California Integrated Waste Management Board

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Contractor's Report To The Board

Evaluation of High Efficiency Oil Filters in the State Fleet

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Executive Summary

The mission of the California Department of Toxic Substances Control (DTSC) Office of Pollution Prevention is to reduce hazardous waste generation. Many State agencies, including the Department of General Services (DGS), operate vehicle fleets and are focused on reducing operating costs as well as protecting the environment.

In the transportation sector, extending oil drain intervals is one way to save money and reduce the generation of used oil, a hazardous waste in California. High efficiency (HE) oil filters, which clean motor oil better than standard filters, extend the useful life of engine oil. However, despite demonstrable savings from reduced motor oil purchases and waste oil generation, HE filter technology has not been widely adopted.

California State agencies operate a combined fleet of more than 70,000 vehicles, which provided an excellent opportunity for demonstrating the cost savings and environmental benefits of this technology. With the goal of source reduction in mind, the California Integrated Waste Management Board (CIWMB) contracted with DTSC to study the benefits and barriers to using HE oil filters.

Study Approach

The project had four goals: (1) discover why State agencies have not yet adopted this technology, (2) identify barriers to its adoption, (3) determine how the barriers could be overcome, and (4) demonstrate the technology's performance in actual fleet operations.

To accomplish these goals, DTSC employed a six-step methodology:

1. DTSC conducted a literature search on HE filters and extended oil drain intervals.
2. Staff then prepared and administered a fleet managers' survey to learn why State agencies have not adopted this technology and what adoption barriers existed.
3. DTSC then held focus group meetings with fleet managers to identify ways to overcome the barriers.
4. Fleets representing a variety of engine types and sizes were then recruited for the demonstration phase. Operators recorded mileages and oil change events for each vehicle. They also collected oil samples and sent them to a private laboratory for analysis of the oil's physical and chemical parameters. This included viscosity, total base number (TBN), oxidation, and nitration, along with oil contaminants such as water, soot, and wear metals. Original drain intervals were used to establish a baseline for comparison. Oil analysis results were used to predict oil degradation rates and propose new oil drain intervals.
5. Next, a cost-benefit analysis of proposed extended drain intervals was prepared from the projected costs and savings for each vehicle type.
6. DTSC staff completed the project with a survey of the operators of vehicles in the demonstration and with the development of an outreach mailer suitable for fleet operators.

Results

Literature Search on High Efficiency Oil Filters

Staff reviewed over 200 articles concerning HE oil filter technology and extended oil drain intervals. Most articles had descriptions of reduction in engine wear, operating costs, and waste generation with HE filter usage. Because most wear results from particles in the 5-20 micrometer (µm) size range (the oil film's thickness between moving parts), numerous studies documented a correlation between filtration efficiency and engine wear.

The HE filters used in this study claimed filtration of particles to 1-2 µm, much better than standard filters of 30-50 µm. Using standard filters is one reason that motor oil needs to be changed; it gets dirty with small particles which results in engine wear. In this regard, standard filters have not improved over the years compared to significant improvements in motor oil quality. The oil change interval set in warranties is a result of standard filters being the limiting factor, not the motor oil quality. Hence, higher quality filters will help to extend motor oil life to its full potential.

Fleet Manager Survey and Focus Groups

To investigate barriers to HE filter technology use, staff mailed surveys to 1,987 fleet managers. Two hundred and sixty-two surveys were returned (a 13 percent response rate) including responses from several State agencies, and other public and private fleet operators representing a broad spectrum of vehicle types and sizes. Concerns consistently reported across fleet size, vehicle type, and operator type included: purchase and installation costs; maintenance expenditures; HE filter performance; and engine warranty limitations.

Fleet operators in five focus groups met to validate the survey results and to identify ways to overcome the barriers. Focus group participants expressed skepticism about the technology's performance claims and identified additional institutional barriers such as service schedules and record-keeping requirements. Focus group recommendations included suggestions to eliminate many adoption barriers, such as encouraging manufacturers to include HE technology as standard equipment on new vehicles. The groups also helped to define the demonstration study goals and to identify what information should be collected.

Demonstration of Extended Oil Service Intervals

Four State agencies, two local school districts, and one local transit agency partnered with DTSC for the study's demonstration phase. Throughout the two-year study, a total of 119 vehicles completed the demonstration and accumulated nearly 3 million miles with no reported engine failures.

Table 1 shows the participating agencies, the number and types of vehicles involved, and summary of information gathered during the study. Projected drain intervals were derived for each vehicle type based on oil sample results, motor oil performance, and contamination limits, and then compared to baseline original drain intervals. In general these projected intervals are conservative and some vehicles of each type studied achieved distances beyond these values.

Drain interval extensions were achieved for DGS vehicles using standard filters and motor oil. CAL FIRE and Caltrans trucks and FAX compressed natural gas (CNG) fueled buses (all using OilGuard HE filters) achieved a three-fold extension to 18,000 miles. Both FUSD and LBUSD bus fleets used the Luberfiner ZGard HE filter and achieved equivalent results with extension to 36,000 miles. CDC buses used puraDYN filters and achieved drain intervals of 50,000 miles.

Table 1. Fleet Vehicle Results Summary

Participating Fleets	Number and Type of Vehicles	Filter Make and Model	Miles Accumulated During Study	Oil Samples Collected	Original Drain Intervals	Proposed Drain Intervals	Projected Payback Period (yrs)
Department of General Services (DGS)	40 passenger cars	Fram X2	798,000	212	6,000	10,000	0.2
California Department of Forestry and Fire Protection (CAL FIRE)	13 two- and three-axle trucks	OilGuard EPS 60	134,980	42	5,000	18,000	3.1
California Department of Transportation (Caltrans)	5 two- and three-axle trucks	OilGuard EPS 60	160,711	39	6,000	18,000	1.3
Fresno Area Express (FAX)	10 city transit buses	OilGuard EPS 60	179,099	56	6,000	18,000	3.7
Fresno Unified School District (FUSD)	14 school buses	Luberfiner ZGard LPF9750	116,618	34	9,000	36,000	2.5
Long Beach Unified School District (LBUSD)	26 school buses	Luberfiner ZGard LPF9750	505,115	57	10,000	36,000	6.8
California Department of Corrections (CDC)	11 coach buses	puraDYN TF 40	949,649	100	10,000	50,000	3.6

Fleet Manager Post-Survey

Participating fleet managers were surveyed at the demonstration’s conclusion. Some managers reiterated concerns voiced in the initial survey and focus group meetings. Cost and warranty limitations were not the main issues, however. Now, operational problems such as logistics, maintenance schedules, and record-keeping became predominant. They expressed satisfaction with the HE filter technology’s performance and reliability; however, only one fleet manager planned to continue using HE filters. There is resistance to changing the prescribed maintenance schedules that operators have followed over time. Clearly, significant barriers remain to adoption of HE filter technology.

One issue mentioned during the demonstration is the difficulty maintaining a separate maintenance schedule for relatively few vehicles. If all vehicles in a fleet were equipped with HE filters this should become a non-issue.

Operators also voiced concern about putting vehicles back into service while waiting for oil analysis results, and then needing to call the vehicle back in for an oil change if the analysis results deemed it necessary. This results in extra costs and disruption. Over time and with experience, operators should become comfortable with a given extended mileage and be able to settle into consistent operation.

Cost-Benefit Assessment

Costs for filters and elements, oil analysis, and labor were balanced against those of lower motor oil purchases, reduced used oil generation and other savings. Proposed extended drain intervals were established from demonstration vehicle results based on oil quality criteria and fleet operator comfort with engine safety. Estimated economic payback periods were determined based on the cost-benefit analysis for each fleet studied.

Table 1 shows payback periods for HE filter-fitted fleets ranging from 1.3 years to 6.8 years. Periods were highly dependent on engine sizes and drain extensions achieved. Oil drain extensions on passenger vehicles had much shorter payback periods primarily because savings from reduced motor oil purchases were offset by only oil analysis test costs. Over time, the overall economics and payback periods should improve, primarily because as fleet managers became comfortable with drain extensions, they typically reduce the number of oil analyses they collect. While not included in this cost-benefit analysis, there will also be an added benefit of increased fleet operating time in the field for many vehicles. Hence, the calculated periods in Table 1 are conservative.

Principal Study Findings and Recommendations

The three key findings and three recommendations from the study are:

Finding 1: For any type of vehicle, oil drain intervals can be simply and safely extended beyond their current level to the maximum mileage recommended by the vehicle/engine manufacturer, or further.

The study confirmed that today's average oil change interval is considerably shorter than the maximum suggested by oil analysis results. The fleet managers' survey showed an average passenger vehicle oil change interval of 4,460 miles, which is well below some manufacturers' recommendations of 7,500 miles or even 10,000 miles. The oil analysis results showed that oil drain intervals can be safely extended for all vehicle types studied. Oil sampling results indicate that in many cases, oil drain intervals can be extended beyond warranty limits.

Finding 2: Fleet operators can further extend oil change intervals by using higher quality oil and by using oil analysis for determining optimum drain intervals.

The oil quality parameter that triggered an oil change was unique to each fleet, the motor oils used, and operating conditions. However, in most cases, the limiting factor was the oil's Total Base Number (TBN), which is a measure of the oil's ability to neutralize acids. Oils with higher initial TBN levels and longer-lasting additive packages are important factors in extending the useful life of engine oil. For engine safety, routine oil analysis is an important tool for ensuring oil functionality.

Finding 3: In larger engines, HE oil filters are an effective and economical technology for extending oil drain intervals.

Typically, diesel engine fleets achieved the greatest extensions when using motor oil with higher initial TBN levels or HE filters that addressed TBN consumption. The puraDYN filter design features a time-released additive package that replenishes the oil's buffering capacity. The Luberfiner ZGard filter has a zinc liner that mitigates acid buildup in the oil. Both address the TBN consumption and provide high filtration, thereby extending oil drain intervals the furthest. Other HE filters with only high particulate filtration also produced lengthened drain intervals.

Recommendation 1: Develop outreach that convinces fleet operators to follow manufacturers' recommendations for oil change intervals and institute routine oil analysis programs for extended oil change intervals.

Targeted outreach is necessary to convince fleet managers of the advantages to extended drain intervals. Outreach should include training on oil sampling and interpretation of oil analysis results. Promotional information featuring this project's results could influence fleet managers and their behavior.

Recommendation 2: To overcome adoption barriers, promote HE filter usage by establishing education, training, and outreach programs for managers with large engine vehicle fleets.

Vehicles with larger engines (higher oil sump capacities) and those that accumulate significant annual mileages appear to be the most appropriate HE filter candidates. Large-engine vehicle fleet managers need outreach programs to help overcome HE technology adoption barriers. Focus group participants recommended promoting testimonials from satisfied HE filter users. Informational fact sheets, training programs, and consultations could lessen vehicle maintenance tracking and operational concerns. A technical resource center for ongoing consultation services and oil condition recommendations would support fleet managers who implement extended drain interval programs. For new vehicles replacing aging fleet models, fleet managers could specify HE filters as original equipment and avoid manufacturers' engine warranty concerns.

Recommendation 3: Vehicle producers, engine manufacturers and oil formulators can endorse extended oil drain intervals.

Vehicle producers and engine manufacturers can include HE oil filters as original equipment, require the use of higher quality motor oils such as synthetics, and install monitoring systems for safely extending oil change intervals. Honda, General Motors, Mercedes-Benz, and BMW use oil change indicator systems on their vehicles. This needs to be expanded to all new vehicles sold by all auto makers. Oil formulators can market oil blends with additive packages and buffering agents designed specifically for extended drain intervals. Procurement specifications can include purchases of vehicles and oils that support extended drain intervals. CIWMB and DTSC should work together to contact vehicle manufacturers with these recommendations.

Introduction

DTSC's Office of Pollution Prevention and Technology Development (OPPTD) demonstrated the performance of high efficiency (HE) oil filters in the State fleet.[1] This report presents the results of the study, and provides recommendations that foster and encourage adoption of HE filter technology in both State and private fleets. This study was designed to:

1. Discover why State agencies have not yet adopted this technology.
2. Identify barriers to its adoption.
3. Determine how the barriers could be overcome.
4. Demonstrate the technology's performance in actual fleet operations.

Each year, Californians purchase approximately 270 million gallons of new oil and generate over 116 million gallons of waste oil. Better oil filter designs would lead to longer drain intervals by cleaning engine oil better than standard filters. This would conserve resources and reduce waste generation.

The trucking industry has used HE oil filters for several decades, claiming they provide better filtration and extend drain intervals. Articles in industry publications describe how "Oil doesn't break down; it just gets dirty," and present case studies of "Million mile trucks – using bypass filters." If the oil change interval on all vehicles in California were doubled, motorists would save hundreds of millions of dollars, and conserve more than 1 million barrels of crude oil each year.

However, HE filter technology has not been widely adopted, despite manufacturer's claims that the filters reduce operating costs and waste generation. Very few State agencies use HE filters on their vehicles. In 2007, the State purchased approximately 311,000 gallons of motor oil for its fleet of over 50,000 vehicles. Doubling the oil change interval with HE filters would decrease motor oil purchases by half and save more than $1 million in purchase costs each year. This study explored why State agencies have not implemented this technology and suggests ways to overcome these barriers.

HE Oil Filter Project Overview

For the HE Oil Filter project, DTSC staff:

1. Identified HE oil filter manufacturers and compiled technical information for remote-mounted bypass, centrifugal/bypass, and combination-type spin-on/bypass filters.
2. Surveyed State, local government, and private fleet managers to identify barriers to HE oil filter use.
3. Held focus group meetings where fleet managers reviewed survey results. These managers inspected the filters and discussed ways to overcome barriers identified in the survey.
4. Designed a demonstration project that addressed the barriers, and measured the filters' environmental benefits and costs savings.

DTSC purchased 119 filters and replacement elements for participating State agencies and local government fleets. The participating fleets installed the filters, collected periodic oil samples, and recorded vehicle mileages and service events. DTSC used oil analysis results to ensure the oil's continued usability and to predict optimum change intervals. Additionally, a cost-benefit analysis of HE oil filter technology was performed.

Background

Used oil includes spent lubricating oils, such as motor and transmission oils, and waste industrial oils. Three primary management methods exist for used oil:[2]

1. Burning waste oil for energy recovery is the most common method.
2. Waste oil can also be recycled by distilling it into marine diesel fuel.
3. Waste oil can be re-refined to meet virgin product standards, and then re-supplied for its original use. Less used oil is re-refined into new lube oil than is managed by any other method.

However, the most desirable management method is decreasing waste oil generation directly through source reduction. Source reduction is preferred because of energy and material conservation. Using HE filters to extend oil change intervals achieves source reduction.

HE filter technology has additional benefits. HE oil filters have been shown to reduce abrasive engine wear. A study by General Motors (GM) (Staley, D.R. 1988) correlated engine wear with filter efficiency.[3] Researchers added dust to the engine oil, and used two different-sized filters. They weighed engine parts before and after testing. GM concluded that dust particles in the exact size of the oil-film thickness, 2 to 22 µm, abrade engine parts at the greatest rate. They also found that the filter's ability to remove the most abrasive particles had been accurately predicted by the single pass efficiency test. Engine wear was reduced by 50 percent with 30 µm filtration versus 40 µm, and by 70 percent with 15 µm filtration.

Physical and Chemical Oil Parameters

Viscosity, the fluid's resistance to flow, is the most important physical parameter used to determine oil condition. It increases when oil oxidizes, or is contaminated by water, soot, or dirt. Viscosity decreases when the oil molecules break down or when oil is diluted with fuel.

The total base number (TBN) measures the oil's acid-neutralizing capacity, and is the most important chemical parameter used to determine oil condition. Acids are formed in the engine during combustion processes. The three main acids are: sulfuric acid from sulfur in the fuel, nitric acid from nitrogen in the air, and organic acids from the oil's thermal breakdown. Initial TBN decreases as the oil's acid-neutralizing components are consumed.

Oil Additive Packages

Zinc dialkyldithiophosphate (ZDDP) is commonly used in engine oils to counter the formation of acids and maintain TBN levels. Diesel and gasoline engine oils with higher initial TBN levels can achieve longer oil drain intervals. Traditional gasoline engine oils have lower initial TBN levels, which are then depleted before the vehicles achieve the higher mileages typical of diesel engines. Motor oils with high levels of zinc and phosphorous damage catalytic converters, which limits their use in automobiles. Depending on different applications, various oil grades and brands have different TBNs. However, synthetic oils generally have higher initial TBNs, and are longer-lasting.

Synthetic Motor Oils

Synthetic motor oils are now common in automobile applications. Originally, they were synthesized from basic petroleum building blocks such as esters and polyalphaolephins.

However, since oil makers won the right to use the "synthetic" label on less expensive Class 3 base stocks, most companies converted to using them. Most synthetics have higher initial TBN levels that provide longer drain intervals. Synthetics also contain less multi-weight viscosity improvers that break down over time. Synthetics show promise for extended change intervals, but they were not part of this study.

HE Oil Filter Designs

Several different HE oil filter designs exist. Generally, these filters are add-on equipment that supplements the standard full-flow filter by filtering a side-stream of the oil. Figure 1 shows the typical oil circulation from the oil pump to the full-flow filter, and then through the engine block. After lubricating engine components, the oil is directed to the bypass filter. Here, it is cleaned to the maximum extent possible, and then returned to the oil sump.

Bypass designs feature a large volume of dense media. Typical claimed pore sizes range from 1-2 μm, compared with a full flow filter's pore size of 25-35 μm. Because of flow restriction, bypass designs filter only about 10 percent of the total oil flow. The combination spin-on/bypass filter design includes both bypass and full-flow filters in a single spin-on unit. Space constraints necessarily mean these filters feature smaller volumes for each type of filter. Additionally, these filters are not available for all vehicle applications.

The centrifugal-type bypass filter uses a rotating cylinder to rapidly circulate the oil. Strong centrifugal forces direct solid contaminants towards the outer wall. There, the contaminants are allowed to build up over extended periods without affecting the filter's performance.

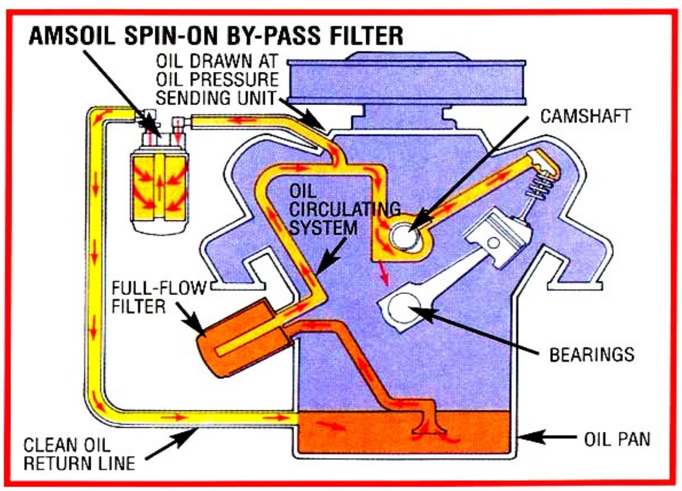


Figure 1. Typical Bypass Filter Installation
(Diagram courtesy of Amsoil Corporation, Superior, Wis.)

Filters that address TBN consumption show an increased capacity for extended drain intervals. One filter design, the puraDYN, features a time-released package of ZDDP. The manufacturer claims this feature helps replenish the oil's buffering capacity, allowing extended drain intervals. Another design, Luberfiner's ZGard, has a zinc liner that mitigates acid buildup in the oil. These designs claim to maintain the oil's buffering capacity, thereby effectively reducing the TBN consumption rate.

Establishing Control Limits for Oil Analysis

Engine manufacturers are reluctant to quantify engine oil contaminants that could impact their warranties. This may partially explain the lack of published control limits for oil condition during extended drain intervals.

Engine manufacturers, oil formulators, analytical laboratories, and proponents of extended oil drain intervals have proposed various oil contamination and wear metal limits. Maximum contamination limits vary for different combinations of oils and engines. Engine wear can be monitored by metal accumulation rates. Engine wear is constant whenever the increase in metal levels is proportional to the mileage. In earlier HE filter studies, researchers postponed oil changes despite results showing high metal levels. They used metal concentrations only as indicators of engine wear, and placed greater focus on the rate of increase rather than the maximum concentration.

Table 2 lists typical sources of metals found in engines. Spectrographic analysis is used to detect increases in normal wear rates, and to quantify both contaminant and additive levels. Standard metals analysis is limited to measuring particles smaller than 10 μm, and is thus of limited value in detecting catastrophic engine failures. In a standard oil analysis, the most significant wear metals are iron, chrome, lead, and copper. Spectroscopy also detects contaminants such as silicon, sodium, potassium, boron, as well as additive package components like magnesium, calcium, barium, phosphorus, and zinc.

Table 3 shows a comparison of oil condition limits from several sources including engine manufacturers and analytical laboratories. CTC Analytical Services (Phoenix, Ariz.) has established general limits for generic, first-time engine samples that do not have any previous analytical history. Herguth Laboratories (Vallejo, Calif.) used conservative values for vehicles without a previous sampling history. For vehicles that were sampled once or twice, Herguth used average values from its database containing over 10,000 results for similar engine and oil combinations. Some labs use only physical and chemical oil parameters to signal an abnormal condition requiring an oil change, and exclude wear metals entirely. Such distinctions are important because fleet managers are more likely to follow the laboratory's oil change recommendations than to attempt establishing their own unique limits.

Contamination is also used to determine the need for an oil change. Soot and combustion solids are of primary concern in diesel engines. Soot is abrasive, and increases the oil viscosity. Elevated soot levels are associated with worn pistons, rings, and cylinders, which allow blow-by of exhaust gases. Excessive idling, restricted air intake, and leaking injector nozzles also increase soot production in diesel engines.

The preceding discussion shows some of the difficulties encountered when attempting to establish limits on oil condition for extended oil drain intervals. Engine manufacturers generally provide limits on only the most basic oil parameters such as viscosity, soot, and iron. Analytical laboratories have published additional recommendations for TBN, oxidation, water, and fuel. Laboratories have also established limits for nitration in gasoline and compressed natural gas (CNG) engine oils, and for sulfination in diesel oils. Meanwhile, wear metals limits are frequently unavailable, and their published values often vary.

Thus, extended drain interval proponents may need to develop unique limits for their vehicles. This also illustrates why installation of the technology on newer vehicles still under the manufacturer's warranty is not an attractive option for fleet operators. Since maximum limits are not provided by engine manufacturers, it is not always possible to prove whether a vehicle has exceeded a safe contaminant level.

Table 2. Typical Metals Found in Engine Oil and Their Sources[4]

Metals	Wear Sources	Environmental and Contamination Sources	Oil Additives
Aluminum (Al)	Piston; shell bearing; bushing; thrust; block; head; blower, additive (grease); cooler cores	Crankcase paint; aluminum manufacturing, aluminum recycling; coal contaminant (trace levels)	
Antimony (Sb)	Bearing alloy; babbitt alloy	Tracer element	
Barium (Ba)	Lube additive	Additive used in well service applications, contaminant carried through breather	
Boron (B)	Lube additive	Coolant additive; mining	
Calcium (Ca)	Lube additive	Water, mining product	
Chrome (Cr)	Various plating, liner, ring, shaft; alloy (stainless steel), e.g., some shafts, gears	Chromate coolant additive (mostly out of use now)	
Copper (Cu)	Bushing; bearing; thrust; piston insert; gear; axial hydraulic piston assembly; cooler cores; rod packing (mostly out of use now)	Copper mines	Occasionally used as an additive in automotive applications
Lead (Pb)	Bearing overlay; bearing alloy; shaft; thrust plating; piston insert; wet clutch	Mining; paint (mostly out of use now)	Gasoline additive (mostly out of use now)
Iron (Fe)	Piston, ring, cylinder, gear; block; head; cam; shaft; roller bearing; shell bearing back; seal	Rust, machining, mining	
Magnesium (Mg)	Lube additive; some turbine metallurgy	Seawater	Oil additive, off-the-shelf supplement
Molybdenum (Mo)	Ring plating, alloy		
Nickel (Ni)	Steel alloy; 'heavy' fuel contaminant (usually with vanadium and sodium); satellite (cobalt-nickel) valve seat		
Phosphorus (P)	Lube additive; synthetic phosphate ester lube	Brass/bronze alloy	Phosphoric acid
Potassium (K)	Coolant additive		
Silicon (Si)	Wet clutch; brake materials	Abrasive (dirt); silicate coolant additive; silicone seal; glass manufacturing	Defoamant additive; synthetic lube
Silver (Ag)	EMD wrist pin bushing/turbo bearing; bearing plating or alloy (needle bearings)	Silver solder	
Sodium (Na)	Lube additive latent (harmless) from lube additive preparation	Coolant additive; salt water	
Tin (Sn)	Bearing/bushing/piston plating or alloy	Manufacturing processes, recycling processes	
Titanium (Ti)	Gas turbine bearings/hubs/blades	Paint (White lead)	
Zinc (Zn)	Lube additive	Galvanized metals/plumbing; brass/bronze alloy	

Table 3. Comparison of Oil Condition Limits from Various Sources

Oil Condition	Caterpillar[5]	Detroit Diesel[6]	Detroit Diesel/MTU	Cummins	Noria[7]	CTC Analytical Services	Chevron LubeWatch Diesel[8]	Chevron Diesel[9]	Herguth Laboratories
Physical/ Chemical									
Viscosity (cSt @ 100 C)	+/- 3.0	12.5 – 16.3	16.3		+/- 25%			+ 25%	16.8
TBN (mg KOH/g)	50%	2		2		3			2
Contaminants									
Soot (% wt)		3	3	3	3	3			1.5 – 3.0
Oxidation (Abs/cm)					25				30
Water FTIR (% vol)	0.5	0.3	0.3		0.25				0.1
Sulfination (Abs/cm)									30
Fuel (% vol)	4	2.5	2.5	5	3	3		5.0	5
Glycol (% vol)	0	0	0		Any				0.2
Metals (ppm)									
Iron		150	150	75 – 100		100	150	100	145
Aluminum				15		18	30	40	5
Chromium				15		12	25	40	5
Copper		30	30	20		30	50	40	21
Lead		30	30	30		30	50	100	10
Tin						18	25		8
Nickel						10	10		4
Silver							5		4
Antimony									
Silicon				15	20	20	25	20	20
Sodium				40	30			50	
Boron					20			20	
Zinc									
Phosphorus									
Calcium									
Magnesium									
Barium									
Molybdenum									
Potassium				40					

Literature Review

Staff began the HE project with a literature review of journal articles and Internet publications. The review included filter manufacturers' product information and independent testing reports to verify manufacturer claims and recommendations. The articles came from engineering and testing reports; trade publications; commercial websites; and federal, State, and private organizations. Article subjects included: extended change intervals, oil analysis, pollution prevention, new and existing filter types, testing, and warranties. Staff assembled a bibliography of 219 papers (Appendix 2). They reviewed all available information on the applicability and warranties for commercially available HE oil filters. The review showed that while motor oil had improved significantly over the years, oil filter capabilities had remained constant.[10]

Other Studies on HE Oil Filters

Additionally, staff identified several reports on other HE oil filter studies. The Idaho National Laboratory (INL) had conducted a three-year study on diesel buses and gasoline-powered Chevrolet Tahoes. Seventeen vehicles were fitted with puraDYN filters. During the testing, more than 980,000 miles were run on the buses and more than 300,000 miles on the Tahoes. Oil condition was monitored by collecting 240 samples from the vehicles. The filters extended the oil drain intervals, reducing oil purchases and waste oil generation by nearly 90 percent. The buses accumulated almost 30,000 miles per year. Installation of HE filters on the buses had a positive payback at 72,000 miles, or slightly less than two-and-a-half years. For the Tahoes, which traveled over 33,000 miles per year, the average payback was at approximately 68,000 miles, or just over two years.

INL established its own physical and chemical contamination criteria for acceptable oil condition. Oil was changed only when its values exceeded or fell below these limitations. The criteria included physical parameters such as viscosity; chemical parameters such as TBN, oil oxidation and nitration; and contaminants such as fuel, water, soot, and glycol. The INL study did not consider wear metal accumulation rates or establish maximum limits.

Another study was conducted in 1997-99 by the North Carolina Department of Natural Resources (NCDNR). North Carolina installed TF Purifiner, Amsoil, and Enviro bypass filters in 60 school buses. Oil analyses were performed every 5,000 miles. Standard full-flow filter changes were reduced to one per year. With these alterations in routine oil sampling and annual oil changes, the return-on-investment was nearly 38 percent, with a 32 month payback period. NCDNR recommended installing these filters on all school buses, and in 2005 added the filters to the State's procurement list.

In 2006, the U.S. Department of Energy issued a report on the use of bypass filters. The report recognized source reduction as a strategic element for minimizing the environmental impacts of used oil, and in conserving finite petroleum resources. Extending the drain interval is essential to reducing waste oil generation. While oil filter technology has remained essentially the same, the report noted continual improvement in motor oil quality over the past 30 years. Today's lowest grade motor oil now has sufficient additives for 8,000–10,000 miles; however, standard filters clog in about 5,000 miles, making an oil change necessary. The report stated that, in some cases, major automobile manufacturers have enough experience with onboard diagnostic systems to use 10,000–12,000 mile oil changes. This more than doubles the current U.S. average oil change interval, which is approximately 4,500 miles. Adopting this new oil change interval would reduce waste oil generation from the automobile sector by half. The report showed that oil change intervals of nearly 20,000 miles can be achieved using fully synthetic oils. Heavy-duty vehicles were shown to achieve oil change intervals of 60,000 miles and more with HE filters.

Benefits resulting from the use of HE oil filters

Cost savings is one major potential benefit resulting from using HE oil filters. Such savings are straightforward and easy to compute; however, other benefits may be intangible and realized only by individual fleet managers based on their unique circumstances. Environmental benefits are in this latter category. HE filters extend the time between oil changes and reduce waste oil generation, which is a significant environmental benefit. However, bulk oil is inexpensive and the payback period can be lengthy. Therefore, minimal savings and high initial investment costs may outweigh environmental benefits. HE oil filter makers also assert that their filters decrease engine wear, thereby reducing maintenance and extending the time between engine overhauls. Those savings were not quantified in this study.

Furthermore, HE oil filters can also be used in stationary or remotely-operating engines which may be difficult to access for servicing. The filters are used to enable extended operation over prolonged periods. Examples are crop harvesters and other farming equipment that cannot be brought in from the field during the planting, harvest, or other critical seasons.

Fleet Managers' Survey

Staff developed a survey to investigate fleet managers' perceptions, previous experiences, and current HE oil filter knowledge. It identified the fleet managers' barriers to technology adoption, and gathered information on their fleet vehicles and operations.

The survey asked fleet managers about the importance of purchase costs and the maximum allowed payback period. Next, they rated concerns over reducing oil purchases, decreasing engine wear, and engine warranties. Managers were asked about increasing their reliance on oil analysis results, and the value they would receive from increased service intervals. Additional questions about filter performance, reliability, and warranties followed. Each issue was rated on a scale of 1 ("Not Important") to 5 ("Very Important.")

The survey also included questions about vehicle types, ownership, and leasing. Information was collected about average annual mileages, oil change intervals, and the operator's familiarity with HE oil filters. Ample space for additional comments and a call-back number were also provided. The fleet managers' survey is included in Appendix 3.

The survey targeted State, local government, and private fleet managers with high annual mileage vehicles. Fleet managers were identified by utilizing all available fleet lists, such as the State's "Green Driving" group; DTSC's vehicle service repair project; university, state, and community colleges; and local school districts. Additional fleets included transit districts, private trucking companies, and taxi cab operators.

In fall 2003, DTSC mailed the survey to 1,987 public and private fleet managers. Table 4 summarizes fleet manager responses to the survey questions.

Table 4. Fleet Manager Survey Questions and Responses

Number of Survey Respondents *A total of 1,987 fleet managers were surveyed by mail*				**262**
Costs and Benefits Resulting from High Efficiency Oil Filter Use *If you were considering whether to purchase high efficiency oil filters for your fleet, how important would these costs and benefits be for you?*				*Average of responses on a scale of 1 to 5 with 5 as most important*
Reducing oil purchases				3.8
Decreasing engine wear				4.3
Increasing the time between vehicle service intervals				3.8
Purchase and installation cost				4.1
Ongoing filter service cost				3.9
Oil analysis results				3.5
Potential effects on engine warranty				4.3
Product support from the filter manufacturer				4.0
Performance and reliability of the filter				4.5
Length of time to recover investment				4.2
Vehicle Information *Complete this table which describes the kinds of vehicles you have in your fleet and how often they are serviced.*				*Total number of vehicles reported for each size and engine classification*
Enter your estimate of how many miles they are driven each year and how many miles they travel between each oil change.	*Number of Managers Operating These Types of Vehicles*	*Average Annual Mileage (*Hours)*	*Average Oil Change Interval*	
Passenger cars	182	17,215	4,459	25,395
Pick-up trucks or vans	221	15,321	4,341	25,445
Medium trucks or vans	180	14,138	4,353	10,808
Large trucks or vans	115	17,692	5,136	6,239
Semi-tractors	90	79,732	9,543	13,973
Buses	82	57,146	6,749	4,455
Off-road vehicles	156	1,662 *	759 *	7,104
Stationary engines	111	349 *	184 *	1,352
Operator Information *Tell us about your fleet management operations:*				
Do you lease your vehicles?				28
Do you service your vehicles in-house?				206
Have you used high efficiency oil filters in the past?				44
Do you specify equipment purchases at your facility?				200
If you were considering whether to purchase high efficiency oil filters for your fleet, what would be the maximum time (months) you would allow for the investment to pay for itself through savings?				16.1

There were 262 surveys returned, which represented a 13 percent response rate comprised of 102 private, 124 local, 30 State, and 6 federal fleet managers. More than 76 percent of the surveys (200) were completed by fleet managers responsible for specifying equipment purchases. The survey represented approximately 95,000 vehicles that traveled a combined 2.5 billion miles annually. Nearly 400,000 oil changes were performed, which generated a conservative estimate of 2 million gallons of waste oil annually.

Table 4 shows the average annual mileages and oil change intervals for various vehicle types. Survey results match the 4,500 mile national average oil change interval for passenger cars.

Barrier Survey Results

Table 5 presents descriptive statistics for cost/benefit survey questions. It provides results for fleet manager sub-groups (current filter users and non-users), and for State, federal, local government, and private fleets.

Cost & Benefit Question Statistics

Table 5 shows the number of responses received, the range of responses (from 1 for “Not Important” to 5 for “Very Important”), and the statistical variability of each response. In identifying the importance of “reducing oil purchases,” the average response by 248 fleet managers (from 262 total) was 3.8.

Of all the cost/benefit questions, the highest average response was 4.5 for performance and reliability of the filter, while the lowest was 3.5 for oil analysis. The overall average response for all survey questions was slightly greater than 4.0, which is as great as the value (4) assigned to the “More Important” response category. Thus, the statistics show that fleet managers considered every question on costs and benefits to be important to them.

Survey responses then were divided into fleet manager subgroups. For current HE filter users, performance and reliability had the highest average of 4.9, while operation & maintenance costs was lowest at 4.0. Perhaps this indicates satisfaction with the technology by these fleet managers. Not surprisingly, non-users ranked oil analysis as least important--perhaps highlighting unfamiliarity with oil analysis and its benefits. Overall, non-users gave lower approval rankings to HE filters than did current users. Presumably, current users were satisfied with the technology’s performance and economics, while non-users indicated a stronger interest in payback periods and other costs.

Of all the questions, the lowest average response was from federal fleets at 3.2 for both operation & maintenance costs and oil analysis. The required payback period was longest for State fleets at 23.7 months and lowest for private fleets at 12.1 months.

Table 5. Descriptive Statistics of Fleet Manager Survey Responses

Descriptive Statistics	Oil Purchases	Engine Wear	Service Intervals	P & I Costs	O & M Costs	Oil Analysis	Engine Warranty	Product Support	Performance & Reliability	Payback Period	Required Payback (Months)
All Respondents 262 responses	**3.8**	**4.3**	**3.8**	**4.1**	**3.9**	**3.5**	**4.3**	**4.0**	**4.5**	**4.2**	**16.1**
n	248	248	248	248	247	248	249	247	249	245	176
Range	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	0 - 120
Standard Deviation	1.189	1.011	1.229	1.020	1.113	1.382	1.100	1.133	0.794	0.981	13.62
95% CI (+/-)	0.169	0.144	0.175	0.145	0.159	0.197	0.156	0.162	0.113	0.140	2.30
Current HE Filter Users 18 responses	**4.5**	**4.8**	**4.3**	**4.1**	**4.0**	**4.4**	**4.8**	**4.3**	**4.9**	**4.2**	**20.4**
n	18	17	17	17	17	16	17	17	16	17	15
Range	3 - 5	2 - 5	2 - 5	2 - 5	2 - 5	1 - 5	3 - 5	3 - 5	4 - 5	3 - 5	12 - 36
Standard Deviation	0.800	0.752	1.105	1.144	1.095	1.115	0.529	0.946	0.243	0.941	10.15
95% CI (+/-)	0.435	0.409	0.601	0.622	0.614	0.606	0.287	0.530	0.132	0.545	6.30
Non-Users 221 responses	**3.7**	**4.3**	**3.8**	**4.1**	**3.9**	**3.4**	**4.2**	**3.9**	**4.5**	**4.2**	**15.9**
n	215	215	215	215	215	215	216	215	216	214	160
Range	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	0 - 120
Standard Deviation	1.182	1.011	1.221	0.998	1.119	1.386	1.129	1.152	0.784	0.986	13.93
95% CI (+/-)	0.181	0.155	0.187	0.153	0.171	0.212	0.172	0.176	0.119	0.151	2.47
State Fleets 30 responses	**3.4**	**3.7**	**3.2**	**4.0**	**3.8**	**3.2**	**4.3**	**3.8**	**4.3**	**3.8**	**23.7**
n	28	28	28	28	28	28	28	28	28	28	18
Range	2 - 5	1 - 5	1 - 5	2 - 5	2 - 5	1 - 5	2 - 5	1 - 5	1 - 5	2 - 5	12 -60
Standard Deviation	1.062	1.243	1.307	1.170	1.166	1.467	1.076	1.228	1.041	1.005	15.7
95% CI (+/-)	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.20
Private Fleets 102 responses	**3.8**	**4.4**	**4.0**	**4.1**	**3.9**	**3.6**	**4.1**	**4.0**	**4.5**	**4.2**	**12.1**
n	96	97	97	97	96	96	97	97	97	96	68
Range	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	0 - 60
Standard Deviation	1.307	1.064	1.262	1.073	1.242	1.476	1.282	1.220	0.830	1.000	9.80
95% CI (+/-)	0.299	0.242	0.287	0.244	0.284	0.338	0.292	0.278	0.189	0.229	2.70
Local Fleets 124 responses	**3.8**	**4.4**	**3.8**	**4.1**	**4.0**	**3.4**	**4.4**	**4.0**	**4.6**	**4.2**	**17.4**
n	118	117	117	117	117	118	118	116	118	115	84
Range	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	1 - 5	1 - 5	1 - 5	3 - 5	1 - 5	0 - 120
Standard Deviation	1.114	0.843	1.150	0.952	0.982	1.290	0.936	1.042	0.686	0.936	15.03
95% CI (+/-)	0.230	0.175	0.238	0.197	0.204	0.266	0.193	0.217	0.142	0.196	3.68
Federal Fleets 6 responses	**4.2**	**3.8**	**3.8**	**3.7**	**3.2**	**3.2**	**3.8**	**3.3**	**4.5**	**3.8**	**22.5**
n	6	6	6	6	6	6	6	6	6	6	6
Range	3 - 5	2 - 5	2 - 5	3 - 5	2 - 4	2 - 5	3 - 5	2 - 4	3 - 5	2 - 5	12 - 36
Standard Deviation	0.983	1.169	1.169	0.816	0.983	1.169	0.753	0.816	0.837	1.169	11.345
95% CI (+/-)	0.900	1.070	1.070	0.747	0.900	1.070	0.689	0.747	0.766	1.070	10.38

Comparison of Fleet Responses

Table 6 provides a statistical comparison of fleet responses using standard tests to discern differences between means. Generally, fleet managers considered each of the cost and benefits presented to them to be important. When measured at the 95 percent confidence level, the average responses for most survey questions were not significantly different. This complicates the ranking of survey responses to identify any particular cost/benefit factor as the most or least important.

However, statistical significance was observed for some questions. Current HE filter users were compared to non-users; differences were observed for oil purchases, oil analysis, engine warranty, and performance & reliability responses. Apparently, current HE filter users recognize the cost savings gained by reducing oil purchases, as shown by their 4.5 ranking versus 3.7 for non-users. By a difference of 4.4 to 3.4, current users recognize the importance of regular oil analysis. Current users ranked engine warranty higher than non-users, by 4.8 to 4.2. Over time, current users may have overcome their warranty concerns by using the technology. Current users also valued HE filter performance more by a difference of 4.9 to 4.5. Thus, non-users are unconvinced that the technology produces tangible benefits.

State fleets differed from private fleets in the areas of engine wear and service intervals. Private fleets considered engine wear to be more important by 4.4 to 3.7, and service intervals to be more important by 4.0 to 3.2. The profit incentive may drive these differences. Private fleets want to maintain their investment in their vehicles, whereas State fleet managers may feel less ownership of their vehicles. Private fleets may see oil service events as a significant cost, so that increasing service intervals may be more beneficial to them than for State fleet managers.

Differences were also observed between State and other fleets. State fleet managers were less concerned about engine wear than were other managers, as shown by a relative importance rating of 4.4 for all other fleets compared to 3.7 for State fleets. In 25 of 30 responses, State fleet managers reported leasing their vehicles, which may indicate less concern about the vehicles' resale value. Of all reporting fleets, only 28 out of 262 respondents reported leasing their vehicles. Therefore, in this survey, vehicle leasing was largely a phenomenon of only State fleets. Other fleets were more concerned with service intervals than were State fleets, by 3.9 to 3.2.

Statistical testing also confirmed the significance of payback periods. Understandably, other fleets were more concerned about payback periods than were State fleets, with an average ranking of 4.2 compared with 3.8 for State fleets. This is confirmed with required payback period differences of 23.7 months for State fleets versus 15.3 months for all other fleets.

Identified Barriers

In addition to oil purchases and oil analysis, identified barriers include the payback period. This indicates fleet manager unfamiliarity with the practice and/or value of regular oil analysis. Predictably, costs and the payback period are important issues. Non-users gave oil analysis results their lowest ranking. Again, this indicates unfamiliarity with oil sample collection, but more importantly, inexperience with the interpretation of and reliance on analytical results.

Non-users are unaware of the requirements, procedures, and benefits of routine oil sampling, a significant obstacle to adopting oil drain interval extension programs and HE filter technology. Statistically, concerns about performance and reliability, engine warranty, and engine wear were indistinguishable.

Table 6. Statistical Comparison of Fleet Responses

Statistical Comparison	Oil Purchases	Engine Wear	Service Intervals	P & I Costs	O & M Costs	Oil Analysis	Engine Warranty	Product Support	Performance & Reliability	Payback Period	Required Payback (Months)
Current HE Filter Users 18 responses	**4.5**	**4.8**	**4.3**	**4.1**	**4.0**	**4.4**	**4.8**	**4.3**	**4.9**	**4.2**	**20.4**
n	18	17	17	17	17	16	17	17	16	17	15
s, Stan Dev	0.800	0.752	1.105	1.144	1.095	1.115	0.529	0.946	0.243	0.941	10.15
Non-Users 221 responses	**3.7**	**4.3**	**3.8**	**4.1**	**3.9**	**3.4**	**4.2**	**3.9**	**4.5**	**4.2**	**15.9**
n	215	215	215	215	215	215	216	215	216	214	160
s, Stan Dev	1.182	1.011	1.221	0.998	1.119	1.386	1.129	1.152	0.784	0.986	13.93
sp, pooled Stan Dev	1.158	0.995	1.213	1.009	1.118	1.370	1.098	1.139	0.760	0.983	13.663
t, table	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960
t, calculated (+/-)	2.763	1.955	1.739	-0.208	0.330	2.724	2.207	1.332	2.264	0.147	1.222
Do Non-User's Responses Differ Significantly from Current HE Filter Users?	**Yes**	**No**	**No**	**No**	**No**	**Yes**	**Yes**	**No**	**Yes**	**No**	**No**
Private Fleets 102 responses	**3.8**	**4.4**	**4.0**	**4.1**	**3.9**	**3.6**	**4.1**	**4.0**	**4.5**	**4.2**	**12.1**
n	96	97	97	97	96	96	97	97	97	96	68
Stan Dev	1.307	1.064	1.262	1.073	1.242	1.476	1.282	1.220	0.830	1.000	9.8
State Fleets 30 responses	**3.4**	**3.7**	**3.2**	**4.0**	**3.8**	**3.2**	**4.3**	**3.8**	**4.3**	**3.8**	**23.7**
n	28	28	28	28	28	28	28	28	28	28	18
s, Stan Dev	1.062	1.243	1.307	1.170	1.166	1.467	1.076	1.228	1.041	1.005	15.7
sp, pooled Stan Dev	1.257	1.106	1.272	1.095	1.225	1.474	1.240	1.222	0.881	1.001	11.229
t, table	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960
t, calculated (+/-)	1.571	2.769	2.897	0.155	0.339	1.344	-0.514	0.700	1.514	2.229	-3.880
Do State Fleet's Responses Differ Significantly from Private Fleets?	**No**	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**Yes**	**Yes**
All Other Fleets 232 responses	**3.8**	**4.4**	**3.9**	**4.1**	**3.9**	**3.5**	**4.3**	**4.0**	**4.6**	**4.2**	**15.3**
n	220	220	220	220	219	220	221	219	221	217	158
Stan Dev	1.196	0.955	1.200	1.003	1.107	1.370	1.105	1.121	0.753	0.968	13.148
State Fleets 30 responses	**3.4**	**3.7**	**3.2**	**4.0**	**3.8**	**3.2**	**4.3**	**3.8**	**4.3**	**3.8**	**23.7**
n	28	28	28	28	28	28	28	28	28	28	18
s, Stan Dev	1.062	1.243	1.307	1.170	1.166	1.467	1.076	1.228	1.041	1.005	15.7
sp, pooled Stan Dev	1.182	0.991	1.212	1.022	1.114	1.381	1.102	1.133	0.790	0.972	13.423
t, table	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960
t, calculated (+/-)	1.912	3.378	2.773	0.248	0.551	1.122	0.056	0.883	1.878	2.295	-2.485
Do State Fleet's Responses Differ Significantly from All Other Fleets?	**No**	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**Yes**	**Yes**

Focus Groups

Following the mail-out and return of the fleet managers' surveys, staff held focus group meetings with State, local government, and private fleet managers. DTSC hired a consultant to conduct meetings where survey results and barriers to HE filter adoption were discussed. Two focus groups met in Sacramento on May 25, 2004; one in Daly City on June 21, 2004; one in Berkeley, on June 23, 2004; and one in San Diego on June 28, 2004. The consultant then prepared a summary report (Appendix 6).

DTSC presented the survey results to focus group participants and asked them about their individual priorities. Similar to the fleet managers surveyed, most focus group participants were unfamiliar with HE filters. These groups expressed more interest in initial costs and payback periods than was found in the survey. Each group questioned the claimed cost savings; however, that posture changed when the filters were displayed. Participants examined 13 HE filters and evaluated a checklist of features. Handling the filters seemed to increase their interest. Filters and manufacturers' information packets became important tools in recruiting fleet manager participation in the demonstration project.

Fleet Manager Survey Validation

To validate fleet manager survey results, focus group participants were shown the relative ranking of various costs and benefits from all survey respondents. While survey respondents ranked performance factors higher than cost factors, focus group participants felt that survey respondents who were administrators considered cost more important while maintenance/service personnel ranked performance factors higher.

Focus group participants felt that the most important performance factor was engine warranty effects. Since engine lubrication failure is very rare, most participants did not put high importance on decreasing engine wear. A city transit fleet manager who wanted to extend his vehicles' engine life was the single exception. State fleet focus group members expressed acceptance of a three-to-five year payback period on the initial investment--which was reported to be half the vehicles' life expectancy. Typically, local governments found one-to-three years as the maximum acceptable payoff period. Interestingly, focus group members gave higher importance to oil analysis, a measure of filter performance, than the survey results indicated.

Approximately half of focus group participants were experienced with oil analysis. Of these, a majority used analysis for engine diagnostics rather than as a tool to extend drain intervals. Measuring oil condition as part of an extended drain interval program was largely unknown to focus groups. They stated a preference for using published or established minimum/maximum limits to determine oil viability. The most important oil failure indicators were TBN and viscosity while the most relevant filter performance measure was metal detection. Focus group participants expressed concern that HE filters decrease the oil analyses' diagnostic value by removing larger metal particles.

Filter Selection Exercise

Thirty participants completed a filter selection exercise where each filter model was scored on the following criteria: (1) performance, (2) design and construction materials, (3) initial purchase and ongoing service costs, (4) ease of oil sample collection and filter change services, and (5) filter warranty.

Of the eleven participants who preferred a particular filter, three chose puraDYN, four chose OilGuard, and three chose Fleetguard. Filter warranty and engine warranty were among the top concerns. Participants praised the puraDYN model for its original equipment manufacturer (OEM) warranty letters stating that filter use would not in itself invalidate the engine warranty; however, some participants thought the puraDYN's 12-month filter warranty was too short. Initial purchase and maintenance costs, including replacement filter element cost, were considered among the most important selection criteria. The filter pore size was of secondary importance. Based on puraDYN's claims of broad material filtration capabilities, participants rated that filter very favorably. Another notable selection criterion was the ease of filter element replacement and the minimal potential for oil spillage during replacement.

Installation concerns included whether:

1. Enough engine compartment space is available for the HE filters.
2. HE filter installation locations can be removed from hot engine components.
3. Feed and drain line routing problems are present.
4. Installation equipment is included in the filter price.

Generally, participants preferred the simpler spin-on filters.

Barrier Identification

Major institutional and servicing barriers that the focus groups identified were: difficulties tracking analyses for large fleets, overcoming skepticism among technicians, and installation and maintenance issues. Several participants claimed HE filters required tracking analyses for countless vehicles while others were troubled by substantial changes to fleet service schedules. Some fleet managers reported mandates that their vehicles be regularly serviced. For example, California law requires that school buses be inspected and serviced every 45 days or 3,000 miles. Typically, a fleet operator schedules service events such as oil changes at multiples of 3,000 miles--perhaps changing oil every 6,000 or 9,000 miles regardless of oil condition.

Meanwhile, other organizations conduct oil changes as part of an overall regularly scheduled service program. Focus group participants felt it difficult to change existing maintenance routines. They predicted general skepticism among technicians who did not follow their regular oil change intervals and left dirty-looking oil in the vehicles. Participants urged technician training to overcome this barrier.

Cost barriers included: large investments in initial equipment purchase and installation, lack of performance and cost-benefit data for making informed purchasing decisions, and oil analysis labor costs. Participants saw a considerable challenge in persuading decision-makers to make HE filter technology investments. They wanted credible, detailed cost/benefit data that could estimate investment payback period. For those managers under budget constraints, purchase and installation costs were significant barriers.

Overcoming the initial cost barrier is crucial. Focus groups suggested that vehicle manufacturers include HE filters as OEM equipment, government agencies negotiate HE filter cost breaks, and that fleets re-use surplus filters on subsequent vehicle purchases. Some participants believed that oil analysis and its tracking would be more expensive and labor intensive than regularly scheduled oil and filter changes. A successful HE filter demonstration accompanied by cost recuperation could overcome this barrier.

Warranty invalidation is one of the most significant barriers identified. While vehicles are under warranty, many participants felt that exceeding recommended oil change intervals was too risky. Suggested solutions included: installation of HE filters after vehicle warranties expire, HE filters as OEM equipment, or engine manufacturers' specifications for acceptable HE filter brands and/or models while under engine warranty along with HE filter oil change interval specifications. Alternatively, engine manufacturers would specify a range of standard oil tests and limits. Within these established limits, extended oil drain intervals could then be used without voiding the warranty.

Perceptual Barriers

The following perceptual barriers proved persuasive: (1) motor oil life extension would be risky, (2) oil analysis labor costs would exceed money saved on fewer oil changes, and (3) HE filter technology would not produce actual cost savings. Many participants also believed that source reduction would be unnecessary if oil is recycled and re-refined. In terms of pollution prevention, most participants were unclear about the difference between recycling and source reduction. They believed that using re-refined oil that met new oil specifications was equivalent to source reduction.

Several participants stated that since oil breaks down because of engine heat, it is too risky to extend oil change intervals, even if the oil is clean. However, several agreed that acceptable oil condition could be confirmed if the analysis showed the proper viscosity. Several participants felt that oil analysis may require the vehicle to come out of service twice, once for sampling and then possibly again if an oil change is recommended by the analysis. Potential savings were not recognized because of perceived labor costs required for tracking oil analyses and filter element disposal.

The focus groups identified the most significant barriers to widespread HE filter use as:

1. Initial cost.
2. Ongoing service and analysis costs.
3. Potential effect on the engine warranty.

Fleet managers wanted detailed cost-benefit information that demonstrates cost savings and estimates the cost recuperation periods and potential performance. This would lessen concerns about engine warranties and encourage HE filter use.

Focus Group Recommendations

Most fleet managers have not used oil analysis to determine oil condition. Training on proper engine oil sampling and oil tracking would be necessary in convincing fleet managers of HE filter safety.

The focus groups suggested that DTSC should use its influence with vehicle manufacturers and gain OEM equipment status for HE filter technology. Such a designation would eliminate the most prominent barriers to widespread HE technology adoption such as engine warranty issues, initial cost justification, and installation costs. They also recommended a DTSC-prepared fact sheet containing basic performance data that challenges misconceptions about oil analysis costs and engine warranties.

DTSC could use testimonials from demonstration participants when promoting HE filter technology. They would exemplify the oil change intervals achieved along with specific vehicle performance and cost-savings data. Endorsing well-known filter brand names may help develop trust and familiarity in HE filter technology.

Advocating acceptable HE filter payback periods and source reduction superiority might compel government fleet managers into seriously considering environmental benefits of the technology. Demonstrating favorable cost recovery from HE filters could motivate private fleet managers. HE filter technology might also be favored by managers seeking a "Green Fleet" certification or other similar incentive/recognition.

Selection of Lab, Filters, and Fleets

Lab Selection

In 2005, DTSC used the competitive bid process for contracting an independent oil analysis laboratory. Appendix 5 shows the Statement of Work (SOW) for the lab. It defined test methods to characterize oil and contaminants for an anticipated 1,200 samples to be collected over a 12-month study period.

Oil samples would be collected from gas, diesel, and CNG vehicles. The bid was developed using a weighting factor of the expected ratios among gas, diesel, and CNG vehicles. An expected 80 percent of the sampling was to be from diesel engines with the remaining 20 percent from gas and CNG engines. Fleet operators collected and shipped samples in lab-provided packaging following laboratory specifications that were consistent with standard practices and chain-of-custody requirements. Each sample package was to be a standard 4-ounce, 38-mm thread-size sample bottle, with a pre-printed bottle label, and pre-addressed, postage-paid shipping box.

During the competitive bid process, DTSC retained Herguth Laboratories (Vallejo, Calif.) as an interim oil analysis laboratory. In April 2005, the lab contract was awarded to Penniman and Brown (Baltimore, Md.). Subsequently, Penniman failed to meet the 48-hour turnaround requirement specified in the SOW that protected vehicles from using "off-spec" oil. Consequently after 20 Penniman-analyzed samples, DTSC directed all subsequent samples to Herguth Laboratories.

Search for HE Oil Filters

From August to November 2003, DTSC staff compiled a list of HE filter manufacturers. Staff also assembled a collection of filters for possible selection and installation into State vehicles. Internet searches, phone contacts to manufacturers, and fleet operators' referrals supplemented the manufacturer's list. Ultimately, staff selected 24 HE filter manufacturers.

In December 2003, staff prepared and sent a 21-point questionnaire[11] to the manufacturers about their filters' features. By April 2004, staff compiled 13 completed questionnaires that represented three HE oil filter types: (1) remote mounted bypass, (2) centrifugal/bypass, and (3) combination spin-on/bypass.

Bypass Filters

Table 7 lists the oil filter manufacturers' information and performance claims**.** Manufacturers returned questionnaires about all three types of filters, but the majority were for remote-mounted bypass filters. The following manufacturers sent completed questionnaires: FiltaKleen, Filtration

Solutions, OilGuard, Oil Purification Systems, Perfect Filtration, Premo, and puraDYN. Amsoil and MotorGuard sent partially completed questionnaires. Centrifugal filters include Spinner II and Vortex.

Fleetguard submitted information on both its centrifugal and a combination spin-on/bypass filter. Luberfiner/Champion also offered a combination spin-on/bypass filter. Some producers provided display or cutaway models for inspection. Several major manufacturers did not reply to the inquiry, including Wix, Baldwin and Donaldson. Filter specification sheets are located in Appendix 6.

Passenger Car Filters

Passenger cars and light trucks are a large portion of the vehicle market. They comprise the majority of private vehicles in the state. An estimated 61 percent of all California vehicles are passenger cars. Meanwhile, light-duty trucks account for 32 percent, with the remaining 7 percent comprised of all medium and heavy-duty trucks. Potential oil savings could be substantial if a suitable filter was found for passenger cars. However, there are few HE oil filter designs claiming to extend oil drain intervals for passenger cars.

Each filter manufacturer underwent substantial research by DTSC staff. This included phone calls and website reviews of major auto supply stores. Staff found several high-end, spin-on filters that contain synthetic media and reinforced structure. However, the Fram X2 Extended Guard, a traditional, spin-on, full-flow filter design, was the only filter located by DTSC that claimed to extend oil change intervals. Its manufacturer claimed an extended 7,000 miles oil-and-filter change interval because of the reinforced, synthetic nylon fiber construction. Its single pass efficiency is approximately 96 percent at 10-20 µm, slightly lower than the 98 percent attributed to other high-end, spin-on filters.

The major manufacturers (Champion, Fram, Purolator, and Wix) also produce most of the full-flow filters that carry other brand names. Many of these “off-brands” are premium filters designed for extra engine protection or heavy duty use. However, during filter selection, staff learned these filters did not claim to extend oil drain intervals beyond the auto manufacturers’ recommendations.

Subsequently, some filter marketers (e.g., Mobil) now offer new products for extended change intervals. Mobil’s filter claims a 15,000-mile extended oil change interval provided Mobil 1 Extended Performance synthetic oil is used. Although synthetic oils have shown growing promise in extending oil changes, they were not part of this study.

Staff also discovered a filter that features a cleanable and reusable screen. This full-flow filter has a metal mesh screen with larger pore sizes than typical bypass filters. Reusable screen filters must be cleaned with a suitable solvent, which generates an additional waste stream. This filter was not included in the study because it was not designed for extended oil drain intervals.

Staff considered bypass filter testing on cars. These smaller-size bypass filters ranged in price from $75 to $122, with filter elements costing from $10 to $15. Even the less expensive of these filters remained too costly to justify an automotive application. The Fram X2 Extended Guard was the only auto-tested filter. Its particle removal efficiency is less than that achieved from bypass filtration. However, marginal oil drain extensions could make an impact since autos generate a large amount of waste oil. By the end of the project, Mercedez-Benz, BMW, Honda, and GM were using oil life sensors, and Ford extended its recommended oil change intervals by 50 percent, from 5,000 miles to 7,500 miles. [12]

Table 7. Oil Filter Manufacturer Information and Performance Claims

Filter Manufacturer	Filter Design	Sump Capacities (qts)	Pore Size (claimed)	Efficiency (claimed)	Warranty	Filter Cost ($)	Element Cost ($)
Filtakleen, Sandy, UT http://www.filtakleen-usa.com/	Bypass w/Cellulose	8, 16, 48, 100	1 µm	66.7% @ 3 µm	2 yr	475 - 649	16- 38
Filtration Solutions, Olathe, KS http://www.fs2500.com/	Bypass w/Cotton	Less than 68, More than 68	2.78 µm	99% for > 3 µm	15 yr	489 - 589	24
Fleetguard http://www.cumminsfiltration.com	Bypass w/Cellulose	5, 85	10 µm	60% @ 10 µm 98.7% @ 20 µm	5 yr	43	N/A
FRAM-X2 Ext. Guard, Perrysburg, OH http://www.fram.com/	Spin-on Full Flow w/Synthetic Fiber	(car)	N/A	94% @ 20 µm	N/A	8	N/A
Gulf Coast / Motor Guard, Gulfport, MS www.bypassfilter.com	Bypass w/Cellulose	6, 12	0.1 µm	N/A	5 yr	150 - 200	1
KleenOil, Leeds, U.K. http://www.kleenoilusa.com/	Bypass w/Cellulose	6, 16,44,172	1 µm	ISO 14/9	Lifetime	329 - 799	22-75
Luberfiner- ZGard, Albion, IL http://www.luberfiner.com/	Spin-On Bypass w/ Zinc-Coated Cellulose	16 - 60	2 µm	75% @ 10 µm	Lifetime	81	35
OilGuard, Oceanside, CA http://www.oilguard.com/	Bypass, Cotton	8, 20,60	1 µm	98.3%@ 10 µm	Lifetime	170 - 220	15- 17
Oil Purification Systems Tampa, FL http://www.oilpursys.com/	Bypass, Melamine Resin	60	3 µm	N/A	10 yr	445	8- 9
Perfect Filtration, Jacksonville, FL www.controlmastersinc.com	Bypass, Cellulose	12, 20, 32, 56	1 µm	98.91% @ 3 µm	1 yr	355 - 462	36- 64
Premo , Tampa, FL http://www.premolube.com	Bypass, Heated, Synthetic	12, 20, 32, 60	3 µm	99.50% @ 3 µm	1 yr	325 - 525	12-35
puraDYN, Boynton Beach, FL http://www.puraDYN.com	Bypass, Heated, Cotton	8, 12, 32, 40, 60	1 µm	N/A	1 yr	258 - 443	17- 34
Spinner II http://www.spinnerII.com	Centrifugal	40 - 100	N/A	N/A	7 yr	425 - 450	N/A
Vortex vfft@vortexfilter.com	Centrifugal, Steel Screen	44,100	N/A	N/A	5 yr	300 - 375	N/A

Matching Filters to Fleets

Table 8 shows oil filter installations on vehicles belonging to State agencies and local governments. Fleet managers attending the focus group sessions were good prospective partners in the study, and helped determine the best match between specific filter designs and individual vehicles. Staff purchased filters for 119 State and local government vehicles. Partnering agencies installed the filters, collected periodic oil samples, and recorded all vehicle mileages and service events.

Staff made extensive efforts to identify and locate State fleets interested in testing the HE filters. They displayed various HE oil filters to interested agencies and then helped them match the filters to their specific vehicles. Staff helped narrow the choices among various bypass filters available and then the agencies made the final choice.

Filter Installation Chronology

Vehicle filter selection and installations began in 2005. Initially, some State fleet managers resisted accepting the HE filters, stating that the filters required extra effort and disrupted routine vehicle servicing schedules. However, after DTSC made presentations directly to their executive staff and, with the assistance of a DTSC marketing specialist, demonstrated how HE oil filters would specifically help their agencies, fleet managers were more receptive toward the filters.

The study’s first partner was the California Department of Corrections (CDC). From their fleet of 30 buses, CDC supplied ten for HE filter installation. In the previous year, they had successfully used a puraDYN filter in a single test bus. In February 2005, DTSC project staff finalized three additional State agency agreements for HE filter installation.

Staff showed the fleet managers and mechanics a variety of appropriate HE oil filters for their specific vehicles. Fleet managers from participating State and local agencies along with survey respondents then made the final filter selections. Most fleet managers performed the filter installations in-house, in order to become familiar with the technology. Some fleets used contractors because they did not have their own mechanics. Technical representatives from the filter manufacturers assisted with installations and provided onsite support.

Despite having the appropriately sized large vehicles, several State agencies declined to participate in the study. Therefore, DSTC staff expanded the candidate search to include local government fleets. From this, Long Beach Unified School District (LBUSD) and Fresno Unified School Districts (FUSD) agreed to test Luberfiner ZGard filters on 20 and 14 buses, respectively.

Then, CDC agreed to equip 15 additional vans with OilGuard filters. This brand was also chosen for 14 CAL FIRE trucks. By summer 2005, staff had identified nearly 100 vehicles for filter installation. Later that year, LBUSD added four more buses, bringing the total vehicle count to 103. DTSC delivered the filters in November 2005.

By the end of 2005, two UC Davis (UCD) trucks, five Caltrans trucks, and one DGS transport truck had been added to the study. In addition, 20 DGS and three UCD[13] cars installed extended-use, full-flow filters.

Part-ordering problems delayed filter installations on CDC vehicles and school buses. CDC buses required additional structural bracing to accommodate larger HE filters, while CDC vans needed an improved drain plug design. LBUSD and FUSD mechanics worked with DSTC staff and identified a detailed school bus parts inventory that was purchased and delivered between January and April 2006.

In late 2006, three LBUSD buses, and 10 Fresno Area Express (FAX) transit buses joined the study. Initially, UCD planned installation of HE filters on five vehicles, but failed to do so because DGS assumed their servicing. Furthermore, CAL FIRE did not install filters on all of the vehicles they had originally planned. Nonetheless, the final vehicles participating totaled 119, excluding 30 control vehicles from DGS and FAX.

Table 8. Oil Filter Installations

Fleet	Number and Vehicle and Engine Type	Engine Type	Sump Capacity	Oil Type and Grade	Filter Brand and Model
California Department of Corrections (CDC)	11 MCI Coach 102 Buses	Detroit Diesel 671	39	Mobil Drive Clean SAE 10W-30 Valvoline All Fleet Plus and Premium Blue SAE 15W-40 Chevron Lubricating Oil SAE 10W-30 Texaco Havoline Formula SAE 10W-30	puraDYN TF 40
	15 GM and Ford Vans	Gasoline GM V8, Ford V10	15	Chevron Supreme Motor Oil SAE 5W-30	OilGuard EPS 20
Department of General Services (DGS)	20 Chevy Cavaliers	Gasoline 4-cylinder	4	Conoco Phillips 76 Firebird LD SAE 10W-30 (re-refined oil)	Fram X2 Extended Guard
	20 Chevy Cavaliers	Gasoline 4-cylinder	4	“ ”	Standard
California Department of Forestry and Fire Protection (CAL FIRE)	5 1985-1997 17-Passenger Crew Carrying Vehicles	International Harvester 1954, 4700, 4900	44	Conoco Phillips 76 Guardol QLT SAE 15W-40 Chevron Delo 400 Multigrade SAE 15W-40	OilGuard EPS 60
	2 1999 Dodge BE 1500 ½ ton PU	Gasoline V8	6	“ ”	OilGuard EPS 20
	1992 GMC C7H042 16' Stakeside	Diesel	12	“ ”	OilGuard EPS 60
	1995 GMC K3500 BDSU 1Ton UB	Diesel	6	“ ”	OilGuard EPS 20
	1991 GMC K2500 ¾ Ton 4WD PU	Gasoline	6	“ ”	OilGuard EPS 20
	1988 Ford LT9000 Transport	Diesel	44	“ ”	OilGuard EPS 60
	1995 International F2574 Transport	Detroit Diesel 350		“ ”	OilGuard EPS 60
	1993 GMC K3599 Dozer Tender	Diesel		“ ”	OilGuard EPS 60
	2002 GMC Sierra 1500 ½ Ton PU	Gasoline V8	6	“ ”	OilGuard EPS 20
	1999 Dodge BE 1500 ½ Ton 4WD PU	Gasoline V8	6	“ ”	OilGuard EPS 20
	Dodge Ram 2500 ¾ Ton 2WD PU	Gasoline V8	6	“ ”	OilGuard EPS 20
	2002 Dodge Ram 1500 ½Ton PU	Gasoline V8	6	“ ”	OilGuard EPS 20
	2005 Ford F350 ¾ Ton PU	Gasoline V10	8	“ ”	OilGuard EPS 20
California Department of Transportation (Caltrans)	2000 Freightliner FC70 Herbicide Spray Truck	Cummins IBS	20	Conoco Phillips 76 Guardol QLT SAE 15W-40 Chevron Multigrade SAE 15W-40	OilGuard EPS 60
	1999 Navistar 4900 Safety Rail Repair	Caterpillar 3126	22-26	“ ”	OilGuard EPS 60
	2003 International Harvester 9400	Cummins N14	44	“ ”	OilGuard EPS 60
	2001 Freightliner FL70	Caterpillar 3126	18-20	“ ”	OilGuard EPS 60
	1996 International Harvester 4900	Detroit Diesel 466	22-26	“ ”	OilGuard EPS 60
Fresno Unified School District (FUSD)	14 Crown Coach Buses	Detroit Diesel 671, 6V92, Cummins 855	39	Chevron Heavy Duty Motor Oil SAE 15W-40	Luberfiner ZGard LFP9750
Long Beach Unified School District (LBUSD)	26 Crown Coach Buses	Detroit Diesel 671	32	Rosemead Soar SAE 15W-40 (re-refined oil)	Luberfiner ZGard LFP9750
Fresno Area Express (FAX)	10 Orion CNG Buses	Detroit Diesel 50 CNG	32	CITGARD CNG SAE 15W-40	OilGuard EPS 60

Filter Testing

The filters were tested both under controlled laboratory conditions and in actual operating fleets. DTSC chose Southwest Research Institute (SwRI) to independently verify filter manufacturer's efficiency and capacity claims. SwRI also tested additive package depletion and water removal in several filters. Appendix 7 contains the SwRI Report. Fleet managers ran the demonstrations and were responsible for all sample collection, mileage recording, and filter servicing. Periodic oil analysis assured the continued oil usability and helped determine new oil drain intervals.

Sample Quality Assurance and Quality Control

Periodically, staff collected quality assurance and quality control (QA/QC) samples. Figure 2 shows a sample being collected from a typical passenger vehicle. Fifteen QA/QC samples were collected in sets of three replicate samples from five different vehicles. Each three-sample replicate set was analyzed without Herguth knowing that they were from the same vehicle. To give a "true" or accepted value for each parameter, the values from each replicate set were averaged. Then, the individual replicate measurements were compared to these averages. The differences are reported as percentages of the average set equal to 100 percent. This method normalizes the data, and yields the precision of the laboratory's analytical technique. It also establishes confidence intervals for the techniques and determines the expected statistical variations for subsequent analyses.

Figure 2. Sample Collection from a Typical Passenger Vehicle

Relative standard deviations for the QA/QC samples are found in Table 9. Herguth showed acceptable control in all their analytical methods, producing 95 percent confidence intervals ranging from 0.81 percent to 9.76 percent. Subsequent analyses can be expected to have values within the lower and upper confidence limits at least 95 percent of the time.

Table 9. Relative Standard Deviation for QA/QC Samples

Parameter	Minimum (%)	Maximum (%)	Relative Standard Deviation (%)	95% Confidence Interval (+/-)	Lower Limit (%)	Upper Limit (%)
Viscosity	95.14	102.43	1.598	0.808	99.19	100.81
TBN	88.39	111.19	5.42	2.74	97.26	102.74
FTIR						
Oxidation	94.29	102.86	1.870	0.947	99.05	100.95
Water	100.00	100.00	0.000	---	100.00	100.00
Sulfination	96.00	108.00	3.239	1.639	98.36	101.64
Fuel	100.00	100.00	0.000	---	100.00	100.00
Glycol	100.00	100.00	0.000	---	100.00	100.00
Metals						
Iron	93.75	106.45	2.940	1.488	98.51	101.49
Aluminum	100.00	100.00	0.000	---	100.00	100.00
Chromium	100.00	100.00	0.000	---	100.00	100.00
Copper	75.00	150.00	19.289	9.761	90.24	109.76
Lead	81.82	128.57	11.543	5.841	94.16	105.84
Tin	100.00	100.00	0.000	---	100.00	100.00
Nickel	100.00	100.00	0.000	---	100.00	100.00
Silver	92.31	115.38	5.036	2.548	97.45	102.55
Antimony	100.00	100.00	0.000	---	100.00	100.00
Silicon	97.67	104.65	1.834	0.928	99.07	100.93
Sodium	96.94	104.80	1.827	0.925	99.08	100.92
Boron	93.70	110.03	3.763	1.904	98.10	101.90
Zinc	92.10	115.14	6.677	3.379	96.62	103.38
Phosphorus	92.19	115.37	6.729	3.405	96.59	103.41
Calcium	93.83	111.81	5.205	2.634	97.37	102.63
Magnesium	93.75	112.50	4.749	2.403	97.60	102.40
Barium	100.00	100.00	0.000	---	100.00	100.00
Molybdenum	95.69	108.19	3.401	1.721	98.28	101.72
Potassium	88.89	111.11	5.261	2.662	97.34	102.66
Minimum	**75.00**	**---**	**0.00**	**0.81**	**90.24**	**---**
Maximum	**---**	**150.00**	**19.29**	**9.76**	**---**	**109.76**
Overall Analytical Average	**94.67**	**108.40**	**3.48**	**2.69**	**98.24**	**101.76**

For example, Table 9 indicates that the TBN test could reliably be within 2.74 percent of the accepted value. As a simple titration, the TBN test--a traditional and more variable "wet chemistry" technique--was expected to show a larger confidence interval. However, Herguth Laboratories uses an automated titration system, which improves the analytical reproducibility.

Overall, the average confidence interval for the entire suite of chemical analyses was 2.69 percent and the QA/QC sample results were acceptable in every case. Table 9 shows the analysis for copper as the worst case, with a 95 percent confidence interval of 9.76 percent. Therefore, Herguth would be expected to produce a subsequent analytical copper result within about 10 percent of the expected value. Results for viscosity, TBN, iron, and lead analyses were found to have 95 percent confidence intervals within six percent or less.

Southwest Research Institute Filter Testing

Southwest Research Institute (San Antonio, Texas) examined filters for soot removal efficiency, and for dust removal capacity. SwRI tested additive package depletion in filters designed to resist acid buildup, and measured water removal in filters featuring a heated element.

Table 10 shows filter testing results for soot removal. To compare soot removal efficiencies, SwRI tested the bypass filters using method ISO/DIS 23556 Performance Test Method for Diesel Engine Soot Removal Devices[14] with Mitsubishi DIA Soot Contaminant. The soot removal test is used only for by-pass filters, and thus was not applicable to standard full-flow filters or the Fram X2. The soot had an average particle size of 200 nanometers and was suspended in CI-4 grade 15W-40 test oil.

SwRI found the average soot removal efficiency for the group was 13.1 percent, with a range of 8.5 to 23.3 percent. This indicates an overstatement in the manufacturer's claims about their filter's soot removing ability. Overall, the puraDYN PFT 40 design led the group in soot removal efficiency.

Table 10. Filter Testing Results for Soot Removal

Filter Model	Soot Removal Efficiency, wt %
puraDYN PFT 40	10.3
OilGuard EPS 60	10.5
Luberfiner ZGard LFP9750	13.5
Premo Plus	11.3
puraDYN PFT 40 with acid	18.6
Luberfiner ZGard LFP9750 with acid	8.8
puraDYN PFT 40 with water	23.3
Premo Plus with water	8.5

Table 11 shows the SWRI test results for dust removal capacity. SwRI used method ISO 4548-12 Full-Flow Oil Filter Test[15] to determine the filter's ability to retain contaminants like dust. This method challenged each filter with ISO 12103-1 A3 medium test dust. Particle count data for the test began at 4 µm. For larger sized particles, both the OilGuard EPS 60 and Luberfiner ZGard LFP 9750 models showed superior retention of the test dust.

Table 11. Filter Testing Results for Dust Removal Capacity

Filter Model	Retained Capacity (Dust), grams
puraDYN PFT 40	4.27
OilGuard EPS 60	33.60[16]
Luberfiner ZGard LFP 9750	37.31[17]
Premo Plus	2.23
Fram X2 Extended	5.86

Water Removal Using Heated Elements

Both puraDYN and Premo Plus systems have a heated element for water removal. An operating engine's oil temperature is greater than boiling water; therefore, any water should evaporate without a heated element. However to verify the manufacturers' claims, water was added to the oil test sump. Evaluations proved inconclusive because the oil temperature was already 105°C and the water may have evaporated before exposure to the heated element.

Reducing the Rate of Additive Package Depletion

Two filter manufacturers claimed that their product reduced oil additive package depletion. The puraDYN filter uses an encapsulated, time-released additive to maintain the TBN. The Luberfiner ZGard filter has a zinc liner that reacts with acids and water and forms solids that can then be filtered out.

In the Luberfiner ZGard system, zinc undergoes the following reactions:

Acids are formed during the combustion process:

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$2\ H_2SO_3 + O_2 \rightarrow 2\ H_2SO_4 \text{ (sulfuric acid)}$$

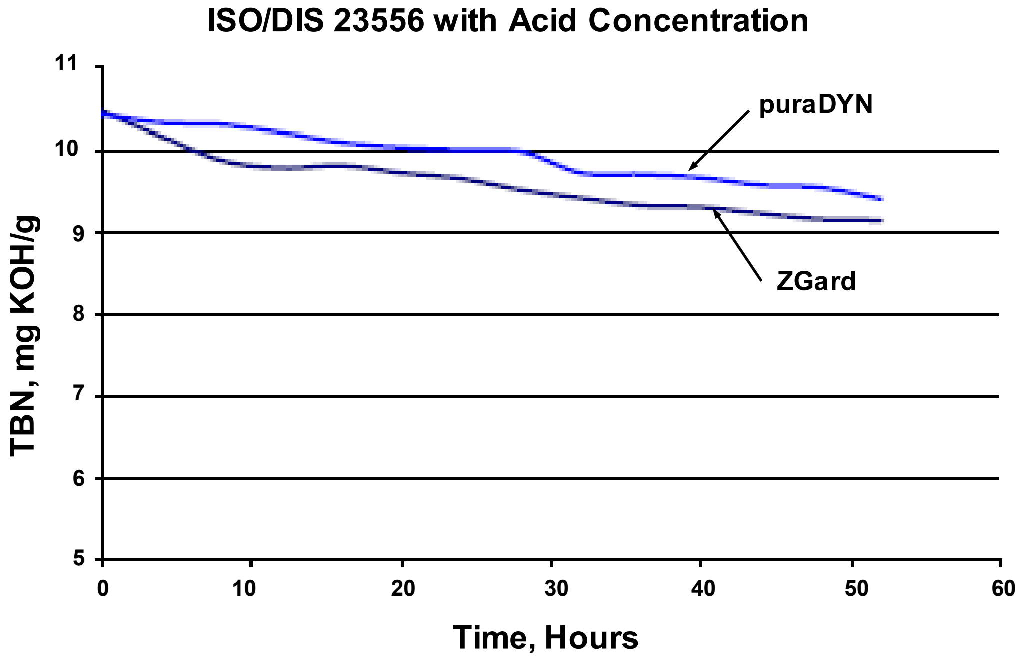
Zinc is available in the ZGard filter and undergoes the following reactions:

$$H_2SO_4 + Zn \rightarrow ZnSO_4 + H_2$$

$$ZnSO_4 + xH_2O \rightarrow ZnSO_4 \cdot xH_2O$$

Figure 3 shows the test results of oil additive package depletion. SwRI evaluated the puraDYN and Luberfiner ZGard filters using a modified ISO/DIS 23556 method that introduced an acid cocktail simulating oil acid buildup. The acid cocktail represented combustion byproducts comprised of sulfuric acid, nitric acid, and acetic acid. Portions of the acid cocktail were added every four hours throughout the 48-hour test. Both filtration systems aided in neutralizing acid and extending the TBN.

Figure 3. Results for the Oil Additive Package Depletion Evaluations



Fleet Demonstrations

Staff provided equipment and technical support for filter installations and operations. They ordered the filters, sampling valves, and sampling equipment for the fleets. During fleet demonstrations and oil samplings, staff collected results, logged them into a database, and consulted with fleet managers about the analyses. For fleet managers' convenience, staff labeled and packaged sampling bottles into return mailers. Staff received lab reports electronically and promptly faxed results to managers enabling quick responses to lab recommendations. Staff then entered results into database and project files.

State and Local Fleets

By May 2006, 150 sample results were received. By August 2006, more than 250 samples were recorded. By April 2007, the database had surpassed 500 analyses. Using database queries, staff was able to evaluate vehicle mileages, costs, and reductions in waste oil generation. Appendix 8 shows fleet mileage and analytical result tables. Appendix 9 is the sample results database. Appendix 10 presents original laboratory reports.

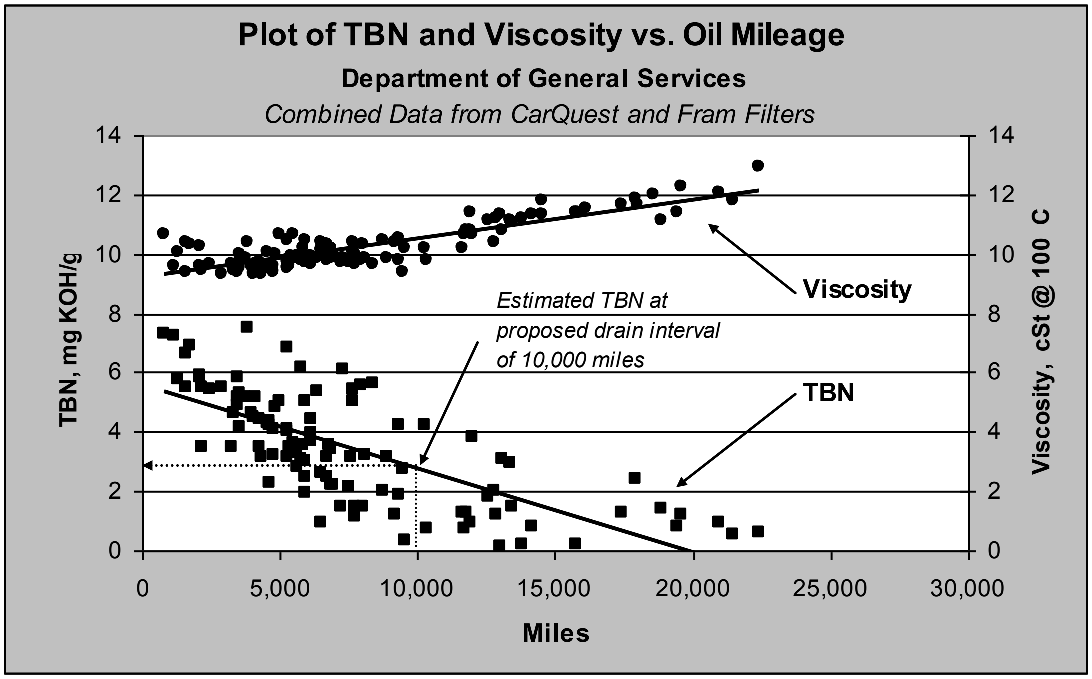
Department of General Services

Since most manufacturers do not offer bypass designs in a size and at a price that would be appropriate for use in smaller vehicles, locating a suitable passenger car filter was difficult. During the selection process the Fram X2 was the only filter identified that claimed to provide extended oil change intervals. The Fram X2 design includes a glass fiber element and a sturdy body. It claimed adequate filtering protection to 7,000 miles.

DGS installed Fram Extra Guard X2 filters on 20 Chevy Cavalier cars. DGS subsequently added 20 additional vehicles to be used as controls. These were equipped with standard CarQuest filters. DGS vehicles had an average annual mileage of 19,971 miles, and accumulated 798,000 miles during the test period.

Figure 4 shows TBN and viscosity vs. mileage for DGS vehicles. The normal trends found with increasing oil mileage are evident, even though the TBN data showed wide scattering. Typically, viscosity increases when dirt and contaminants accumulate, and TBN decreases as combustion products are formed and the oils' initial neutralizing capacity is depleted. Apparently, some variation was caused by differences in the mechanical performance of individual vehicles.

Figure 4. Plot of TBN and Viscosity vs. Mileage for DGS vehicles



Many DGS samples had to be rejected because of sampling errors. Of 187 DGS samples reviewed, staff determined 54 were collected after, rather than before, the oil was changed. These samples showed initial starting TBN values lower than expected for fresh oil, indicating that a complete oil drain was not accomplished. These samples, therefore, were of little value in determining the rate of TBN depletion or estimating the maximum oil drain interval, and were disregarded. Eight additional samples showed TBN values of 0.1, which is the detection limit for the analysis, and so were also disregarded. No differences could be ascertained between the Fram X2 and the standard Car Quest filters performance. Therefore, the data from both filters was combined.

The buffering capacity (TBN) appeared to fail before other oil parameters, and was identified as the limiting factor for extending drain intervals in these vehicles. The previous DGS oil change interval was 6,000 miles. Based on TBN values, the analysis showed the oil to be acceptable up to approximately 10,000 miles. The averaged fleet results suggest that the iron concentration would be about 13 ppm at 10,000 miles, and Herguth Laboratories recommended a maximum iron concentration of 23 ppm for these vehicles. The highest iron concentration was 83 ppm, but was recorded on a vehicle that had traveled 24,100 miles before an oil change. For the DGS vehicles, both nitration and oxidation would be predicted to remain below the recommended maximum of 30 units at 10,000 miles. Averaged fleet results suggest that at 10,000 miles the nitration would be less than 25 and the oxidation would be approximately 16. Even beyond 20,000 miles, additional parameters such as viscosity and other wear metals appeared to remain in the acceptable range.

California Department of Forestry and Fire Protection

The Department of Forestry and Fire Protection (CAL FIRE) received OilGuard filters for installation on 18 trucks. CAL FIRE fleet managers expressed concern about operating their fleets on two different schedules: those with the filters, and those without. CAL FIRE also faces the unique problem that its vehicles are frequently called away from their home base and regular maintenance personnel. While on duty, the vehicles may be serviced by mechanics or contractors who are unaware of the modified oil change intervals. Additionally, the vehicles typically undergo a full maintenance service event, including an oil change, upon returning to their home base.

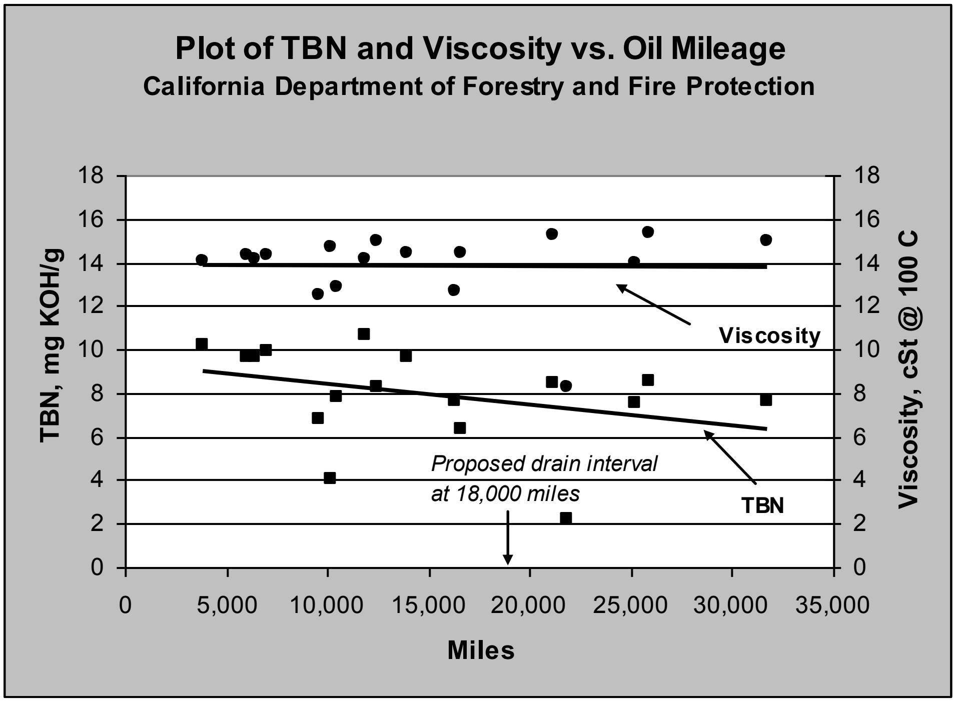
Figure 5 shows a CAL FIRE Crew Carrying Vehicle. CAL FIRE's vehicles traveled an average of 16,873 miles during the study, with a total of 134,980 miles. CAL FIRE's vehicles travel an average of 13,110 miles annually.

Figure 5. CAL FIRE Crew Carrying Vehicle Fitted With an OilGuard HE Oil Filter

Figure 6 shows the TBN and viscosity vs. mileage results for CAL FIRE vehicles. The original oil change interval was 5,000 miles. With the HE filters, the oil appears to remain acceptable beyond 18,000 miles. Wear metal accumulation showed that about 75 ppm of iron would be expected at an oil change interval of 18,000 miles; Herguth recommended maximum levels of 75-150 ppm for these vehicles. CAL FIRE vehicles featured both gasoline- and diesel-powered engines. Measures of oil degradation such as nitration, sulfination, and oxidation all showed a high degree of variability, and could not be used to predict an optimal oil change interval.

Service vehicles operating off-road would be expected to encounter additional oil contaminants. These could include dirt and dust, represented in the analysis by a viscosity increase, and by elevated silica and sodium levels. Figure 6 indicates that the filters appeared to maintain adequate control of viscosity levels throughout the study's course. Silica and sodium were not noted as problems in these vehicles, but should be monitored in any fleet that operates under these off-road conditions.

Figure 6. Plot of TBN and Viscosity vs. Mileage for CAL FIRE vehicles



Department of Transportation

Figure 7 shows a typical HE oil filter installation on a Department of Transportation (Caltrans) service truck. Caltrans installed HE filters on five heavy-duty diesel-engine trucks. Caltrans vehicles included models with both Cummings and Detroit Diesel engines on International Harvester and Freightliner trucks. All were fitted with OilGuard EPS 60 filters. Caltrans vehicles traveled 160,711 miles during the study, and with the HE filters were able to extend their drain interval from 6,000 to 10,626 miles. One vehicle traveled 28,933 miles with acceptable oil parameters.

The maximum iron level recorded was 38 ppm on a vehicle with just 8,214 miles on the oil. Based on the fleet average, the expected iron concentration should be approximately 25 ppm at 18,000 miles. The maximum oxidation and sulfination levels recorded were 16 and 11 units, respectively, well below the recommended 30-unit maximums.

Figure 7. Caltrans Truck with HE Oil Filter

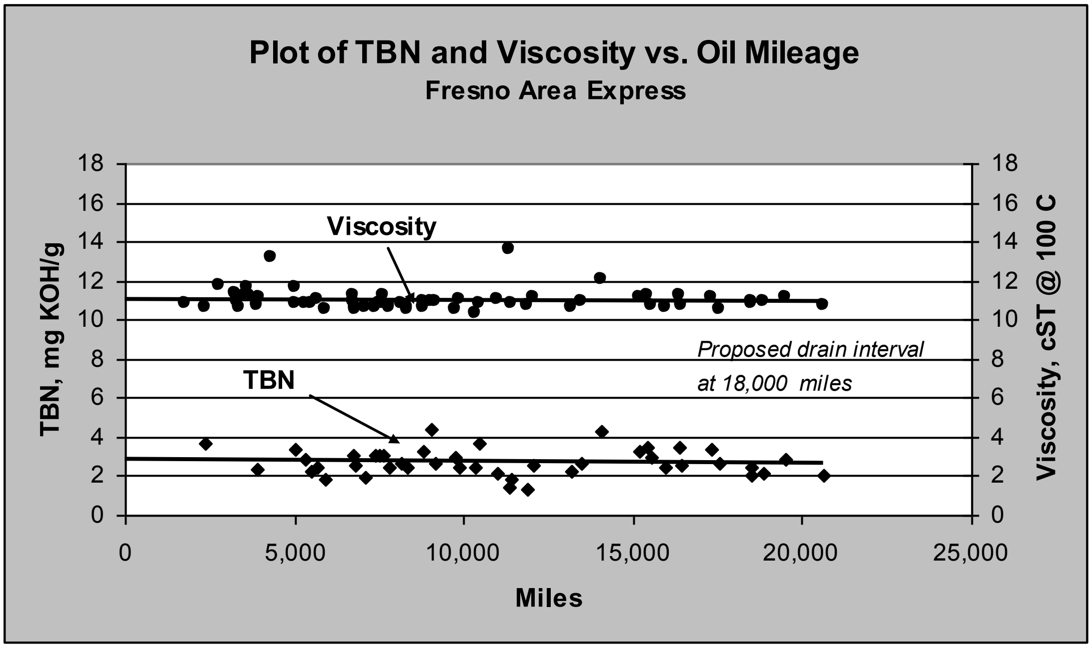
Fresno Area Express

Fresno Area Express (FAX) installed HE filters on ten CNG buses. The FAX buses were added in late 2006, in the project's later phases. FAX sampled the buses frequently, so by April 2007 six or more samples had been collected from each. FAX also began sampling 11 "control" buses with standard filters in early 2007. FAX buses average 46,461 miles annually, and accumulated 179,099 miles during the course of the study.

Using HEPO (formerly OilGuard) HE oil filters, the FAX buses achieved a substantial increase from 6,000 miles to an average of 17,900 miles. In the best case, the oil analysis showed the oil condition to still be acceptable at nearly 20,000 miles. They will probably use twice their original oil change interval, or 12,000 miles, upon full adoption of the technology in the fleet. The FAX fleet manager considers TBN to be the main indicator of oil condition.

TBN, viscosity, oxidation, nitration, and wear metals were considered to establish maximum oil drain intervals for the FAX fleet. Because of the oil used in CNG engines, the initial TBN is lower than that found in other fleets. Fresh CNG oil has an initial value of 5.3. Still, the resulting TBN values appeared to be satisfactory during the course of the sampling. TBN values appeared to be stable, and generally remained above 2.0. Viscosity was also steady, but at a level that was somewhat lower than recommended. The average viscosity was 11.0, whereas the recommended minimum value is 12.0. Figure 8 shows a plot of TBN and viscosity vs. mileage for the FAX fleet.

Figure 8. Plot of TBN and Viscosity vs. Mileage for FAX vehicles



Fresno Unified School District

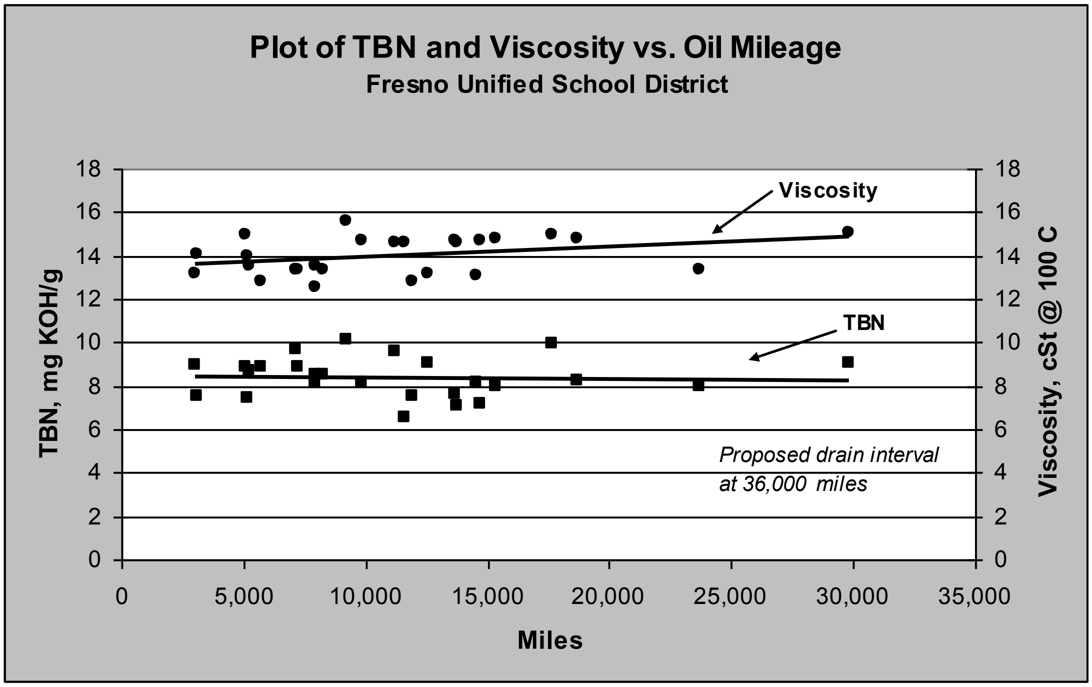
The Fresno Unified School District (FUSD) installed Luberfiner LPF9750 ZGard filters on 13 school buses. The buses traveled 116,618 miles with the HE oil filters during the study period, with an average annual mileage of 17,840 miles. The vehicles achieved an average of nearly 13,000 miles between oil changes compared to a previous change interval of 9,000 miles. In the best case, a bus went almost 30,000 miles. Viscosity and TBN changed little over time in these study vehicles.

Staff evaluated TBN, viscosity, and oil degradation (as measured by oxidation and sulfination) to determine the oil change interval for the FUSD fleet. Because of the zinc featured in the ZGard design, the TBN was maintained at an acceptable level during the test. No FUSD samples failed due to low TBN values. All samples had TBN values above 6.0, close to the initial value of the fresh oil, and well above the minimum level. Because this filter design appears to maintain the TBN satisfactorily, another oil parameter should be used to determine the maximum oil change interval.

In such cases staff considered oxidation and sulfination to identify degraded oil. However, as with TBN, staff found no unacceptable oxidation or sulfination results during the test, so these parameters also could not be used to predict the maximum oil change interval.

In addition, viscosity was maintained at acceptable levels during the test period, and also could not be used to predict a maximum interval. Thus none of the normal indicators, TBN, viscosity, oxidation and sulfination, were limiting factors for this filter or this fleet, when operating under these conditions. The fleet manager reports that he is satisfied with the performance of the filters, and feels that he can safely double his current change interval with these filters. Figure 9 shows a plot of TBN and viscosity vs. mileage for the FUSD vehicles.

Figure 9. Plot of TBN and Viscosity vs. Mileage for FUSD vehicles



Long Beach School District

The Long Beach Unified School District (LBUSD) installed Luberfiner ZGard filters on 26 of their diesel-engine school buses. The first five filters were installed in 2005, an additional 16 in 2006, and the remainder in 2007. The LBUSD fleet averages 13,530 miles annually, and accumulated 505,115 miles during the test period. The previous oil change interval was 9,000 miles. During the study, the average drain interval achieved with the HE filters was 16,033 miles. In most cases, oil analysis showed the oil was still usable at 18,000 miles. Iron concentrations appear to be higher in these vehicles, although 95 percent of the readings were less than 150 ppm at 18,000 miles.

Like the FUSD school buses, LBUSD had similar results with their ZGard filters. The extended mileages achieved could be partially due to zinc in the filter. As with the FUSD fleet, TBN did not diminish quickly enough in the LBUSD fleet to be useful in establishing a maximum change interval. Also, neither oxidation nor sulfination reached maximum levels during the test period. Wear metals for this fleet appeared to be higher initially than with other similar fleets. This could be due to the year or make of the vehicles, or the past maintenance history of the vehicles, but is probably not due to the relative age of the vehicles. FUSD buses had lower iron levels, and an average fleet age of 336,352 miles, while LBUSD buses had higher iron levels, with an average fleet age of 316,404 miles.

California Department of Corrections

The California Department of Corrections (CDC) installed puraDYN filters on ten of their diesel-engine buses, and provided additional oil samples and mileage information from another existing puraDYN installation. CDC also added OilGuard HE filters to 15 of their GMC gasoline-powered vans. However, six vans had chronically excessive levels of potassium and sodium. Coolant leaks were identified by lab reports and articles on oil analysis as the likely source. The CDC contract mechanic and Herguth Laboratories technical staff both said that high-mileage GMC V8s are prone to coolant seepage due to poor engine design, coupled with high mileages on the vehicles. In May 2006, CDC replaced the GMC vans with Ford V10s. Figure 10 shows typical buses from the CDC fleet.

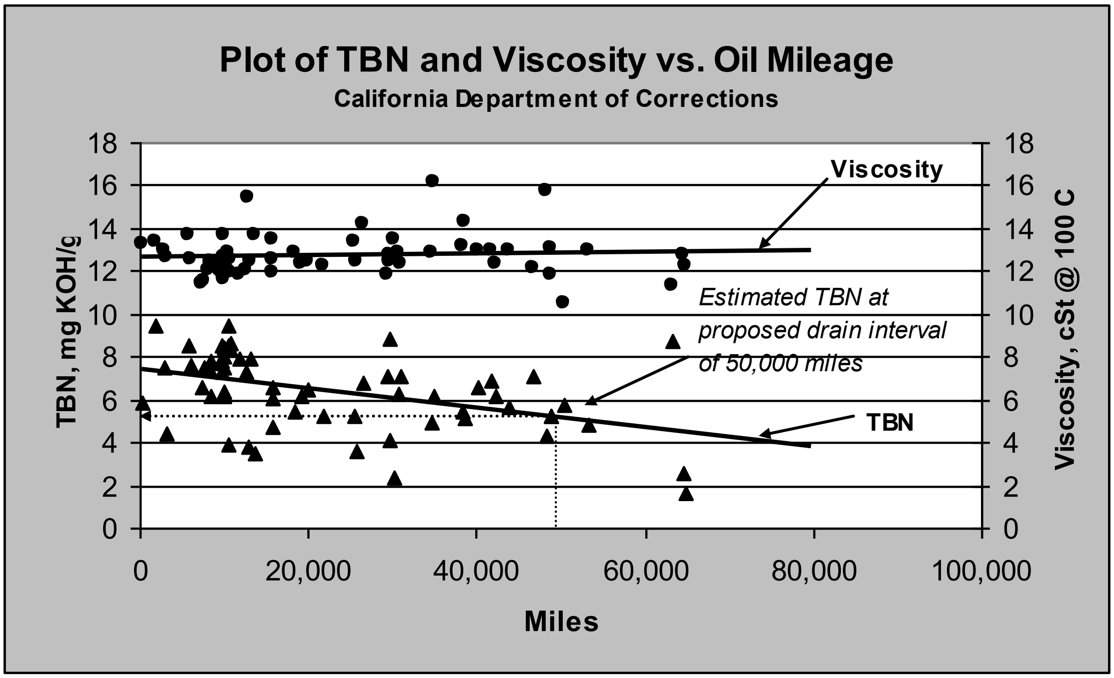
Figure 10. Department of Corrections Buses

Figure 11 shows a plot of TBN vs. mileage for the CDC buses. The TBN line represents the average for all the CDC buses, which accumulated 949,649 miles with puraDYN filters during the study. The data identifies trends that could be used to establish new oil change intervals. Analytical labs typically use physical and chemical parameters, and wear metals, to determine the maximum oil change interval. Figure 11 shows that few CDC buses experienced TBN levels below 2.0, and then only after greatly extended mileage. This effect is presumably due to the additive package in the puraDYN system. CDC uses a variety of oils because their vehicles are serviced in multiple contract locations.

In several instances buses achieved change intervals greater than 50,000 miles, and one achieved a drain interval of 79,777 miles. However, due to inadvertent oil changes that were not based on oil condition, the average oil change interval was just 23,162 miles. No vehicles showed high levels of wear metals during the test period. The highest iron concentration recorded was 77 ppm with 38,481 miles on the oil. Herguth and other laboratories recommend maximum iron concentrations of 75-150 ppm. TBN appeared to be the oil parameter that would reach a minimum value first, and would therefore be the parameter that new oil change intervals would be based upon. The puraDYN filters appear to address acid formation adequately on these vehicles. This results in acceptable TBN values to 50,000 miles and beyond. Based on the averaged results, the iron concentration should be approximately 50 ppm after 50,000 miles. Maximum values for oxidation and sulfination were 27 and 26, respectively, safely below the recommended maximum of 30.

During the study period, the vans accumulated 213,290 miles but were unable to achieve the higher drain intervals seen in the buses. For the vans, the average drain interval was 10,157, although the highest recorded oil drain interval was 44,721 miles.

Figure 11. Plot of TBN vs. Mileage for CDC buses



Fleet Manager's Post-Demonstration Survey

Staff prepared and sent post-demonstration surveys to all participating fleet managers. These surveys included cost/benefit questions and collected managers' opinions and overall experiences about HE filter usage (Appendix 11). Staff sent the post-demonstration survey to 14 participating fleet managers, and six managers responded. Table 12 summarizes the fleet managers' responses. While some managers repeated the same concerns as those of focus groups, cost was never the main issue with either current or past filter users. Disruption of maintenance schedules, filter servicing, and oil analysis costs continued to be main concerns. However, fleet managers rated "Increasing the Time Between Oil Changes" as the most important benefit.

Table 12. Fleet Manager Post-Demonstration Survey Opinions

Benefits from Using High Efficiency Oil Filters *Average of fleet manager responses from 1 to 3, with 1 being most important*	Average response
Reducing oil purchases	2
Decreasing waste generation	1.8
Increasing the time between oil changes	1.2
Costs Associated with High Efficiency Oil Filters *Average of fleet manager responses from 1 to 5, with 5 being most important*	Average response
Cost for purchase and installation	2.6
Time for servicing filter	3.2
Cost for oil analysis	3.2
Disruption of maintenance schedules	3.2
Time for sampling oil	3

Table 13 shows fleet managers' post-demonstration experiences. Of the fleet managers surveyed, half felt that the technology's performance and reliability had been satisfactory; however, only one manager planned to continue using HE filters. Half of the fleet managers planned to use oil sampling and analysis for determining new drain intervals. The continued problematic themes of logistics, maintenance schedules and recordkeeping were recurrently noted in conversations and in both pre- and post-demonstration surveys. However, the majority of fleet managers reported an overall positive experience from their participation in the study.

Table 13. Fleet Manager Survey of Demonstration Experiences

Experiences using High Efficiency Oil Filters *Total of 6 respondents out of 14 managers surveyed*	*Number answering "yes"*
Do you plan to increase oil drain intervals by using HE oil filters?	1
Do you plan to use oil sampling and analysis to establish new drain intervals?	3
Are you satisfied with the performance and reliability of HE oil filters?	3
Do you feel that potential effects on engine warranty have been addressed adequately?	2
Do you feel that using HE oil filters has helped to decrease engine wear?	1
Did you learn something useful from your participation in the HE oil filter project?	2
Overall, was your participation in the HE oil filter project a positive experience?	4

One manager felt that the filters afforded "better productivity" to his fleet. Another stated the filters would "free up mechanics' time … and save the department money." Yet another added "engine longevity" as a perceived HE technology benefit. Nevertheless, the primary filter benefit was seen as "increasing the time between oil change intervals." Furthermore, 50 percent of fleet managers reported that they intended to use oil sampling and analysis for establishing new drain intervals. These opinions look encouraging for adoption of oil drain interval extension programs in the future.

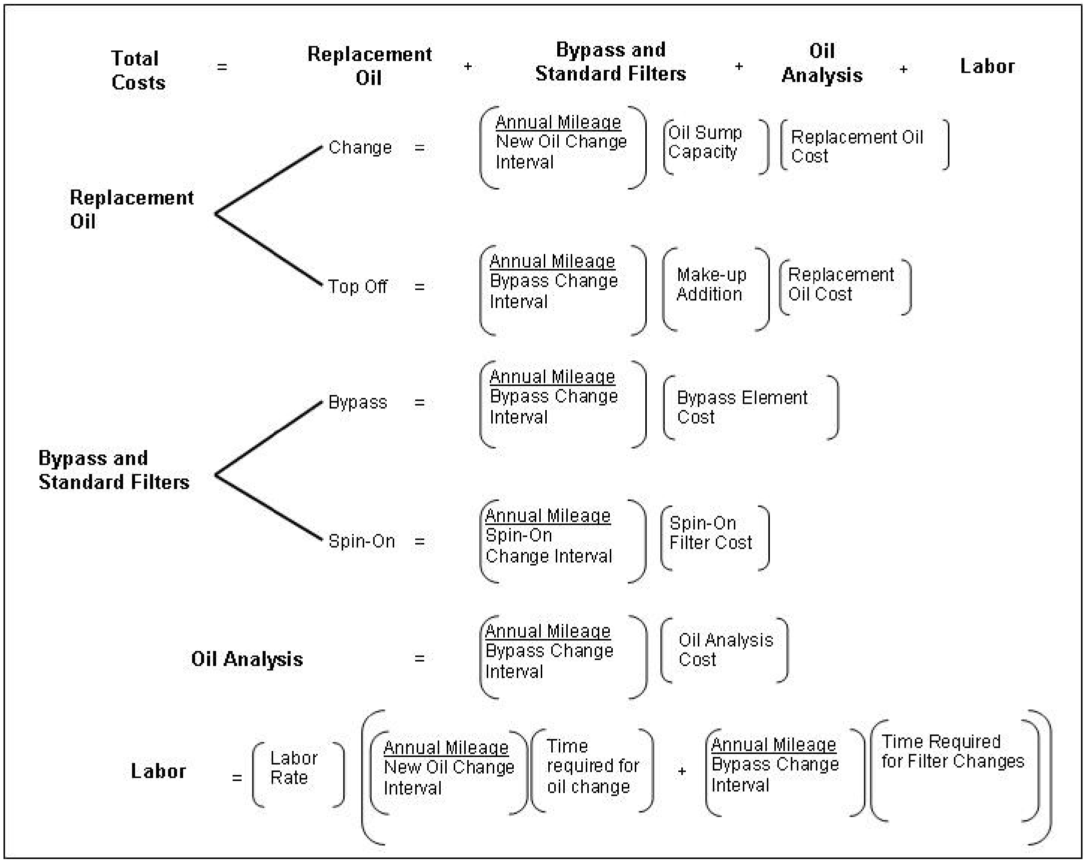
Cost/Benefit Analysis of HE Oil Filters

Costs and savings from HE oil filter usage are calculated by factoring together the costs of replacement oil, bypass and standard filters, oil analysis, waste oil and filter disposal, and labor. Figure 12 shows the cost algorithm for calculating filter expenditures. The vehicles' annual mileages and the new oil change intervals are essential factors in determining HE technology investment's payback period.

For the larger vehicles, the calculated costs are compared with a typical express oil change service for semi-trucks. These services charge approximately $160 for an oil change. Their lube service labor rate alone can be as high as $77 per hour.

For some categories, comparable costs are difficult to determine. For example, the various oil costs are based on purchase volumes, container size, delivery frequency, and other market factors. Therefore, two fleet managers may report different costs for the same oil.

Figure 12. Cost Calculation Formula



DTSC staff used individual fleet managers' costs in determining savings and payback periods. Overall, 5,500 quarts of oil were saved during the study. Individual fleet waste reductions ranged from 50 percent to 80 percent. Table 14 shows the costs and payback periods averaged for each fleet. For HE filters, payback periods were positive in every case, and ranged from 1.3 to 6.8 years. The DGS fleet could achieve extended drain intervals merely by implementing an oil analysis program; hence, their payback period was essentially immediate. For the longer payback periods, the length of time is primarily a function of the annual mileage and the new oil drain interval.

Table 14. Averaged Fleet Costs and Payback Periods

Current Costs	DGS	CAL FIRE*	Caltrans	FAX	FUSD	LBUSD	CDC - Buses
Annual Mileage (mi/yr)	20,317	13,110	25,000	46,461	17,840	13,530	52,847
Change Interval (mi)	6,000	5,000	6,000	6,000	12,000	12,000	10,000
Sump Capacity (qts)	4	26	44	32	36	32	43
Oil ($/qt)	1.57	1.75	1.38	1.76	1.75	1.42	1.73
Spin-On Filter ($)	2.18	15.00	19.91	7.80	7.80	11.90	20.47
Oil Disposal ($/gal)	0.10	0.00	0.16	0.00	0.00	0.06	0.00
Oil Analysis Frequency (mi)	6,000	5,000	6,000	6,000	12,000	12,000	10,000
Oil Analysis ($/sample)	15.00	15.00	15.00	15.00	15.00	12.75	15.00
Labor ($/hr)	57.00	40.00	39.00	34.85	29.00	29.00	70.00
Oil Change (hr)	0.4	1.0	1.0	1.5	0.5	1.0	1.0
Filter Change (hr)	0.00	5.00	0.50	0.33	0.25	0.25	0.50
Filter Disposal ($/drum)	0.02	50.00	52.50	0.00	65.00	0.00	0.00
Proposed Schedule							
Filter Make and Model	Fram X2	OilGuard EPS 60	OilGuard EPS 60	OilGuard EPS 60	Luberfiner ZGard LPF9750	Luberfiner ZGard LPF9750	puraDYN TF 40
Bypass Filter Cost ($)	9.24	158.00	158	158.00	79.76	79.76	391.30
Bypass Element Cost ($)	0.00	22.00	22	22.00	55.06	55.06	35.85
Installation Time (hr)	0.0	2.0	2	2.0	2.0	6.0	2.0
New Spin-On Filter Change Interval (mi)	10,000	18,000	18,000	18,000	12,000	12,000	50,000
Bypass Element Change Interval (mi)	0	6,000	6,000	6,000	36,000	36,000	10,000
Make-Up Oil (qts)	0	2	2	3	4	4	7
New Oil Analysis Interval (mi)	10,000	18,000	18,000	18,000	36,000	36,000	50,000
New Oil Change Interval (mi)	10,000	18,000	18,000	18,000	36,000	36,000	50,000
Current Cost ($/yr)	**162.06**	**305.46**	**682.65**	**1017.47**	**151.04**	**119.88**	**950.03**
Projected Cost ($/yr)	**111.59**	**228.70**	**494.68**	**955.19**	**96.66**	**82.63**	**813.31**
Projected Savings ($/yr)	**50.47**	**76.77**	**187.98**	**62.27**	**54.38**	**37.25**	**136.72**
Purchase and Installation($)	**9.24**	**238.00**	**236**	**227.70**	**137.76**	**253.76**	**531.30**
Payback Period (yrs)	**0.2**	**3.1**	**1.3**	**3.7**	**2.5**	**6.8**	**3.6**

* Some costs are estimated.

HE Oil Filter Project Conclusions

The California Integrated Waste Management Board (CIWMB) contracted with the Department of Toxic Substances Control (DTSC) to study high efficiency (HE) oil filters on State vehicles. The project was designed to:

1. Discover why State agencies had not yet adopted this technology.
2. Identify barriers to its adoption.
3. Determine how the barriers could be overcome.
4. Demonstrate the technology's performance in actual fleet operations.

HE filters were demonstrated on 119 vehicles including large diesel trucks and buses, medium-size gasoline trucks, passenger cars, and compressed natural gas buses. The vehicles accumulated 2,844,172 miles, and 540 oil samples were collected and analyzed. No engine failures were reported during the study. DTSC found that it is possible to achieve longer oil change intervals without observable impacts on engine life.

Follow manufacturers' recommendations for oil change intervals and institute routine oil analysis programs to extend oil change intervals

Staff used existing oil change intervals to establish a baseline for comparison. Staff then used oil analysis results to propose new oil drain intervals. DTSC found that for most fleets, oil drain intervals can be extended beyond their current level to the maximum level recommended by the vehicle manufacturer- and beyond.

The fleet manager survey confirmed that today's average oil change interval is considerably shorter than the maximum suggested by oil condition-based analysis results. The fleet managers' survey showed an average passenger vehicle oil change interval of 4,460 miles, well below some manufacturers' recommended 7,500 or even 10,000 miles. The oil analyses showed that oil drain intervals can be extended for all vehicle types studied. Oil sampling results indicate that in many cases, oil drain intervals can be extended beyond the maximum level recommended by the vehicle manufacturer.

For fleets that have already extended their oil drain intervals to the maximum recommended by the manufacturer, many can further extend oil change intervals by using better oil and by establishing oil analysis programs to determine the optimum drain interval.

Routine oil analysis is an important tool that ensures good oil condition and provides safety for the engine. In some cases, oil sampling alone can be used to extend drain intervals. A basic oil analysis program including physical and chemical parameters, like viscosity, TBN, oxidation, nitration, and common oil contaminants, like water, dirt, and wear metals, would be sufficient to ensure oil condition and satisfy fleet managers.

Establish education, training, and outreach programs to promote adoption of HE filter technology

Significant challenges remain before extended oil drain intervals and HE filter technology will be adopted on a large scale. The fleet manager's post-test survey showed continued skepticism even among participants in the study. The survey showed that fleet managers are reluctant to change the way they currently manage their fleets.

Therefore, outreach programs targeting fleet managers are necessary to help them establish oil drain extension programs using HE filter technology. The results of this demonstration study will be instrumental in persuading fleet managers to adopt HE filter technology. Fleet managers recommended promoting HE filters using testimonials from project participants.

In the closing survey of fleet managers following the demonstration, some managers repeated concerns initially raised by the focus groups. As shown in Table 5 for current users, and again in Table 12 following the demonstration, cost was not the main issue with either group of fleet managers. Logistics, maintenance schedules, and recordkeeping were common problems repeated in both sets of surveys, and were noted in conversations throughout the study. Half of the fleet managers surveyed planned to use oil sampling and analysis to establish new drain intervals. Half of the participating fleet managers surveyed felt that the performance and reliability of the technology had been satisfactory. However, only one manager planned to continue using HE filters. Other fleets said the main benefit of the filters was "increasing the time between oil change intervals." This is encouraging for future efforts to extend oil drain intervals.

DTSC completed the study by preparing a cost-benefit analysis for the technology based on the proposed drain intervals. Using the proposed intervals, DTSC found that HE oil filters would reduce new oil purchases, decrease waste oil generation, and have a positive payback period.

Therefore, DTSC found that in appropriate fleets, high efficiency oil filters are an effective and economical technology for (1) achieving longer oil drain intervals, (2) reducing new oil purchases, and (3) decreasing waste oil generation. However, significant barriers to adoption of HE filter technology continue to exist.

Vehicle makers, engine manufacturers, and oil formulators can endorse extended oil drain intervals

Fleet managers suggested that DTSC should encourage vehicle manufacturers to include HE technology as OEM equipment. Availability of HE filters as stock equipment would eliminate many of the barriers to widespread adoption of technology, including engine warranty issues and justification of high purchase and installation costs.

Fleet operators, engine manufacturers, and oil formulators should be enlisted in efforts to extend oil drain intervals, reduce oil purchases, and decrease waste oil generation. Oil formulators should develop brands that are designed to last longer by using higher levels of additive packages and buffering agents. Engine manufacturers should install sensors to measure oil condition in real time, delaying oil changes until necessary. Engine manufacturers should include high efficiency oil filtration systems as standard equipment, thus avoiding concerns over engine warranty issues.

Recommendations for future studies and outreach efforts

Staff identified several areas that present potential avenues for further investigation. The cost and benefit data could be presented to the fleet managers to show them how savings can be achieved in their fleets. Staff could develop projections on optimal oil drain intervals based on the data collected during the study.

Recycled oil should be another subject of future investigation. The public may assume that all used oil collected for recycling ultimately returns as fresh, replacement oil. This assumption shows that the consumer is comfortable with the concept of reusing motor oils; however, there is in fact, very little demand for re-refined oil. In California, many State agencies, school districts, and public transit agencies purchase re-refined oil, but sales to the general public are slow.

Although most of the available used motor oil is collected for recycling, the majority of oil collected is burned, rather than re-refined (Boughton, et al).

Many fleet managers inquired about the use of synthetic oils. Synthetic oil makers claim their technology extends oil change intervals. Some fleet managers requested assistance evaluating synthetic oils in their HE filter-equipped vehicles. Although the oil quality parameter that triggered an oil change was unique to each fleet, to the motor oil used, and to the vehicle's operating conditions, in most cases the limiting factor was the oil's TBN. Higher initial TBN levels and longer-lasting additive packages were shown to be important factors in extending the useful life of engine oil. Currently, many synthetic oils provide guaranteed oil drain intervals of 15,000 miles.

Staff has conducted considerable outreach efforts to date, and plans additional events in the future. They used a September 2006 press release, the project website, and a pollution prevention HE oil filter fact sheet to promote the results of the study. The press release was printed on October 3, 2006, in the Central Valley Business Times; the project website home page was featured in San Francisco City's Clean and Green Scene.

Staff also gave several presentations on the HE oil filter project. Groups receiving presentations included the Western Regional Pollution Prevention Network's Pollution Prevention Conference in San Diego on October 10, 2006, and the Northern California Jiffy Lube Franchise Owners Association in Sacramento on November 16, 2006. Several presentations have been given to boards, departments, and offices from the California Environmental Protection Agency.

Staff is currently developing outreach materials that will be available to fleet managers and other decision makers, policymakers, and people who can influence industry. A pollution prevention fact sheet will include a summary of the project, testimonials from those successfully using HE oil filters, and the benefits of using HE oil filters. Outreach materials currently available are included in Appendix 12. Staff anticipates providing public presentations of the study's results. Details of the study's results can be found at: http://www.dtsc.ca.gov/TechnologyDevelopment. DTSC expects to continue assisting fleet managers and others interested in the technology.

Publication of this report will encourage California's consumers, business leaders, and policymakers to adopt policies, procedures, and technologies that provide maximum benefits for their fleets and to the public.

Abbreviations and Acronyms

CAL FIRE – California Department of Forestry and Fire Protection
CALTRANS – California Department of Transportation
CARB – California Air Resources Board
CDC – California Department of Corrections
CIWMB – California Integrated Waste Management Board
CNG – compressed natural gas
DGS – Department of General Services
DTSC – Department of Toxic Substances Control
FAX – Fresno Area Express
FUSD – Fresno Unified School District
HE oil filter – High efficiency oil filter
ISO/DIS – International Standards Organization/Draft ISO Standard
LBUSD – Long Beach Unified School District
OEHHA – Office of Environmental Health Hazard Assessment
P2 – Pollution Prevention
SwRI – Southwest Research Institute
TBN – total base number
ZDDP – zinc dialkyldithiophosphate

Metals abbreviated in this report include:

Fe Iron	Ag Silver	Mg Magnesium
Al Aluminum	Sb Antimony	Ba Barium
Cr Chromium	Si Silicon	Mo Molybdenum
Cu Copper	Na Sodium	K Potassium
Pb Lead	B Boron	Ca Calcium
Sn Tin	Zn Zinc	
Ni Nickel	P Phosphorus	

Appendices List

Most appendices are stored electronically on a compact disk. Hard copies of original contract, complete literature review articles and CIWMB invoices are available upon request. For copies, contact Ed Benelli at ebenelli@dtsc.ca.gov or (800) 700-5854.

1. Scope of Work, Contract, and Quarterly Reports
2. Complete Literature Review List
3. Fleet Manager Survey
4. Focus Group Report
5. Laboratory Statement of Work
6. Filter Specification Sheets
7. Southwest Research Institute Report
8. Table of Vehicle Mileages and Oil Changes
9. Sample Results Database
10. Original Laboratory Reports
11. Fleet Manager's Post Survey
12. Outreach Materials

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Endnotes

[1] The Scope of Work, Contract, and all Quarterly Reports for the agreement between the California Integrated Waste Management Board and the Department of Toxic Substances Control are included in Appendix 1.

[2] Boughton, Bob and Horvath, Arpad, *Environmental Assessment of Used Oil Management Methods*, Environmental Science & Technology, 38 (2), 353 -358, 2004.

[3] Stanley, David R., General Motors Corp., "Correlating Lube Oil Filtration Efficiencies with Engine Wear" Truck and Bus Meeting and Exposition, Indianapolis, Indiana, November 7–10, 1988.

[4] CTC Analytical Services (Phoenix, AZ).

[5] Caterpillar Machine Fluids Recommendations, October 2004.

[6] Detroit Diesel Lubricating Oil, Fuel and Filters, 2004.

[7] http://www.practicingoilanalysis.com/results.asp?search=metals

[8] Personal communication August 30, 2006, Glenn Asauskas, Chevron.

[9] Ibid.

[10] Cavette, Chris, From Spin-ons to Microns, Firecheif.com/news, February 2001. Accessed August 12, 2008.

[11] Company contact & address; how filters extend oil life, remove water, coolant or fuel; how they replenish additives; pore size, make-up oil, oil flow rate, years available, filter units sold, patent status, warranty, California sales support, miles between changes, engine type applicability, filter sizes and costs; OEM warranty letters and current customers.

[12] By 2007, Honda and GM had oil life sensors on most of their vehicles. Ford also announced moving its recommended change interval from 5,000 to 7,500 miles. (Bibliography: "GM Oil Life System…" and Gill, G., "Ford Extends Oil Change Intervals.")

[13] However, UC Davis never installed the filters.

[14] ISO/DIS 23556, Performance Test Method for Diesel Engine Soot Removal Devices in Lubricating Oils – Initial Filtration Efficiency, International Organization for Standardization (ISO) 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, 2005.

[15] ISO 4548-12, Methods Of Test For Full Flow Lubricating Oil Filters For Internal Combustion Engines- Part 12: Filtration Efficiency Using Particle Counting , And Contaminant Retention Capacity, International Organization for Standardization (ISO) 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, 1999.

[16] Test terminated after 40 hours.

[17] Test terminated after 6 hours – possible manufacturing defect.

[18] Selected articles from Appendix 2. Complete literature review list.

[19] See list of Fitch articles in Appendix 2. Complete literature review list.

[20] See Appendix 2. Complete literature review list.