer service intervals) or toxicity of used oils (formulation without zinc additives). Extending oil change intervals from the national average 4500 miles to 9000 miles would halve the total emissions found in this paper (*20*). Considering the growth in population and total vehicle miles traveled, no significant decrease in volumes should be expected soon without significant public awareness campaigns. There is some change underway in lubricating oil formulations to meet increasing emission control requirements; however, it is unlikely that reformulation will result in total removal of zinc phosphate additives.

The potential zinc, cadmium, copper, and lead emissions from used oil-derived fuels from California are on the order of emissions from all of California's major stationary sources combined. On the basis of the results of this study, there remains great room for improvement of the used oil management system. Because the combustion of untreated used oil as fuel occurs primarily outside of California, the impacts may not be directly damaging to California. However, California's global environmental footprint can be significantly decreased. The large environmental burden can be substantially reduced by supporting the alternative used oil management methods. Significant reduction in impacts could be realized by providing incentives for treatment (regulatory control methods) and by supporting markets for processed used oil products (market development methods).

Used oil processing is a costly endeavor and profits are slim because the market value of products is benchmarked by the value of crude oil (*21*). While the products derived from used oil processing may be cost competitive in the marketplace, the market volumes may be limited by several factors. For example, the limited asphalt flux market has often restricted the volume of used oil processed to MDO fuel. Approval of performance grade asphalt specifications in California for use of the flux material in roadway asphalt concrete would greatly improve the flux market. Increased procurement of finished rerefined oil products is environmentally preferable due to reuse of a nonrenewable resource for its original intended use. Distillation to clean fuels such as MDO is also an environmentally preferred choice. Policy makers can use these LCA results to support the rerefined oil and MDO/asphalt flux markets as well as the facilities providing these products. This would in turn convince operators to develop increased used oil processing capacity.

Currently, the rerefining facility operator in California is proposing to double the rerefining capacity, which will improve the economics for rerefined oil products. To address the limited flux market, the distillation facility in California could be upgraded with improved technology to produce a 75% MDO yield at the current 40 million gal per year capacity with an additional benefit of lower net energy input. Proposals to double the rerefining capacity and to upgrade distillation equipment can also be supported based on benefits presented in this paper. These two changes combined would decrease the total heavy metals emissions outlined in this paper by 40%.

Acknowledgments

The conclusions reached herein represent those of the authors and do not necessarily represent those of the State of California.

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