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U.S. Department of Energy FreedomCAR & Vehicle Technologies – Oil Bypass Filter Technology Evaluation Third Quarterly Report April-June 2003

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August 2003

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ABSTRACT

This Third Quarterly report details the ongoing fleet evaluation of an oil bypass filter technology by the Idaho National Engineering and Environmental Laboratory (INEEL) for the U.S. Department of Energy's FreedomCAR & Vehicle Technologies Program. Eight full-size, four-cycle diesel-engine buses used to transport INEEL employees on various routes have been equipped with oil bypass filter systems from the PuraDYN Corporation. The reported engine lubricating oil-filtering capability (down to 0.1 microns) and additive package of the bypass filter system is intended to extend oil-drain intervals. To validate the extended oil-drain intervals, an oil-analysis regime monitors the presence of necessary additives in the oil, detects undesirable contaminants and engine wear metals, and evaluates the fitness of the oil for continued service. The eight buses have accumulated 185,000 miles to date without any oil changes. The preliminary economic analysis suggests that the per bus payback point for the oil bypass filter technology should be between 108,000 miles when 74 gallons of oil use is avoided and 168,000 miles when 118 gallons of oil use is avoided. As discussed in the report, the variation in the payback point is dependant on the assumed cost of oil. In anticipation of also evaluating oil bypass systems on six Chevrolet Tahoe sport utility vehicles, the oil is being sampled on the six Tahoes to develop an oil characterization history for each engine.

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Oil Bypass Filter Technology Evaluation Third Quarterly Report

INTRODUCTION AND BACKGROUND

This quarterly report of the oil bypass filter technology performance evaluation covers the evaluation period April through June 2003.[1] Eight PuraDYN PFT-40 (40-quart capacity) oil bypass filter systems (Figure 1) are being tested on eight Idaho National Engineering and Environmental Laboratory (INEEL) buses. The eight buses are equipped with the following types of four-cycle diesel engines:

- Three buses, Series-50 Detroit Diesel engines
- Four buses, Series-60 Detroit Diesel engines
- One bus, Model 310 Caterpillar engine.

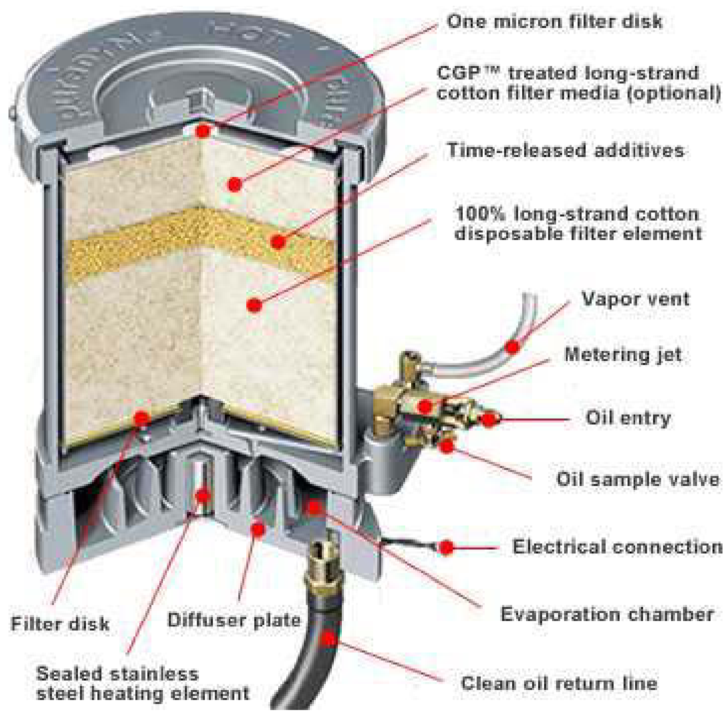

Figure 1. Cutaway drawing of a puraDYN oil-bypass filter.

The first quarterly report extensively details the project background, safety considerations, preliminary economic analysis, and the test plan (Evaluation Test Plan EVH-TP-146 is available as Attachment 1 in the *Oil Bypass Filter Technology Performance Evaluation – First Quarterly Report,* INEEL/EXT-03-00129).[2] The second quarterly report details the revised filter change schedule for the test and shows preliminary trends of the oil analysis report for one of the buses.[3]

Items reported in this Third Quarterly Report include:

- Bus mileage and performance status
- Preliminary trends in oil analysis
- Revised economic analysis
- Ancillary data
- Status of the light-duty vehicle filter evaluation.

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[1] The DOE FreedomCAR and Vehicle Technology Program Office funds these activities.

[2] The First Quarterly Report is available at http://avt.inel.gov/oil_filter/pdf/oilfilter_bypass1.pdf.

[3] The Second Quarterly Report is available at http://avt.inel.gov/oil_filter/pdf/oilfilter_qtr1_03.pdf.

BUS MILEAGE AND PERFORMANCE STATUS

During this quarter, the eight buses traveled approximately 82,000 miles (Figure 1). Typically, the buses travel established routes carrying INEEL workers during their morning and evening trips to and from the INEEL test site. In addition, efforts were made by the fleet operation managers to assign the eight buses to shuttle runs during off-peak hours to add evaluation mileage. Table 1 details the mileage status of the eight test buses. Figure 2 shows the total evaluation miles per bus, by evaluation quarter.

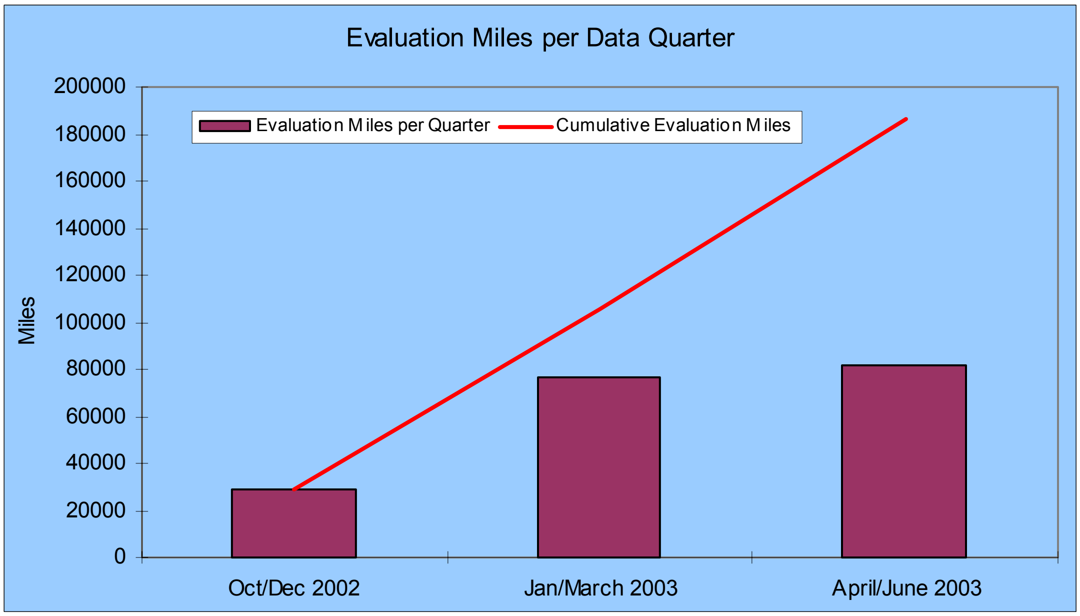

Figure 1. Quarterly and cumulative evaluation miles per evaluation quarter.

Table 1. Test buses and test mileage on the oil to 6/30/03.

Bus Number	Starting Date	Bus Mileage at Start Date	Current Bus Mileage (06/30/03)	Total Oil Evaluation Miles
73425	12/18/2002	41,969	55,581	13,612
73432	2/11/2003	47,612	68,302	20,690
73433	12/4/2002	198,582	220,393	21,811
73446	10/23/2002	117,668	147,202	29,534
73447	11/14/2002	98,069	112,991	14,922
73448	11/14/2002	150,600	169,978	19,378
73449	11/13/2002	110,572	129,076	18,504
73450	11/20/2002	113,502	159,786	46,284
		Total Test Miles to Date (06/30/03)		184,735

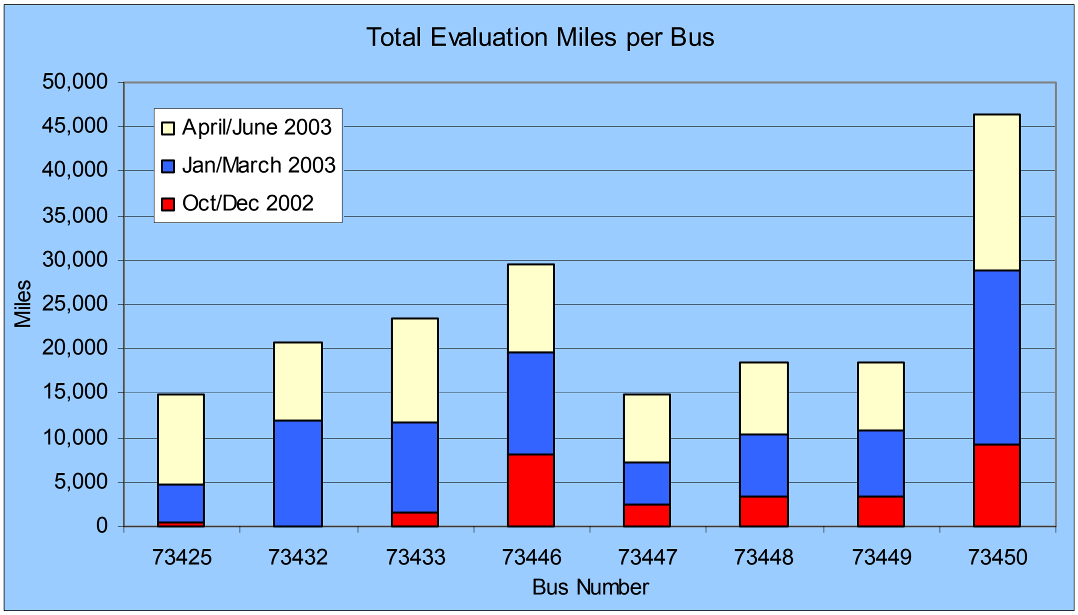

Figure 2. Total evaluation miles per bus by testing quarter.

PRELIMINARY TRENDS IN OIL ANALYSIS REPORTS

An oil analysis sample is captured at each filter replacement (initially at the start of the test, at 6,000 miles, at 12,000 miles, and at each 12,000-mile interval thereafter). The sample is split three ways; two portions are sent to two independent laboratories for analysis, and the third portion is archived at the INEEL (discussed in the *First Quarterly Report*). The data from both laboratory analysis reports are compiled to document the oil quality and the engine metal-wear pattern profiles and trends.

Selected Trends in Bus 73450

Bus 73450 has the most mileage of all the test buses and, consequently, has had the most (four) oil analyses performed. Table 2 reports the sampling results for the bus. Based on the data points from the four oil analysis samples, event trends appear to be developing. It is too early in the evaluation process, however, to pronounce any definitive conclusions, but it is worth discussing the format of the oil analysis reports and some of the initial testing results. Testing results to date support the belief that each engine is unique, and each engine has its own wear pattern. The trends shown in Table 2 are for the Caterpillar 310, six-cylinder, four-cycle engine. Other engines in the test show their own specific anomalies, which will be presented as more data become available.

As seen in Table 2, Column 1 lists the test variables. Columns 2 through 6 are the test results from the CTC Analytical Services laboratory. Columns 7 through 11 are the test results from ANA Laboratory. Columns 2 and 7 are the average of three test results performed by each laboratory on the new oil before it was put into the bus.

Column groups 3 and 8, 4 and 9, 5 and 10, and 6 and 11 are the sets of respective testing results from the two laboratories for the analyses performed at 6,934; 14,545; 25,871; and 43,031 miles. Column 12 lists generic or rule-of-thumb value limits (again, discussed in the *First Quarterly Report*).

Table 2. Bus 73450 oil analysis reports.

Test Lab		CTC Analytical Services				ANA Laboratory					Value Limits
1	2	3	4	5	6	7	8	9	10	11	12
Test report No.	See footnote [1]	5533	22936	63963	134512	See footnote[1]	R03A0 00013	R03A0 16418	R03C0 13020	R03F0 14840	
Test date		12/18/02	1/21/03	3/17/03	6/16/03		12/2/02	1/21/03	3/17/03	6/16/03	
Miles on oil	New oil[1]	6,934	14,545	25,871	43,031	New oil[1]	6,934	14,545	25,871	43,031	
Status		Abno	Normal	Normal	Abno.	Sat.	Sat.	Abno.	Sat.	Abno.	
TBN	10.1	8	6.4	5.5	9.0	10.5	7.9	8.2	5.4	4.8	>3.0
Iron	2	20	50	91	206	<1	13	114	86	181	<=100
Chromium	0	1	2	4	5	<1	<1	6	3	6	<=12
Lead	0	1	1	4	11	<1	<1	8	1	10	<=30
Copper	0	4	6	12	20	<1	<1	96	6	16	<=30
Tin	0	0	0	0	0	<1	<1	10	5	<1	<=18
Aluminum	1	3	2	3	4	<1	<1	4	4	3	<=18
Nickel	0	0	0	0	0	<1	<1	<1	<1	1	<=10
Silver	0	1	2	1	2	<1	<1	<1	<1	1	
Silicon	7	4	2	4	7	<1	4	5	3	8	<=20
Boron	0	1	0	1	1	<1	<1	11	1	1	
Sodium	4	7	5	1	9	<1	<1	25	1	7	
Magnesium	16	32	33	28	35	17	24	74	12	34	
Calcium	3321	2907	3128	3381	3001	2209	1510	1993	2216	3188	
Barium	0	0	0	0	0	<1	<1	<1	<1	<1	
Phosphorus	1265	1091	1171	1082	1084	1129	1072	870	789	1175	
Zinc	1384	1282	1278	1220	1288	1299	1190	948	860	1281	
Molybdenum	0	0	1	1	3	<1	<1	2	<1	2	
Titanium	0	0	0	0	0	<1	<1	1	<1	<1	
Vanadium	0	0	0	0	0	<1	<1	2	<1	<1	
Potassium	0	58	30	24	0	<1	<1	9	7	28	
Fuel	NA.	<1	<1	<1	<1	<0.5	<0.5	<0.5	<0.5	<0.5	
Viscosity at 100ºC	15.37	13.41	12.94	12.79	12.56	15.5	13.49	13.12	12.6	12.55	12.5–16.29
Percent water	0.0	0	0	0	0	<0.05	<0.05	<0.05	<0.05	<0.05	<5.0
Soot % vol	NA	0.4	0.2	0.7	0.7	<0.2	<0.2	<0.2	1.1	0.9	<=3.0
Glycol	NA	Neg.	Neg.	Neg.	Neg.	none	none	none	none	none	<50

1. The new oil values represent an average of three separate reports conducted on various dates.

TBN = total base number.

NA = not applicable; note that the two labs use different terms for like conditions: normal/satisfactory; negligible/none

There does not appear to be a definitive national standard of specific values to draw from when determining the suitability of the oil or for determining when it "must" to be changed. Each oil analysis laboratory has its own standards or limits that they follow. This is based on the belief that each engine is unique and each has its own unique signature in regard to engine wear metals. However, there does appear to be agreement that two items are important to consider:

- Trend: are the values becoming more negative?
- Rate of change: has the value doubled since the last analysis?

There are some generally accepted value limits, which are listed in column 12 of Table 2 and are discussed in Attachment 1 of the *First Quarterly Report*.

Bus mechanics use their experience, and test report values and trends to identify the health of the engines and the condition of the oil in each engine. INEEL mechanics have historically used trending test results to identify potential engine problems. In addition, a single out-of-norm test result for one test variable may not be reason for concern. For example, the 96-parts per million (ppm) test result for copper in Column 9 varies significantly from the 6-ppm result in Column 4 (both results were obtained with 14,545 miles on the oil). The two subsequent tests in Columns 5 and 9 do not repeat the high copper trend. The 96-ppm copper test result in column 9 is considered an anomaly, not an indication of an engine wear problem.

Iron increase in PPM

A negative trend of iron values is shown in the CTC laboratory reports, columns 2 through 5. The results for the 6/16/03 (43,031 mile) oil analysis specimen indicates an iron level of 206 ppm (column 6) and a status of "Abnormal" because the 206-ppm value was more than twice as high as the previous test result of 91 ppm (column 5).

Analysis from the other laboratory did not reflect as high a concentration of iron. However, the test report also listed the iron level as abnormal because the level (181 ppm, column 11) was more than twice the previous level of 86 ppm, as shown in column 10. The mechanics have subsequently retested the oil, to check the iron levels. The iron ppm result of the subsequent test was 21% lower. This subsequent test is not shown in Table 2 because it was performed in July, and July data will be reported in the next quarterly report.

The authors would be derelict, if they did not point out that bus 73450 went 5,160 miles beyond the scheduled bypass filter replacement when the oil was changed on 6/16/03 (columns 6 and 11 in Table 2). How this affected the test results is unknown.

Wear Rate Analysis

In addition to the above mentioned lengthened filter replacement interval, the negative trend of iron values can be somewhat misleading when viewed in the conventional manner. Typically, oil analysis is performed on oil discarded at the scheduled servicing interval. For the oil bypass filter system evaluation, the oil is not changed, just evaluated (and filter(s) changed). The iron particulates in the oil of bus 73450 are increasing as the miles accumulate. Another measure of oil quality with extended oil drain interval is to consider the wear rate. Wear rate is determined by dividing the total ppm of metal in the oil by each 1,000 miles traveled. Table 3 shows the wear rate calculated from the last five oil analysis reports from CTC Analytical Services. With the exception of the 6/16/03 test result, the wear rate is relatively constant. Therefore, the higher iron level (measured in ppm) is not considered to be deleterious. Note that the bypass filter was not changed on 7/2/03 when only an oil analysis was performed to recheck the condition of the oil.

The test results for the oil during the bypass system evaluation reveal several factors that must be considered when evaluating the oil, including:

- Engines have their own wear metal signature
- Oil analysis laboratories have their own values or limits on oil quality
- Oil analysis results databases are based on oil that is discarded at each servicing interval
- Oil analysis reports from different laboratories are sometimes contradictory

- Judgment to change the motor oil has a qualitative flavor instead of a purely quantitative one
- A database of oil analysis reports germane to extended oil drain interval tests has not been identified.

Table 3. Bus 73450 wear rate results from CTC Analytical Services.

Test Date	Iron (ppm)	Miles on Oil	Wear Rate
1/8/2003	20	6,934	2.9
1/21/2003	50	14,545	3.4
3/17/2003	91	25,871	3.5
6/16/2003	206	43,031	4.8
7/2/2003	162	45,968	3.5

ppm = parts per million.
Wear rate = ratio of ppm to each 1,000 miles traveled.

The number of items tested in an oil analysis report depends on the amount of money paid for each test; the more tests desired, the more money it costs. Typically, the reports have five basic aspects:

1. Engine wear metal analysis, such as iron and copper
2. Chemical tests for pollutants, such as water, fuel, soot, and coolant in the oil
3. Oil condition analysis, such as viscosity and TBN (total base number) values
4. Previous test results
5. Judgment and comments on the condition of the engine or oil; for example, is the status normal, abnormal, or critical?

Just because an engine has a high or higher level of engine wear metal, it does not appear to significantly reduce the lubricating value of the oil. A high wear metal concentration trend tells the mechanic or fleet owner that a bearing or engine part is wearing, and to avoid a catastrophic and costly engine failure they should take appropriate action. However, the oil quality values reflected in the chemical and oil condition tests (TBN, viscosity, soot content, water level, and glycol level) do reflect fitness for service and are the metrics for determining oil quality during this test.

MAKEUP OIL ADDED WHEN CHANGING THE FULL-FLOW AND BYPASS-FLOW FILTERS

In the preliminary economic analysis presented in the first quarterly report, makeup oil was not factored into the life-cycle economic analysis. This quarterly report does include makeup oil in the economic analysis and is defined as follows:

- *Oil added during normal vehicle use or lost from leaks.* Since the engines are relatively new, they do not typically need oil between filter servicing. However, bus 73432, a series 50, Detroit Diesel does require periodic oil. Eight quarts where added during the April-June quarter, wherein the bus traveled 8,718 miles. Makeup oil use from leaks and normal engine use is not included in the economic analysis, as this oil loss is not related to use of the bypass filter technology.
- *Oil added when changing the full-flow and bypass-flow filters*. How often the full-flow oil filters are changed is different when comparing the traditional oil change regime to the bypass filter regime; different amounts of oil must be added for each regime. In practice, the crankcase is overfilled by one to two gallons, depending on the number of filters replaced. The engine is then run for a few minutes, and the filter(s) fills with oil and the crankcase normalizes to the correct oil level. Makeup oil use records were reviewed, and this practice was evident.

The INEEL service mechanic indicated that four quarts of oil are removed from the system when the bypass flow filter/additive cartridge is changed, and four quarts are also removed when the two full-flow filters are changed (two quarts per each full-flow filter). Empirical data were generated to verify and validate the mechanic's observations. Sets of both new and used (oil soaked) bypass and full-flow filters were weighed on a calibrated scale, as were the plastic bags holding the used filters and oil. Table 4 shows the empirical data, which verify the mechanic's observations.

Table 4. Makeup oil added to a bus during filter change.

Item	Weight in Grams	Volume in Gallons
Oil and one-gallon plastic jug	3478.4	
Plastic jug	-188.7	
Net weight of one gallon of oil[1]	3289.7	1.0
Full-flow filter (double bagged)	3249.7	
Bags (7-mil plastic)	-285.3	
Net weight of full-flow filter w/oil	2964.4	
New full-flow filter	-1272.6	
Oil in full-flow filter[2]	1691.8	0.51
Used bypass filter (double bagged)	4783.4	
Bags (7 mil plastic)	-285.3	
Net weight of bypass filter w/oil	4498.1	
New bypass filter	-1403.2	
Oil in full-flow filter[2]	3094.9	0.94

1. 15W-40
2. Represents new oil volume added to system each time the filter is replaced.

REVISED DIESEL BUS ECONOMIC ANALYSIS

In addition to including the cost of makeup oil, the economic analysis has been expanded to include three scenarios:

- *Traditional oil changes with the Shell oil costing $7.20 per gallon.* This is the oil cost per gallon that the INEEL has been paying for the oil used in the oil bypass system evaluation. The INEEL bus shop requested the oil be purchased in one-gallon containers for this evaluation. This scenario is included to allow life-cycle analysis for the traditional oil change method, which assumes the same cost for oil as the bypass filter cost analysis. The Shell oil can be purchased in 55-gallon drums at a lower cost (about $5.60 per gallon). The $7.20 value is used for this analysis.
- *Traditional oil changes with the oil costing $4.17 per gallon.* This is the oil cost per gallon that the INEEL has been paying for the American Choice partially recycled oil, purchased in 55-gallon drums. This scenario is included as it is the base case for how the INEEL was changing the oil before the oil bypass evaluation, and this is also the actual traditional oil cost.
- *Bypass Filter system with the oil costing $7.20 per gallon*. As discussed in previous quarterly reports in greater detail, the Shell oil was chosen for use on buses equipped with the oil bypass systems.

At the start of all three analyses, we assumed the bus was full of fresh oil. All of the costs are in 2003 dollars.

Traditional Oil Changing Life-Cycle Costs at $7.20 per Gallon

The makeup oil costs incurred when changing filters are included within this traditional oil changing life-cycle cost analysis (see Appendix A). The eight buses have various oil capacities of 28, 38, and 40 quarts each. The weighted average capacity is 35.25 quarts per bus. In this analysis, we assumed that 9.8 gallons of oil are added during every oil change (8.8 gallons capacity + 1/2 gallon for each of the two full flow oil filters). The modeled cost for oil is $7.20 per gallon. After 180,000 miles, the total projected cost for the labor, material, and parts required for traditional oil changes is $2,040 per bus.

Traditional Oil Changing Life-Cycle Costs at $4.17 per Gallon

The makeup oil costs incurred when changing the oil filters are also included within this traditional oil changing life-cycle cost analysis (see Appendix B). The eight buses have various oil capacities of 28, 38, and 40 quarts each. We again assumed that the weighted average capacity is 35.25 quarts per bus and that 9.8 gallons of oil are added during every oil change (8.8 gallons capacity + 1/2 gallon for each of the two full-flow oil filters). The modeled cost for oil is $4.17 per gallon. After 180,000 miles, the total projected cost for the labor, material, and parts required for traditional oil changes is $1,595 per bus.

Bypass Filter Evaluation Life-Cycle Costs

The makeup oil costs are included separately in the oil bypass filter life-cycle cost analysis (see Appendix C). The average 8.8 gallons oil capacity is again used. However, makeup oil use varies, depending on whether the full-flow filters are changed and if the bypass filter element is changed. For this reason, the makeup oil costs are shown in Appendix C, in the column "Makeup Oil Costs." Note that during the first 12,000 miles, both full-flow filters and the bypass filter are changed twice, at 6,000 and 12,000 miles. The costs for both are included in the first 12,000-mile costs. After 180,000 miles, the total projected cost for the labor, material, and parts required for the servicing with an oil bypass system is $1,536 per bus.

Cost Comparison and Oil Use Savings

The bypass filter system has a lower economic life-cycle cost (payback point) commencing at about 108,000 miles compared to the traditional oil change method when the oil costs $7.20 per gallon, and at about 168,000 miles compared to the traditional oil change method when the oil costs $4.17 (Figure 3). The amount of oil saved at the 108,000-mile payback would be 74 gallons per bus; at the 168,000-mile payback it would be 118 gallons per bus. Recognize that none of the eight buses equipped with the oil bypass systems has accumulated more than 46,000 miles. Therefore, it is premature to definitively state that the oil bypass system scheme has the most desirable economic life-cycle costs.

ANCILLARY DATA

On 5/19/03, oil bypass system-equipped bus 73446 had an alternator failure. The cause of the failure was not reported, but the mechanic who rebuilds the alternators reported that the alternator was unlike any heretofore repaired—the oil-cooled alternator was clean on the inside. There were no deposits of sludge or pockets of dirt on the component parts, typical with previous alternator repairs. There will always be failures of mechanical parts, but reason dictates that if an alternator is cooled with clean oil and no sludge builds up on the parts, the alternator will be cooler and therefore less prone to heat-related failures. This is only one data point, but it is a possible maintenance benefit for oil bypass filter systems-equipped buses.

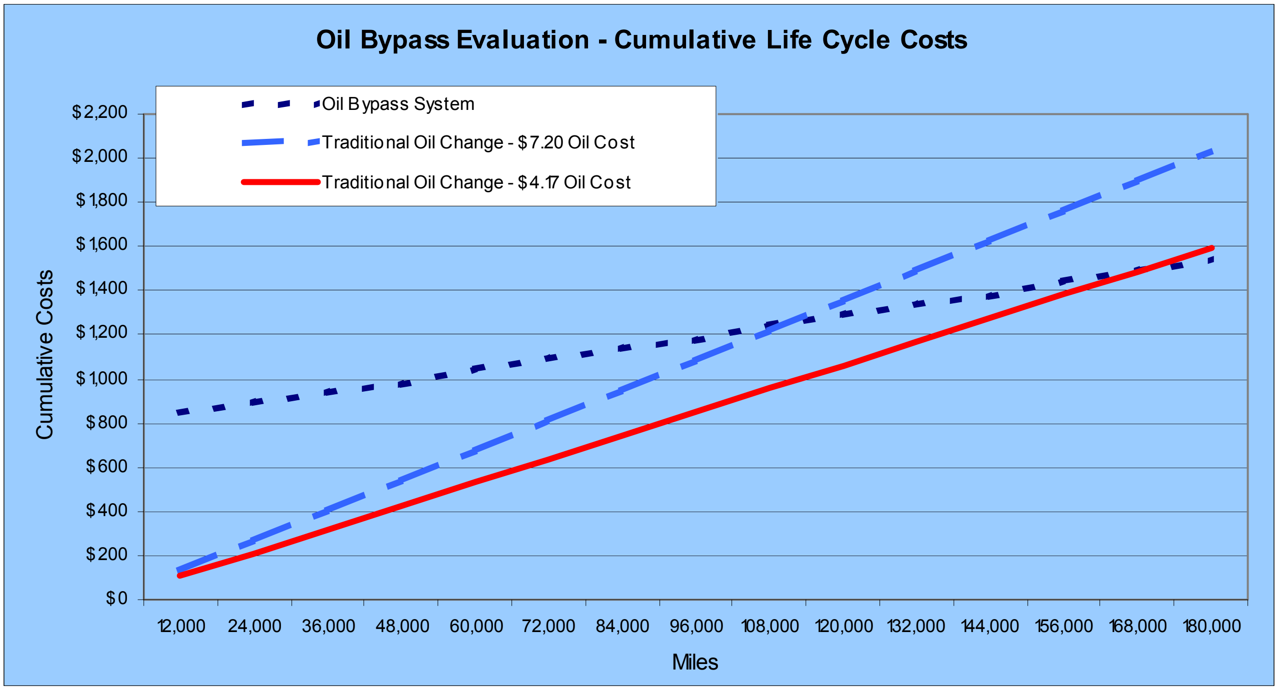

Figure 3. Cumulative life-cycle costs for the three modeled scenarios.

LIGHT-DUTY VEHICLE FILTER EVALUATION

Installation of oil bypass filter systems is scheduled to begin during the fall of 2003. Six model year 2002 Chevrolet Tahoe sport utility vehicles have been selected for testing. Six PuraDYN PFT-8 filter systems (8-quart capacity) with replacement filters have been obtained, and the test plan has been approved for use. One system will be installed to validate the installation procedure, and then the remainder of the five systems will be installed when the vehicles are scheduled for regular servicing.

In order to establish a historical baseline of engine wear metals, oil analysis specimens are being collected and analyzed. To date, eight analysis reports have been received. Six of the reports show what appear to be high levels of copper (between 58 and 242 ppm). The oil will continue to be sampled on the Tahoes, until several samples have been analyzed per vehicle. This will provide the basis to compare future samples once the oil bypass systems are installed. The intent is to continue using the American Choice partially recycled oil in the Tahoes after the bypass systems are installed.

SUMMARY

- Eight PuraDYN PFT-40 (40-quart capacity) oil bypass filter systems are being tested on eight Idaho National Engineering and Environmental Engineering Laboratory (INEEL) buses. The eight buses have traveled 185,000 miles to date. With a 12,000-mile servicing schedule, this represents about 15 avoided oil changes and the avoidance of disposing of about 130 gallons of oil.
- Depending on the cost of oil used for the economic life-cycle analysis, the current payback point for the oil bypass filter system appears to be between 108,000 and 168,000 miles. The amount of oil

saved at the 108,000-mile payback would be 74 gallons per bus; at the 168,000-mile payback it would be 118 gallons per bus.

- The used oil the INEEL generates is picked up for recycling at no direct cost to the INEEL. However, there are some hidden costs to the INEEL for the temporary storage of the oil. These costs will be investigated during the next evaluation quarter. In addition, other DOE and private fleets will be contacted to identify their oil disposal costs.
- The two traditional oil change analyses show that the unit cost for the oil can have a significant impact on the payback period compared to the oil bypass system. This is intuitive: the higher the oil cost, the more favorable the economics of extending or eliminating oil-change intervals. The economic life-cycle analysis will be rerun as additional cost factors are identified and quantified, or if an oil change is required.
- As measured by total ppm, there is a trend of increasing iron particles in bus 73450's oil, but the quality of the oil is still within perceived specifications. In addition, when the iron levels are examined on a wear-rate ratio basis (ppm of iron per 1000 miles of traveled), after 46,000 miles the overall wear rate ratio has remained fairly consistent.
- There are often conflicting oil testing results between the two test laboratories for the same oil sample. In addition, it appears that there are different standards or levels of acceptance of oil contamination within the industry. Therefore, knowing when the oil must be changed is qualitative.
- The light-duty vehicle filter evaluation will begin after three oil analysis reports have been completed for each vehicle.
- To aid determination of motor oil fitness for service, an oxidation test will likely be added to the oil analysis suite of tests.

APPENDIX A

TRADITIONAL OIL CHANGING COSTS at $7.20 PER GALLON OIL

Traditional Oil Changing Costs - $7.20 Oil								
Oil Change Intervals	**Cumulative Bus Mileage**	**Full Flow Filter Cost**	**Full Flow Filter Change Labor Cost (1)**	**Oil Cost per change (2)**	**Oil Change Labor Cost (3)**	**Total Cost per Oil "Event"**	**Cumulative 12,000 mile Intervals**	**Cumulative Costs at 12,000 mile intervals**
12,000	12,000	$8.60	$14.23	$70.56	$42.60	$135.99	12,000	$135.99
12,000	24,000	$8.60	$14.23	$70.56	$42.60	$135.99	24,000	$271.98
12,000	36,000	$8.60	$14.23	$70.56	$42.60	$135.99	36,000	$407.97
12,000	48,000	$8.60	$14.23	$70.56	$42.60	$135.99	48,000	$543.96
12,000	60,000	$8.60	$14.23	$70.56	$42.60	$135.99	60,000	$679.95
12,000	72,000	$8.60	$14.23	$70.56	$42.60	$135.99	72,000	$815.94
12,000	84,000	$8.60	$14.23	$70.56	$42.60	$135.99	84,000	$951.93
12,000	96,000	$8.60	$14.23	$70.56	$42.60	$135.99	96,000	$1,087.92
12,000	108,000	$8.60	$14.23	$70.56	$42.60	$135.99	108,000	$1,223.91
12,000	120,000	$8.60	$14.23	$70.56	$42.60	$135.99	120,000	$1,359.90
12,000	132,000	$8.60	$14.23	$70.56	$42.60	$135.99	132,000	$1,495.89
12,000	144,000	$8.60	$14.23	$70.56	$42.60	$135.99	144,000	$1,631.88
12,000	156,000	$8.60	$14.23	$70.56	$42.60	$135.99	156,000	$1,767.87
12,000	168,000	$8.60	$14.23	$70.56	$42.60	$135.99	168,000	$1,903.86
12,000	180,000	$8.60	$14.23	$70.56	$42.60	$135.99	180,000	$2,039.85
Totals		$129.00	$213.45	$1,058.40	$639.00	$2,039.85		

(1) $56.90 labor rate X 0.25 hours

(2) 9.8 gallons x $7.20 (Cost of 15W-40 test oil) 35 qt. crankcase and 4 qt. for makeup oil in filters

(3) $56.80 labor rate X .75 hours

APPENDIX B

TRADITIONAL OIL CHANGING COSTS at $4.17 PER GALLON OIL

Traditional Oil Changing Costs - $4.17 Oil								
Oil Change Intervals	**Cumulative Bus Mileage**	**Full Flow Filter Cost**	**Full Flow Filter Change Labor Cost (1)**	**Oil Cost per change (2)**	**Oil Change Labor Cost (3)**	**Total Cost per Oil "Event"**	**Cumulative 12,000 mile Intervals**	**Cumulative Costs at 12,000 mile intervals**
12,000	12,000	$8.60	$14.23	$40.87	$42.60	$106.30	12,000	$106.30
12,000	24,000	$8.60	$14.23	$40.87	$42.60	$106.30	24,000	$212.60
12,000	36,000	$8.60	$14.23	$40.87	$42.60	$106.30	36,000	$318.90
12,000	48,000	$8.60	$14.23	$40.87	$42.60	$106.30	48,000	$425.20
12,000	60,000	$8.60	$14.23	$40.87	$42.60	$106.30	60,000	$531.50
12,000	72,000	$8.60	$14.23	$40.87	$42.60	$106.30	72,000	$637.80
12,000	84,000	$8.60	$14.23	$40.87	$42.60	$106.30	84,000	$744.10
12,000	96,000	$8.60	$14.23	$40.87	$42.60	$106.30	96,000	$850.40
12,000	108,000	$8.60	$14.23	$40.87	$42.60	$106.30	108,000	$956.70
12,000	120,000	$8.60	$14.23	$40.87	$42.60	$106.30	120,000	$1,063.00
12,000	132,000	$8.60	$14.23	$40.87	$42.60	$106.30	132,000	$1,169.30
12,000	144,000	$8.60	$14.23	$40.87	$42.60	$106.30	144,000	$1,275.60
12,000	156,000	$8.60	$14.23	$40.87	$42.60	$106.30	156,000	$1,381.90
12,000	168,000	$8.60	$14.23	$40.87	$42.60	$106.30	168,000	$1,488.20
12,000	180,000	$8.60	$14.23	$40.87	$42.60	$106.30	180,000	$1,594.50
Totals		$129.00	$213.45	$613.05	$639.00	$1,594.50		

(1) $56.90 labor rate X 0.25 hours

(2) 9.8 gallons x $4.17 (Cost of 15W-40 test oil) 35 qt. crankcase and 4 qt. for makeup oil in filters

(3) $56.80 labor rate X .75 hours

APPENDIX C

BYPASS FILTER SYSTEM COSTS

Oil Bypass System Costs - $7.20 Oil										
Bypass System Action Intervals (1)	Cumulative Bus Mileage	Bypass Filter Element Cost	Bypass Filter Element Change Labor Cost (2)	Full Flow Filter Cost (3)	Makeup oil costs (4)	Full Flow Filter Change Labor Cost (3)	Intial Bypass System Parts and Labor Costs (5)	Total Cost per Oil "Event"	Cumulative 12,000 mile Intervals	Cumulative Costs at 12,000 mile intervals
12,000	12,000	$21.00	$28.40	$17.20	$28.80	$28.40	$728.50	$852.30	12,000	$852.30
12,000	24,000	$21.00	$14.20		$7.20			$42.40	24,000	$894.70
12,000	36,000	$21.00	$14.20		$7.20			$42.40	36,000	$937.10
12,000	48,000	$21.00	$14.20		$7.20			$42.40	48,000	$979.50
12,000	60,000	$21.00	$14.20	$8.60	$14.40	$14.20		$72.40	60,000	$1,051.90
12,000	72,000	$21.00	$14.20		$7.20			$42.40	72,000	$1,094.30
12,000	84,000	$21.00	$14.20		$7.20			$42.40	84,000	$1,136.70
12,000	96,000	$21.00	$14.20		$7.20			$42.40	96,000	$1,179.10
12,000	108,000	$21.00	$14.20	$8.60	$14.40	$14.20		$72.40	108,000	$1,251.50
12,000	120,000	$21.00	$14.20		$7.20			$42.40	120,000	$1,293.90
12,000	132,000	$21.00	$14.20		$7.20			$42.40	132,000	$1,336.30
12,000	144,000	$21.00	$14.20		$7.20			$42.40	144,000	$1,378.70
12,000	156,000	$21.00	$14.20	$8.60	$14.40	$14.20		$72.40	156,000	$1,451.10
12,000	168,000	$21.00	$14.20		$7.20			$42.40	168,000	$1,493.50
12,000	180,000	$21.00	$14.20		$7.20			$42.40	180,000	$1,535.90
	Totals	$336.00	$227.20	$34.40	$151.20	$56.80	$728.50	$1,535.90		

(1) Two change outs of all filters during the first 12,000 miles.
(2) $56.90 labor rate X 0.25 hours
(3) The change-out interval of the full flow filters is 48,000 miles. Required at 60k, 108k, 156k cumulative miles
(4) Makeup oil costs $7.20 per gallon.
(5) Includes initial bypass filter element cost in system cost of $302, installation kit cost $121, 5 hours labor X $56.90