APPENDIX A

HEXATRIACONTANE TRACER BLENDING PROTOCOL

Protocol For Deuterated N-Alkane Handling, Storage, and Mixing

5/14/07 Rev0 MED/DH

Readme:

I followed the SOP below and I have the following notes to make. I found that heating the oil on the hotplate did a very good job of dissolving the n-alkane. I would consider it an essential, not optional step. A stir bar was used but I found that a large stir bar (18" long) worked even better since the oil is so viscous, especially when cool. Use both stir methods if you have them. Also, I was able to transfer the relatively hot beaker of oil to a large container by myself, but I think it's a job best suited for two people (one to hold the funnel, one to pour).

- Dave Hardie

Objective:

Completely dissolve 100 g of deuterated n-alkane tracer in 20 quarts of motor oil, contained in a 6 gallon fuel/oil container with no contamination of the container, laboratory facilities, clothing, or skin with the tracer.

Equipment:

- 6 gallon or larger plastic fuel/oil container with sealing pour spout
- Two 5-liter Pyrex beakers
- Large glass or plastic funnel with a large bore neck for transferring oil from beaker to 6 gallon container
- 20 quarts of lube oil (Mobil/Exxon 15W40 for diesel engines, classification CH4 or better, meeting EGR engine requirements)
- Magnetic stirrer/hotplate
- Large magnetic stirring bar (~2-3")
- Magnetic stir bar retrieval rod (long enough to retrieve stirrer from 5L beaker)
- Tyvek coveralls
- Latex gloves
- Plastic garbage bags for (1) discarded Kimwipes, Tyvek coveralls, tracer vials, and gloves, and (2) 20 empty quart containers of oil.
- 2 vials (50 g each) of deuterated hexatriacontane powder delivered from DRI

Overview:

The deuterated tracer (n-hexatriacontane, 100g) is to be dissolved in a total of 20 quarts of oil. This tracer was delivered in two separate vials, each containing 50 g of compound as a white powder. The dissolving of this material will be done in 4 batches of 4 quarts each, with the remaining oil used to rinse down the equipment used to dissolve and transfer each batch to the 6 gallon container. A second beaker is used to hold the stir bar and

retrieval rod between batches. Latex gloves and Tyvek coveralls will be worn while conducting these steps. Bottles in which the oil was delivered, as well as the tracer vials, coveralls, and gloves will be discarded in a sealed plastic bag to prevent subsequent accidental contamination of lab facilities, hands, and clothing.

Other than ordinary laboratory procedures to prevent spillage, the only special care required is avoiding any traces of the deuterated alkane or alkane-containing oil on the outside of the 6 gallon container, clothing, hands, or lab equipment. Glassware should be clean and dry, but no special cleaning procedures are needed.

Note: This protocol assumes that the new motor oil being used is obtained in 1-quart plastic bottles. If delivered in larger packages (e.g. 1-gallon), then one additional 1-liter or 1.5-liter beaker can be used to measure and transfer the desired amounts of oil from the large container to the 5-liter beakers. It is not necessary that the tracer be uniformly dissolved through the entire 20 quarts in the 6 gallon container, as it will be thoroughly mixed when added to the engine.

Procedure:

1. N- hexatriacontane-d74 is packed in two separate vials; each contains 50 g of this compound. They should be kept in a safe and clean place, no need to refrigerate.
2. Before handling the tracer, assemble all needed equipment. Label the 6 gallon container using an indelible marker and/or tied-on tag "*15W40 diesel lube oil with alkane tracer,*" and put on Tyvek coveralls and gloves.
3. Open the 6 gallon container and insert the funnel, being sure that it is sufficiently vertical to allow oil to be poured into the container without the funnel overflowing.
4. Place the 5 L beaker on the hotplate and place the stir bar in it.

Batch 1

5. Add 2 quarts of oil to the beaker.
6. Carefully add approximately half of one vial of tracer to the beaker, being careful not to allow the light powder to become airborne.
7. Add another 2 quarts of oil to the beaker, and turn on the stirrer to dissolve the tracer. The tracer should dissolve fairly readily. The oil may be heated slightly to accelerate this process.
8. When dissolved, turn off the stirrer (and hotplate if used) and use the rod to retrieve the stirrer. Transfer the stirrer and rod to the other 5 L beaker, avoiding dripping oil on any surfaces.
9. Check gloves to be sure they do not have oil on the palms or fingertips making them slippery. If so, remove and discard them in the plastic bag, turning them inside out, and put on fresh gloves. Pour the oil from the beaker into the 6 gallon container, carefully avoiding overflowing the funnel and any drips. After pouring, if necessary, Kimwipes can be used to remove small amounts of oil on the beaker pour spout to prevent drips. These should be immediately discarded in the plastic bag, and not placed on laboratory surfaces.

Batch 2

10. Repeat steps 5 through 9 using the second half of the tracer in the first vial and another 4 quarts of oil (quarts 5 to 8).

Batch 3

11. Repeat steps 5 through 9 using the first half of the second vial of tracer and another 4 quarts of oil (quarts 9 to 12).

Batch 4

12. Repeat steps 5 through 9 using the remainder of the tracer and another 4 quarts of oil (quarts 13 to 16).

Rinsing Equipment to Capture Remaining Tracer

13. Set aside the hotplate/stirrer.
14. Add ½ quart of oil to the beaker used for mixing, pouring oil down the sides of the beaker to rinse down the tracer-containing oil (quart 17).
15. Pour the rinse oil from the beaker into the 6 gallon container.
16. Repeat steps 14 and 15 three times, using ½ quart of oil each time (quarts 17 and 18).
17. Use 1 quart of oil to rinse the tracer containing oil off of the stir bar and retrieval rod by holding the retrieval rod with stir bar attached over the second beaker so the stir bar is approximately 3 inches above the bottom of the beaker. Slowly pour the oil down the side of the rod so that it coats and rinses the rod and stir bar. Do not let the stir bar come in contact with the rinse oil in the bottom of the beaker. (quart 19)
18. Transfer the stir bar and retrieval rod to the beaker used for mixing tracer.
19. Pour the rinse oil from the rod and stirrer into the 6 gallon container.
20. Rinse the beaker with ½ quart of oil, pouring down the sides to wash down tracer containing oil, and pour into the 6 gallon container (quart 20).
21. Repeat step 20 with the last ½ quart of oil (quart 20).
22. Remove the funnel from the container and place in one of the beakers.
23. If any tracer-containing oil is on the gloves, remove the gloves (turning inside out, and discarding in the garbage bag), and put on fresh gloves.
24. Replace the filler cap on the 6 gallon container.
25. Discard tracer vials in the plastic garbage bag.
26. Discard the empty oil bottles in the other plastic garbage bag(s) and seal with a twist tie.
27. Clean the funnel, stir bar, retrieval rod and beakers using your standard laboratory procedures for organics.
28. Remove the gloves, turning them inside-out, and discard in the plastic bag.
29. Remove the Tyvek coveralls, turning them inside-out, discard in the plastic bag, and seal the plastic bag.
30. If not immediately being taken to the field, store the 6 gallon container in a secure area.

Contact:

Dave Hardie - Chemist
Research Scientist
University of Washington, DEOHS

4225 Roosevelt Way, NE – Suite 100
Campus Box: 354695
Seattle, WA 98105
206 616-2679
dhardie@u.washington.edu

Mark Davey – Project Manager
University of Washington, DEOHS
206 221-7721
medavey@u.washington.edu

End

APPENDIX B

TWO COLD CO FUELS ANALYSES RESULTS

TABLE B1. HYDROCARBON SPECIATION RESULTS OF TWO COLD CO FUELS

		Original COLD CO Fuel	New Cold CO Fuel		
		EM-5574-F	EM-6802-F	Original - New	Original / New
Group	Component	%Vol	%Vol	Difference, %	Ratio
Paraffin	Propane	0.014	0.004	0.01	3.5
Paraffin	n-Butane	0.528	2.422	-1.89	0.2
Paraffin	n-Pentane	5.841	5.173	0.67	1.1
Paraffin	n-Hexane	2.338	2.113	0.23	1.1
Paraffin	n-Heptane	0.918	0.875	0.04	1.0
Paraffin	n-Octane	0.287	0.314	-0.03	0.9
Paraffin	n-Nonane	0.834	0.787	0.05	1.1
Paraffin	n-Decane	1.218	1.093	0.13	1.1
Paraffin	n-Undecane	0.269	0.093	0.18	2.9
Paraffin	n-Dodecane	0.006	0.008	0.00	0.8
Paraffin	n-Tridecane	0	0.003	0.00	0.0
I-Paraffins	i-Butane	2.959	4.022	-1.06	0.7
I-Paraffins	2,2-Dimethylpropane	0.13	0.081	0.05	1.6
I-Paraffins	i-Pentane	20.161	17.194	2.97	1.2
I-Paraffins	2,2-Dimethylbutane	0.486	0.401	0.09	1.2
I-Paraffins	2,3-Dimethylbutane	0.58	0.475	0.11	1.2
I-Paraffins	2-Methylpentane	2.379	1.994	0.39	1.2
I-Paraffins	3-Methylpentane	1.317	1.119	0.20	1.2
I-Paraffins	2,4-Dimethylpentane	0.178	0.137	0.04	1.3
I-Paraffins	2,2,3-Trimethylbutane	0.041	0.037	0.00	1.1
I-Paraffins	3,3-Dimethylpentane	0.062	0.055	0.01	1.1
I-Paraffins	2-Methylhexane	1.096	1.01	0.09	1.1
I-Paraffins	3-Methylhexane	0.575	0.516	0.06	1.1
I-Paraffins	2,2,4-Trimethylpentane	3.741	4.542	-0.80	0.8
I-Paraffins	2,2-Dimethylhexane	0.028	0.035	-0.01	0.8
I-Paraffins	2,2,3-Trimethylpentane	0.072	0.069	0.00	1.0
I-Paraffins	2,5-Dimethylhexane	0.228	0.246	-0.02	0.9
I-Paraffins	2,4-Dimethylhexane	0.188	0.189	0.00	1.0
I-Paraffins	3,3-Dimethylhexane	0.019	0.018	0.00	1.1
I-Paraffins	2,3,4-Trimethylpentane	0.249	0.207	0.04	1.2
I-Paraffins	2,3-Dimethylhexane	0.064	0.055	0.01	1.2
I-Paraffins	2-Methylheptane	0.177	0.187	-0.01	0.9
I-Paraffins	4-Methylheptane	0.069	0.068	0.00	1.0
I-Paraffins	3-Methylheptane	0.145	0.151	-0.01	1.0
I-Paraffins	3-Ethylhexane	0.103	0.113	-0.01	0.9
I-Paraffins	2,2,5-Trimethylhexane	0.023	0.016	0.01	1.4
I-Paraffins	2,4-Dimethylheptane	0.023	0.015	0.01	1.5
I-Paraffins	2,6-Dimethylheptane	0.036	0.028	0.01	1.3
I-Paraffins	2,5-Dimethylheptane	0.062	0.042	0.02	1.5
I-Paraffins	3,5-Dimethylheptane	0.018	0.011	0.01	1.6
I-Paraffins	2,3-Dimethylheptane	0.042	0.022	0.02	1.9
I-Paraffins	3,5-Dimethylheptane	0.023	0	0.02	NA

		Original COLD CO Fuel	New Cold CO Fuel		
		EM-5574-F	EM-6802-F	Original - New	Original / New
Group	Component	%Vol	%Vol	Difference, %	Ratio
I-Paraffins	4-Ethylheptane	0.014	0.008	0.01	1.8
I-Paraffins	4-Methyloctane	0.101	0.052	0.05	1.9
I-Paraffins	2-Methyloctane	0.146	0.076	0.07	1.9
I-Paraffins	Heptane, 3-ethyl-	0.026	0	0.03	NA
I-Paraffins	3-Methyloctane	0.172	0.116	0.06	1.5
I-Paraffins	C10 - IsoParaffin - 1	0.013	0.006	0.01	2.2
I-Paraffins	2,2,4-trimethylheptane	0.073	0.092	-0.02	0.8
I-Paraffins	C10-isoparaffin-x	0	0	0.00	NA
I-Paraffins	2,3-Dimethyloctane	0.058	0.087	-0.03	0.7
I-Paraffins	2,2-Dimethyloctane	0.097	0.094	0.00	1.0
I-Paraffins	2,5-Dimethyloctane	0.142	0.15	-0.01	0.9
I-Paraffins	2,7-Dimethyloctane	0.057	0.053	0.00	1.1
I-Paraffins	2,4-Dimethyloctane	0.046	0.069	-0.02	0.7
I-Paraffins	2,6-Dimethyloctane	0.179	0.215	-0.04	0.8
I-Paraffins	C10 Isoparaffin -1	0.047	0.054	-0.01	0.9
I-Paraffins	3-Methyl-5-ethylheptane	0.067	0.123	-0.06	0.5
I-Paraffins	5-Methylnonane	0.148	0.177	-0.03	0.8
I-Paraffins	4-Methylnonane	0.25	0.245	0.01	1.0
I-Paraffins	2-Methylnonane	0.283	0.24	0.04	1.2
I-Paraffins	3-Ethyloctane	0.049	0.061	-0.01	0.8
I-Paraffins	3-Methylnonane	0.286	0.273	0.01	1.0
I-Paraffins	Heptane, 2,2,3,5-tetramethyl-	0.03	0.053	-0.02	0.6
I-Paraffins	C11-Isoparaffin-2	0.039	0.043	0.00	0.9
I-Paraffins	C10 - IsoParaffin - 5	0.045	0.075	-0.03	0.6
I-Paraffins	2,3,3-trimethyloctane	0.026	0.046	-0.02	0.6
I-Paraffins	C11-Isoparaffin-3	0.022	0.033	-0.01	0.7
I-Paraffins	C11 Isoparaffin-4	0.075	0.079	0.00	0.9
I-Paraffins	C11-Isoparaffin-5	0.184	0.209	-0.03	0.9
I-Paraffins	3-Ethylnonane	0.095	0.059	0.04	1.6
I-Paraffins	C11-Isoparaffin-6	0	0.035	-0.04	0.0
I-Paraffins	C11-Isoparaffin-7	0.099	0.113	-0.01	0.9
I-Paraffins	C11-Isoparaffin-8	0.045	0.039	0.01	1.2
I-Paraffins	C11-Isoparaffin-9	0.032	0.036	0.00	0.9
I-Paraffins	C11- Isoparaffin-11	0.11	0.063	0.05	1.7
I-Paraffins	C11- IsoParaffin - 13	0.13	0.057	0.07	2.3
	C12 - IsoParaffin - 1	0.009	0	0.01	NA
Mono-Aromatics	C12 - IsoParaffin - 2	0	0.004	0.00	0.0
Mono-Aromatics	C12 - IsoParaffin - 4	0	0.006	-0.01	0.0
Mono-Aromatics	Benzene	0.491	0.611	-0.12	0.8
Mono-Aromatics	Toluene	11.942	16.076	-4.13	0.7
Mono-Aromatics	Ethylbenzene	0.058	0.035	0.02	1.7
Mono-Aromatics	m-Xylene	0.171	0.186	-0.02	0.9
Mono-Aromatics	p-Xylene	0.06	0.06	0.00	1.0
Mono-Aromatics	o-Xylene	0.178	0.05	0.13	3.6

		Original COLD CO Fuel	New Cold CO Fuel		
		EM-5574-F	EM-6802-F	Original - New	Original / New
Group	Component	%Vol	%Vol	Difference, %	Ratio
Mono-Aromatics	i-Propylbenzene	0.103	0.021	0.08	4.9
Mono-Aromatics	n-Propylbenzene	0.744	0.695	0.05	1.1
Mono-Aromatics	1-Methyl-3-ethylbenzene	2.598	2.385	0.21	1.1
Mono-Aromatics	1-Methyl-4-ethylbenzene	1.198	1.112	0.09	1.1
Mono-Aromatics	1,3,5-Trimethylbenzene	1.411	1.438	-0.03	1.0
Mono-Aromatics	1-Methyl-2-ethylbenzene	1.066	0.735	0.33	1.5
Mono-Aromatics	1,2,4-Trimethylbenzene	4.311	3.419	0.89	1.3
Mono-Aromatics	i-Butylbenzene	0.09	0.093	0.00	1.0
Mono-Aromatics	1,2,3-Trimethylbenzene	0.984	0.531	0.45	1.9
Mono-Aromatics	1-Methyl-3-i-propylbenzene	0.038	0.024	0.01	1.6
Mono-Aromatics	1-Methyl-4-i-propylbenzene	0.019	0.018	0.00	1.1
Mono-Aromatics	1,3-Diethylbenzene	0.159	0.087	0.07	1.8
Mono-Aromatics	1-Methyl-3-n-propylbenzene	0.402	0.254	0.15	1.6
Mono-Aromatics	1-Methyl-4-n-propylbenzene	0.265	0.126	0.14	2.1
Mono-Aromatics	n-Butylbenzene	0.047	0.044	0.00	1.1
Mono-Aromatics	1,3-Dimethyl-5-ethylbenzene	0.475	0.187	0.29	2.5
Mono-Aromatics	1,2-Diethylbenzene	0.045	0.026	0.02	1.7
Mono-Aromatics	1-Methyl-2-n-propylbenzene	0.173	0.098	0.08	1.8
Mono-Aromatics	C9 - Aromatic - 1	0.086	0.051	0.04	1.7
Mono-Aromatics	1,4,Dimethyl-2-ethylbenzene	0.442	0.171	0.27	2.6
Mono-Aromatics	1,3-Dimethyl-4-ethylbenzene	0.448	0.205	0.24	2.2
Mono-Aromatics	1,2-Dimethyl-4-ethylbenzene	1.085	0.436	0.65	2.5
Mono-Aromatics	1,3-Dimethyl-2-ethylbenzene	0.06	0.033	0.03	1.8
Mono-Aromatics	1-Methyl-4-t-butylbenzene	0.013	0.035	-0.02	0.4
	1-Ethyl-3-i-propylbenzene	0.008	0	0.01	NA
Mono-Aromatics	1,2-Dimethyl-3-ethylbenzene	0.127	0.141	-0.01	0.9
Mono-Aromatics	1-Ethyl-4-i-propylbenzene	0.015	0.014	0.00	1.1
Mono-Aromatics	C11 - Aromatic - 1	0.009	0.014	-0.01	0.6
Mono-Aromatics	1,2,4,5-Tetramethylbenzene	0.41	0.425	-0.02	1.0
Mono-Aromatics	1,2,3,5-Tetramethylbenzene	0.781	0.606	0.18	1.3
Mono-Aromatics	C11 - Aromatic - 2	0	0.002	0.00	0.0
Mono-Aromatics	C11 - Aromatic - 3	0.015	0.066	-0.05	0.2
Mono-Aromatics	1,2-Di-i-propylbenzene	0.021	0.074	-0.05	0.3
Mono-Aromatics	1-methyl-4-(1-methylpropyl)be	0.039	0.109	-0.07	0.4
Mono-Aromatics	C11 - Aromatic - 4	0	0.051	-0.05	0.0
Mono-Aromatics	n-Pentylbenzene	0.006	0.023	-0.02	0.3
Mono-Aromatics	tert-Pentylbenzene	0.034	0.11	-0.08	0.3
Mono-Aromatics	1-Methyl-2-n-butylbenzene	0.014	0.051	-0.04	0.3
Mono-Aromatics	C11 - Aromatic - 7	0.017	0.064	-0.05	0.3
Mono-Aromatics	1,4-Di-i-propylbenzene	0.027	0.095	-0.07	0.3
Mono-Aromatics	C11 - Aromatic - 9	0.294	0.131	0.16	2.2
Mono-Aromatics	C11 - Aromatic - 10	0	0.011	-0.01	0.0
Mono-Aromatics	1,3-Di-n-propylbenzene	0.027	0.067	-0.04	0.4
Mono-Aromatics	C11 - Aromatic - 11	0.016	0.038	-0.02	0.4

		Original COLD CO Fuel	New Cold CO Fuel		
		EM-5574-F	EM-6802-F	Original - New	Original / New
Group	Component	%Vol	%Vol	Difference, %	Ratio
Naphthalenes	1-ethyl-2,4,5-trimethylbenzen	0.014	0.02	-0.01	0.7
Naphthalenes	C11 - Aromatic - 13	0	0.003	0.00	0.0
Naphtheno/Olefino-Benzs	2-Methylnaphthalene	0	0.006	-0.01	0.0
Naphtheno/Olefino-Benzs	1-Methylnaphthalene	0	0.003	0.00	0.0
	C12 - Aromatic - 1	0.003	0	0.00	NA
Indenes	5-Methylindan	0.134	0.209	-0.08	0.6
Indenes	2-Methylindan	0.269	0.267	0.00	1.0
Indenes	Indan	0.262	0.235	0.03	1.1
Indenes	2-Methylindan	0.088	0.034	0.05	2.6
Indenes	1H-Indene, 2,3-dihydro-1,2-dim	0.012	0.007	0.01	1.7
Indenes	4-Methylindan	0.12	0.273	-0.15	0.4
Indenes	4,7-Dimethyl Indane	0.005	0.004	0.00	1.3
Mono-Naphthenes	1,1-Dimethyl Indane	0.005	0.021	-0.02	0.2
Mono-Naphthenes	Dimethyl Indane - 1	0	0.005	-0.01	0.0
Mono-Naphthenes	Cyclopentane	0.449	0.452	0.00	1.0
Mono-Naphthenes	Methylcyclopentane	1.562	1.585	-0.02	1.0
Mono-Naphthenes	Cyclohexane	1.536	1.638	-0.10	0.9
Mono-Naphthenes	1t,3-Dimethylcyclopentane	0.168	0.171	0.00	1.0
Mono-Naphthenes	1c,3-Dimethylcyclopentane	0.152	0.157	-0.01	1.0
Mono-Naphthenes	1t,2-Dimethylcyclopentane	0.268	0.271	0.00	1.0
Mono-Naphthenes	Methylcyclohexane	1.657	1.87	-0.21	0.9
Mono-Naphthenes	1,1,3-Trimethylcyclopentane	0.04	0.04	0.00	1.0
Mono-Naphthenes	Ethylcyclopentane	0.055	0.06	-0.01	0.9
Mono-Naphthenes	1c,2t,4-Trimethylcyclopentane	0.038	0.038	0.00	1.0
Mono-Naphthenes	1t,2c,3-Trimethylcyclopentane	0.03	0.029	0.00	1.0
Mono-Naphthenes	1,3-dimethyl-t-cyclohexane	0.164	0.183	-0.02	0.9
Mono-Naphthenes	1,1-Dimethylcyclohexane	0.042	0.038	0.00	1.1
Mono-Naphthenes	3c-Ethylmethylcyclopentane	0.01	0.008	0.00	1.3
Mono-Naphthenes	3t-Ethylmethylcyclopentane	0.014	0.011	0.00	1.3
Mono-Naphthenes	1c,4-Dimethylcyclohexane	0.045	0.044	0.00	1.0
Mono-Naphthenes	1c,2-Dimethylcyclohexane	0.02	0.012	0.01	1.7
Mono-Naphthenes	Ethylcyclohexane	0.121	0.096	0.03	1.3
Mono-Naphthenes	1c,2t,4t-Trimethylcyclohexane	0.062	0.032	0.03	1.9
Mono-Naphthenes	C9 - MonoNaph - 4	0.016	0.007	0.01	2.3
Mono-Naphthenes	1c,2t,4c-Trimethylcyclohexane	0.014	0.012	0.00	1.2
Mono-Naphthenes	Cyclohexane, 1,2,4-trimethyl-,	0.02	0.02	0.00	1.0
Mono-Naphthenes	Cyclopentane, 1-methyl-2-propyl-	0.017	0.032	-0.02	0.5
Mono-Naphthenes	trans-1,3-Diethylcyclopentane	0.1	0.119	-0.02	0.8
Mono-Naphthenes	C10 - MonoNaph - 1	0	0.005	-0.01	0.0
Mono-Naphthenes	1,1-Methylethylcyclohexane	0.078	0.136	-0.06	0.6
Mono-Naphthenes	1-Methyl-2-propyl-cyclopentan	0.005	0.008	0.00	0.6

		Original COLD CO Fuel	New Cold CO Fuel		
		EM-5574-F	EM-6802-F	Original - New	Original / New
Group	Component	%Vol	%Vol	Difference, %	Ratio
Mono-Naphthenes	1,2,3,5-t-Tetramethylcyclohex	0.141	0.198	-0.06	0.7
Mono-Naphthenes	1,2,3,5-c-Tetramethylcyclohex	0	0.025	-0.03	0.0
Mono-Naphthenes	i-Butylcyclohexane	0.075	0.107	-0.03	0.7
Mono-Naphthenes	C10 - MonoNaph - 2	0.024	0.034	-0.01	0.7
Mono-Naphthenes	1t-Methyl-2-n-propylcyclohexan	0	0.017	-0.02	0.0
n-Olefins	n-ButylCyclohexane	0.076	0.1	-0.02	0.8
n-Olefins	C11-MonoNaphthene-2	0.021	0.008	0.01	2.6
	t-Butene-2	0.003	0	0.00	NA
	c-Butene-2	0.004	0	0.00	NA
	Pentene-1	0.004	0	0.00	NA
	t-Pentene-2	0.012	0	0.01	NA
	c-Pentene-2	0.006	0	0.01	NA
n-Olefins	Hexene-1	2.812	4.587	-1.78	0.6
n-Olefins	t-Nonene-3	0	0.013	-0.01	0.0
Iso-Olefins	C10-n-Olefin	0.02	0.031	-0.01	0.6
Iso-Olefins	3-Decene	0.009	0.018	-0.01	0.5
	5-Undecene	0.007	0	0.01	NA
Iso-Olefins	3-Methyl-c-pentene-2	0	0.008	-0.01	0.0
	2-Methylbutene-1	0.008	0	0.01	NA
	2-Methylbutene-2	0.017	0	0.02	NA
Iso-Olefins	3-Methyl-t-hexene-2	5.403	4.294	1.11	1.3
Iso-Olefins	C8 - Diolefin - 1	0.012	0.011	0.00	1.1
Iso-Olefins	3-Heptene, 4-methyl-	0.069	0.073	0.00	0.9
Iso-Olefins	C9 - IsoOlefin - 1	0.012	0.009	0.00	1.3
Iso-Olefins	2,3-Dimethylheptene-2	0.016	0.023	-0.01	0.7
Iso-Olefins	C10 - IsoOlefin - 2	0.039	0.054	-0.02	0.7
Iso-Olefins	C10-IsoOlefin-4	0.006	0.009	0.00	0.7
Iso-Olefins	C10 Iso-olefin - 5	0.023	0.062	-0.04	0.4
Iso-Olefins	C10 Iso-olefin - 6	0.017	0.025	-0.01	0.7
Iso-Olefins	C10-IsoOlefin-7	0.053	0.076	-0.02	0.7
Iso-Olefins	C10 - IsoOlefin - 8	0	0.021	-0.02	0.0
Iso-Olefins	2,3-Dimethyl-2-octene	0.013	0.03	-0.02	0.4
Iso-Olefins	C10-IsoOlefin-12	0.043	0.08	-0.04	0.5
Naphtheno-Olefins	C10-IsoOlefin -15	0.101	0.128	-0.03	0.8
Naphtheno-Olefins	3-Nonene, 3-methyl-, (E)-	0.014	0.03	-0.02	0.5
Naphtheno-Olefins	C8 - Naph-Olefin - 1	1.368	1.047	0.32	1.3
	1-Ethyl-2-Methylcyclopentene	0.036	0.02	0.02	1.8
	C9-NaphthenoOlefin-6	0	0	0.00	NA

APPENDIX C

LUBRIZOL LETTER REPORT
LIGHT-DUTY HIGH PM EMISSIONS VEHICLE

June 9, 2008

Mr. Lew Williams
The Lubrizol Corporation
29400 Lakeland Blvd.
Wickliffe, OH 44092-2298
lewis.williams@lubrizol.com

Ref: Letter Report, "Selecting the High Smoke Emissions Vehicles,"
SwRI Project No. 03-11309.

Dear Mr. Williams:

The location, selection process for the candidate vehicles, and final decision to pick the 'high-emitting' gasoline vehicle were performed by SwRI and approved in consultation with the members of the CLOSE and AVFL-14 projects. SwRI's criteria for high-emitting vehicle was not based on make, model, type of owner, mileage, or any other a priori assumptions regarding the likelihood of any specific type of vehicle being a good candidate. With decades of emission regulations in place, and manufacturers producing extremely durable engine and exhaust control systems, SwRI recognizes that 'smoking' vehicles are not the norm in the existing fleet of operational vehicles; therefore, any vehicle selected is atypical.

1.0 BACKGROUND

According to the proposed scope of work the high-emitting gasoline vehicle was defined as "a gasoline-fueled vehicle with visible smoke related to lubrication oil. The RFP requests a PM emission rate greater than 200 mg/mi over the Unified Driving Cycle (UDC). In SwRI's experience, vehicles that continually and consistently emit "white" smoke related to lubricating oil typically have PM emission rates well above this value (Whitney 2000, 1998). This vehicle will likely be solicited from SwRI employees, families, and friends. Candidate vehicles will be screened for visual indication of consistent "white" smoke emissions during a variety of driving conditions. Although the RFP states that there is no restriction on vehicle age or mileage, consideration will be given to the representativeness of the vehicle, as well as its ability to be safely and repeatably tested on a chassis dynamometer."

2.0 SOLICITATION

The following notice was sent by email to all SwRI employees:

WANTED: Smoking Car

A project in the Office of Automotive Engineering requires a test car that emits visible smoke during all running conditions and needs frequent oil fills. Cars, half-ton pickups, and SUVs could be utilized. The vehicle should be in otherwise sound mechanical condition and driven regularly. We will pay the owner $500 plus provide an intermediate-size rental car for approximately 10 weeks. If you know of such a car and we choose to use it, a finder's fee of $100 is available. Contact Jim Carroll at 522-5015 or (mailto:jcarroll@swri.org).

3.0 RESPONSES AND SELECTION PROCESS

SwRI received 22 responses to the email solicitation. SwRI used the following selection criteria in generally descending order of importance to pick the high emitting test vehicle:

1. Visible smoke upon hot start, at idle, during acceleration, and at steady speed.
2. Relatively modern emission control system, i.e. equipped with exhaust catalyst, closed-loop control, fuel injection.
3. Automatic transmission.
4. Stock engine, exhaust system, and drivetrain.
5. Driven regularly.
6. Fully operational drivetrain and brake system.
7. No external engine oil leaks.
8. None or easily repairable engine codes.
9. Owner had good knowledge of vehicle history.
10. Known high oil consumption.

List of responses received and reasons for rejection of candidates:

1998 Saturn SE2 Coupe – could not connect an ECM reader to the wiring harness without the horn on the vehicle blowing, symptom of wiring harness degradation or ECM problem.

1988 Chevrolet Caprice – owned for just two weeks, not driven, fouled plugs within two weeks.

1988 Chevrolet Camaro IROC – owner unresponsive.

1995 Mitsubishi Eagle Talon – standard transmission.

1963 Ford Fairlane – too old, produced prior to emissions controls.

1993 Toyota Tercel – standard transmission.

1995 Acura Integra – engine rebuilt once to high output configuration, then put back to original configuration. Not ‘stock.’

1986 Chevrolet truck – no catalyst.

1994 Jeep Grand Cherokee – no catalyst.

1995 Mitsubishi Eclipse – standard transmission.

1995 Mitsubishi Eagle Talon – aftermarket performance exhaust and intake system, standard transmission.

1995 Nissan 240SX – smoke visible upon acceleration only, no smoke at idle, startup, or at steady speed. Some oil seepage around head cover gasket.

1994 Mercury Cougar – owner unresponsive.

1998 Pontiac Gran Prix – some smoke at start, but not enough during steady-state operation.

1993 Mazda Protégé – standard transmission.

1998 Mitsubishi Montero – standard transmission

1999 Dodge Neon – initially thought to be a good candidate, but found oil leaks at head cover gasket and crankshaft main seal; also the engine had a mechanical knock.

1991 Acura – coolant leak, brakes unsafe, transmission shifted poorly, the engine shuddered. Best candidate for recycling.

1990 Honda Accord – no smoke at idle, not enough smoke during acceleration.

1999 Dodge Durango – smoke visible at idle only.

1990 Honda Accord – smoked if engine was revved, otherwise there was no smoke visible.

4.0 RECOMMENDED VEHICLE

1993 Mercury Grand Marquis

- Visible smoke upon hot and cold starts, at idle, during acceleration, and at steady speeds.
- Relatively modern emission control system.
- Automatic transmission.
- Stock engine, exhaust system, and drivetrain.
- Driven weekly.
- Fully operational drivetrain and brake system.
- No external engine oil leaks.
- Engine code set was traced to EGR system. EGR lines were cleaned and controls were replaced. Codes were cleared and have not re-set since.
- Owner had knowledge of complete vehicle history.

The owners indicated that at approximately 30,000 miles they took it to the dealer due to what they believed was excessive oil consumption. The dealer conducted an oil consumption test and determined it to be approximately 1 quart every 1,200 miles. The dealer assured the owners that this was within normal specifications and that there was no problem with the vehicle. The owners noticed visible smoke at approximately 50,000 miles, and it has gotten progressively worse over the years.

The vehicle has approximately 125,000 miles on the odometer and emits visible "blue" smoke during both cold and warm conditions. A set of preliminary four-phase Unified Cycle tests were conducted to evaluate the repeatability of this vehicle. Composite and phase-level particulate emission results are given in Table 1. Composite gaseous emission results are given in Table 2. These results indicate the test vehicle has relatively repeatable emissions and should meet the needs of this project.

TABLE 1. FOUR-PHASE UNIFIED CYCLE PM EMISSION RATE, MG/MI

	Phase 1	Phase 2	Phase 3	Phase 4	Composite
Test 1	31.2	77.3	133.6	130.3	101.1
Test 2	41.4	79.5	133.9	142.9	108.3
Test 3	35.8	61.7	156.7	118.8	91.0

TABLE 2. COMPOSITE UNIFIED CYCLE PM EMISSION RATE, G/MI

	THC	CO	NO_X
Test 1	0.55	6.6	1.7
Test 2	0.70	8.1	1.7
Test 3	0.66	7.3	1.7

Due to concern regarding the failure mode of the this high PM emitter that SwRI recommended for testing, an effort was undertaken to evaluate and document the mechanical status of the vehicle as regards oil consumption. Evaluations included the following:

- Spark plugs were removed, inspected, and photographed.
- Each cylinder piston top, cylinder wall, and cylinder head was inspected and rated by borescope.
- A compression and leak down check was performed on each cylinder.
- Oil consumption was determined gravimetrically over 300 miles of highway operation.
- The vehicle owner was contacted in an effort to get more detailed information regarding observed oil consumption for this vehicle.

Figures 1 through 8 are photographs of the spark plugs pulled from the vehicle's engine. The numbering convention is cylinders/plugs 1-4 are front-to-back from the right cylinder bank if viewed from the driver, and plugs 5-8 are the left cylinder bank. The plugs did not appear to be fouled; they are dry, and some show electrode loss and unidentified white deposits.

Figure 1. Spark Plug 1

Figure 2. Spark Plug 2

Figure 3. Spark Plug 3

Figure 4. Spark Plug 4

Figure 5. Spark Plug 5

Figure 6. Spark Plug 6

Figure 7. Spark Plug 7

Figure 8. Spark Plug 8

The results from the cylinder compression check, and leak down tests are shown in Tables 3, and 4, respectively. The compression test variation is good (within 10%) on the right bank but poor on the left bank. Cylinder leak down results are poor to bad (5-10% is good). The cylinders showed no sign of bore polishing or scuffing during the borescope inspection.

TABLE 3. CYLINDER COMPRESSION TEST

Right Cylinder Bank		Left Cylinder Bank	
Cyl 1	130 psi	Cyl 5	110 psi
Cyl 2	140 psi	Cyl 6	140 psi
Cyl 3	130 psi	Cyl 7	150 psi
Cyl 4	130 psi	Cyl 8	130 psi

TABLE 4. CYLINDER LEAK DOWN TEST

Right Cylinder Bank		Left Cylinder Bank	
Cyl 1	14%	Cyl 5	28%
Cyl 2	24%	Cyl 6	28%
Cyl 3	18%	Cyl 7	14%
Cyl 4	36% (Checked 2 times)	Cyl 8	38% (Checked 2 times)

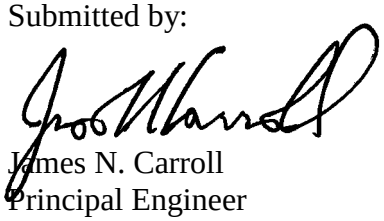
SwRI completed the 300 mile oil consumption test. On 3/3/08, the vehicle was filled with the a preweighed amount of test oil and a new preweighed oil filter. The vehicle was operated for 457 miles. This included the 150 miles of highway driving at 65 to 70 mph, plus the chassis dyno testing presented in Tables 1 and 2. The oil consumption for the 457 miles was 2.37 lbs of oil. On 4/21/08, the oil and used oil filter were drained and the weights recorded. The used oil and the used filter were reinstalled and the vehicle underwent another accumulation interval of 300 miles on the highway at 65 to 70 mph. On 4/24/08 the used oil and used filter were drained and the weights recorded. The oil consumption for the 300 miles was 1.85 lbs of oil.

Using a density of 1.8 lb per quart of oil, the average oil consumption on the candidate smoking vehicle equates to 319 miles per quart. This is consistent with what was reported by the owner who stated that he has been adding 1 quart about every 300 miles.

5.0 CLOSURE

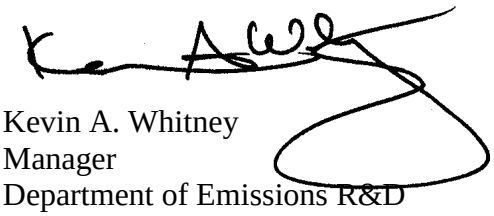
Following the completion of the smoking vehicle evaluation, all data was presented to the CLOSE/AVFL-14 team. The team recommended the use of the high emitting vehicle for the project. It is clear that this particular vehicle is atypical and not representative of this or any other make or model of on-highway high-mileage vehicle.

Submitted by:



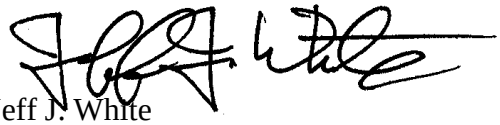
James N. Carroll
Principal Engineer
Department of Emissions R&D

Reviewed by:



Kevin A. Whitney
Manager
Department of Emissions R&D

Approved by:



Jeff J. White
Director
Department of Emissions R&D

/sat

U:\Carroll\WP\FINALS\03-11309 Letter Report_Lubrizol_6-4-2008.doc

APPENDIX D

DESERT RESEARCH INSTITUTE REPORT ON RENO FUELS

TABLE D1. HOPANES AND STERANES IN FUELS FROM RENO NEVADA

	Hopanes and Steranes, ug/gram								
Reno Fuels	Chevron Diesel	Chevron Premium	Chevron Regular	Shell Diesel	Shell Premium	Shell Regular	Texaco Diesel	Texaco Premium	Texaco Regular
hop15	0.418	0.000	0.000	0.332	0.000	0.088	0.320	0.000	0.000
hop17	0.720	0.111	0.132	0.743	0.106	0.039	0.609	0.097	0.122
hop19	0.267	0.006	0.108	0.205	0.080	0.081	0.203	0.157	0.092
hop20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop21	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop22	0.158	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
hop27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ster42	0.161	0.000	0.000	0.223	0.000	0.000	0.158	0.000	0.000
ster43	0.372	0.000	0.018	0.364	0.000	0.000	0.348	0.000	0.000
ster44	0.225	0.000	0.000	0.191	0.000	0.000	0.206	0.000	0.000
ster45_40	0.064	0.000	0.000	0.672	0.000	0.000	0.000	0.000	0.000
ster46	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ster47	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ster48	0.000	0.000	0.000	0.000	0.000	0.000	0.221	0.000	0.000
ster49	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ster50	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.000
ster51	0.064	0.000	0.000	0.057	0.000	0.007	0.041	0.000	0.000
ster52	0.022	0.000	0.000	0.044	0.000	0.039	0.000	0.000	0.000
ster53	0.108	0.005	0.000	0.065	0.055	0.017	0.088	0.007	0.000

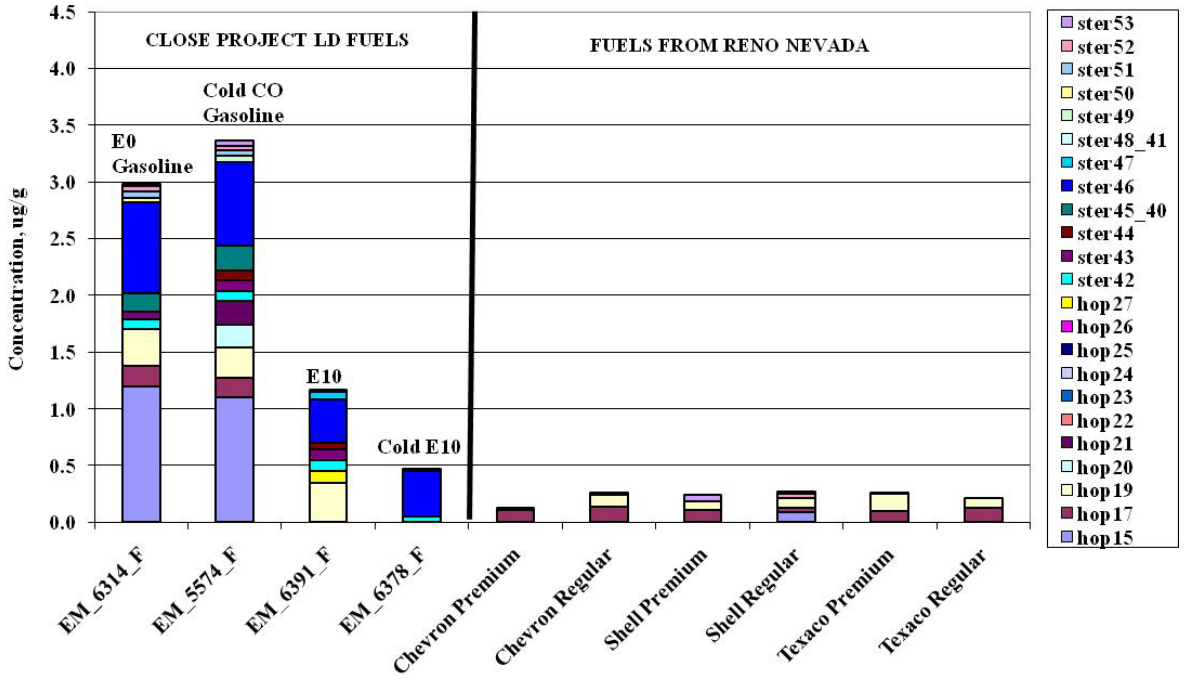


FIGURE D1. CLOSE PROJECT LIGHT-DUTY FUELS AND RENO FUELS HOPANES AND STERANES CONCENTRATIONS

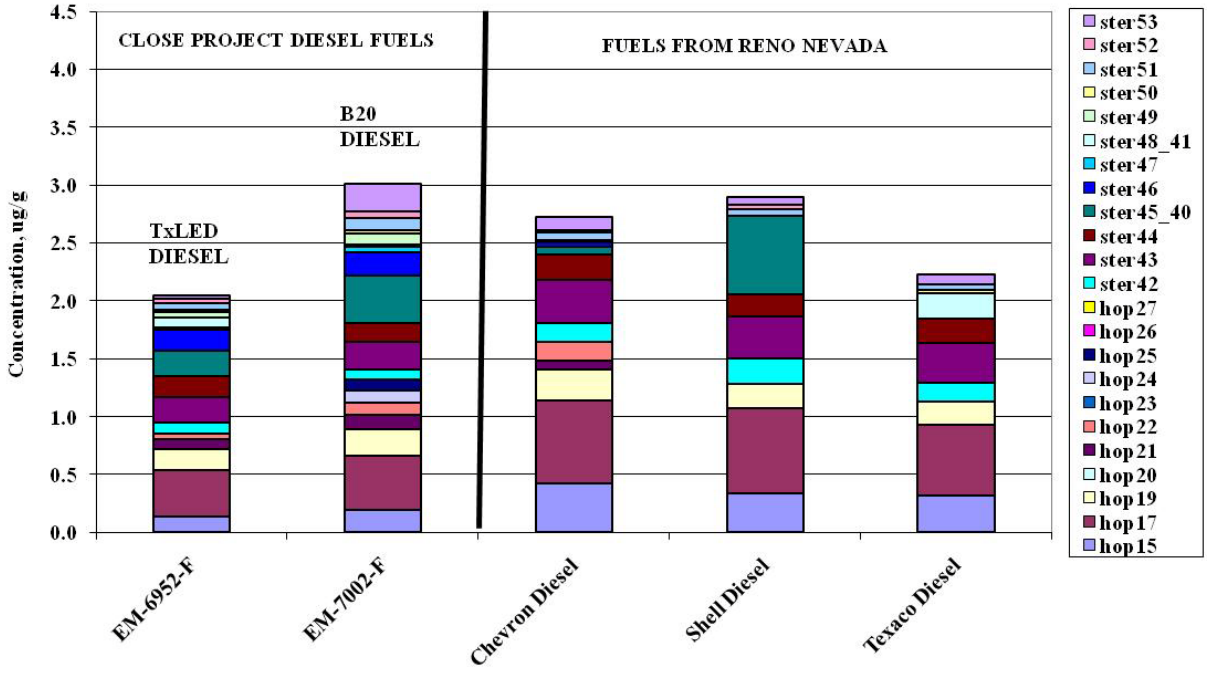


FIGURE D2. CLOSE PROJECT AND RENO DIESEL FUELS HOPANES AND STERANES CONCENTRATIONS

APPENDIX E

HEAVY-DUTY SMOKER REPORT ON CPS VEHICLES

July 16, 2009

Dr. Douglas R. Lawson
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401

Email: Doug_Lawson@nrel.gov

Subject: Heavy-Duty Diesel Candidate Vehicles for "CLOSE: Collaborative Lubricating Oil Study on Emissions"
NREL Subcontract Number AEV-7-66409-01, SwRI Project No. 03.13012

1.0 DISCUSSION

SwRI was invited to inspect heavy-duty vehicles at City Public Service (CPS) Company, which is the electrical utility in the San Antonio area. The vehicles have been released from service and can be used in the CLOSE program as heavy-duty diesel PM emission test vehicles. Table 1 contains information regarding the vehicles we inspected.

These vehicles were used as construction and repair support vehicles for CPS. All the vehicles are 1993 to 1998 models. Although many show low mileage accumulation, their engines were operated while the vehicle was at a stand still to power auxiliary systems such as lifts, winches, pumps, welders, etc. Thus the engines can have many more hours of operation than the vehicles.

During our inspection of the vehicles each one was started and allowed to come to normal operating temperature for 5 to 10 minutes but they were not driven. During warm up the engine was quickly accelerated, operated at a few steady-state no-load points, and left to idle a few times. The exhaust plume from each vehicle was watched for smoke during operation and notes are included in Table 1.

Three vehicles are candidates for use as high PM emission test vehicles. Vehicle #88153 had clean engine exhaust upon start up but as the engine warmed up smoke was released. The exhaust smelled of lubricant, rather than diesel fuel, which indicates that its fuel system is operating normally and its oil control is compromised. Vehicle #88443 smoked upon start, during accelerations, and at elevated no-load speeds while cold, but did not smoke once the engine warmed. Vehicle #52159 showed slight smoke during start up and during accelerations, but none at idle.

Table 1. Heavy-Duty Diesel Vehicle Inspections

VEHICLE NUMBER	VEHICLE #88153 HIGH PM EMISSION TEST CANDIDATE	VEHICLE #88443	VEHICLE #52159	VEHICLE #88195	VEHICLE #98484	VEHICLE #52183 NORMAL PM EMISSION TEST CANDIDATE
VEHICLE MODEL	’93 Ford F600	’98 International 4700 T444E	’94 Ford Type L90460	’96 Ford 1996 F80350	International 4700 DT 466	Ford ’94 Type L9460
VEHICLE TYPE			Tow truck			5th Wheel truck
MILEAGE	160,722 miles	39,558 miles		66,542 miles	79,843 miles	
AXLE	Single axle	Single axle	Tandem axle	Single axle	Single axle	Tandem axle
ENGINE	Ford 5.9L 403A, Model B5.9-160	Navistar Model B175F 7.3L, Family #WNVXH044FNA	8.3L Ford Model C8.3-225		Model A175 I-6 466 c.i., 175 hp	Cummins Engine
GVW, LB	23,100		45,000			45,000
VIN NUMBER	#1FDWK64C5RCA21384	#1HTSCABL5WH558209	#1FDYL90E8SVA19584	#1FDYF80E3TVA06230		#1FDYL90E3SCA19587
NOTES	Dead battery	Good puff of smoke at start.	Smoke on start, idles clean.	Clean at start, then engine died, then black on restart.	Dead battery	Clean exhaust.
	No smoke at start and low idle.	Good puff of smoke at tip in.	Slight fog at tip in.	Does not idle when cold.	Wisp of smoke at startup.	
	After warm up, there was plenty of smoke upon tip in, acceleration, and at high idle.	Slight smoke at high idle, but none at low idle.		Wisping smoke at idle “white” smoke.	Some smoke (smells of diesel fuel) on first high idle rise.	
	Smoke did not smell of diesel fuel, rather, it smelled of oil.	After extended idle, very little smoke even at tip in.		When warm, high idle exhaust was clean.	Seems to misfire on tip in.	
				Exhaust smells of fuel.	Once warm, slight smoke haze, still smells like diesel.	

Vehicles #88195 and #98484 produced exhaust with a strong diesel smell indicating a problem with their fuel systems.

2.0 TEST VEHICLE RECOMENDATIONS

Vehicle #52183 did not smoke during startup, accelerations, or at higher speed no-load operation. SwRI recommends that this vehicle be used for the normal emitter heavy-duty diesel tests.

For the high PM emitter tests, SwRI recommends that vehicle #88153 be utilized. It produced the greatest level of smoke and its exhaust did not smell of diesel fuel.

3.0 CONCLUSION

SwRI plans to test CNG fueled heavy-duty vehicles before HD diesel vehicles but has had difficulty locating them, and suspects that they may not be available by the time medium-duty vehicle testing is completed. Therefore, SwRI requests input from CLOSE project supporters regarding our recommendations for the HD diesel vehicle testing. We can then begin more detailed inspections of the vehicles in preparation for testing and move into the next phase of tests without interruption.

Sincerely:

James N. Carroll, Principal Engineer
Light-Duty Vehicle Emissions Section
Emissions Research and Development