January 17, 2014

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Executive Director/APCD
San Joaquin Valley Unified APCD
1990 East Gettysburg Ave
Fresno, CA 93726

SUBJECT: Final Report, City of Manteca Hybrid Refuse Collection Vehicle Grant, Agreement No. C-15655-A

The San Joaquin Valley Air Pollution Control District gave the City of Manteca a grant in the amount of $242,500 towards the purchase of two (2) E3 Parker-Run Wise Hybrid Refuse Collection Vehicles. The total cost of the two vehicles was $886,321.96.

Background and Objectives: The City operates a collection program for trash/recycling and green waste within the City limits for residents and businesses six days a week. We have a minimum of seventeen (17) collection vehicles on the road each day. It is imperative to deploy innovative clean air technologies than can reduce carbon emissions and fuel consumption during our collection procedures. The purpose of purchasing the two (2) Parker RunWise Advance Series Hybrid Drive collection vehicles was to see if we could reduce emissions and fuel consumption in our everyday operations. Our fleet is reaching maturity and will need to be replaced over the next couple years. We need to find the best medium heavy-duty trucks that can do the job, reduce diesel fuel usage, reduce NOx and carbon emissions and reduce maintenance costs. Our hope is that these Hybrid trucks will fill the bill.

Executive Summary: An independent contractor, INFOWEDGE, was hired to conduct emissions testing on both the Hybrid vehicles and the standard collection vehicles and run comparison studies.
INFOWEDGE purchased some data collection equipment and rented some equipment.
The first step was to examine the drive cycles of each type of vehicle; hybrid and conventional.
The data collection equipment was installed in Unit 2080. Data collected from this is attached.
The data shows speed, altitude, engine load, engine speed, fuel rate and engine temperature.
Data was collected for three (3) days. The report shows that routes each day are relatively the same.

Collection areas are relatively the same. Terrain covered is relatively the same. This eliminates the concern for outside variables and shows that each route and trash cans picked up are pretty standard each day.

The Solid Waste Division ran a fuel comparison study in June and July 2013 between Unit 2080 , the Hybrid and Unit 2070 a conventional truck. We used the same driver in both vehicles; did the same routes; picked up the same commodities and used the same disposal sites.
We tracked the starting and ending mileage each day; gallons of fuel used, type of commodity and tons picked up. We ran the test for three (3) consecutive weeks with each vehicle. The results are attached. Our conclusion showed the Hybrid trucks used less fuel. Over the three (3) week periods Unit 2070 traveled 429 miles and used 216.8 gallons of diesel. That averages out to 1.98 miles per gallon. Unit 2080 (Hybrid) traveled 428 miles and used 162.4 gallons of diesel. That averages out to 2.64 miles per gallon. The savings averaged out to 0.66 miles per gallon. Hypothetically speaking if diesel is costing $2.00/gallon the savings for this three week test would have been: $108.8. If we had seventeen hybrid trucks for those three weeks; the savings would have been $1849.60. It is estimated that the fuel savings over a year would be $32,000 if our entire fleet were Parker RunWise Systems; based on our crude analysis.

Emissions testing equipment was installed on Unit 2079 a RunWise Hybrid vehicle and on Unit 2074 a conventional collection vehicle. Both vehicles did the same route, covering the same number of miles in the same area.
The particulate measurement system is manufactured by ProcessMetrix and is based upon the two-angle measurement of laser light scattered by the particles in the exhaust. As the vehicles were driven on their routes, they were followed by the consultant to make sure that the data was being collected properly. When the vehicles returned from their routes, they were fueled, washed and the data was downloaded. Attached to this report is a comparison of the fuel and emissions results as reported by INFOWEDGE. Based on this report the Parker RunWise Hybrid trucks saved 42% in fuel and 90% both in NOx and PM emissions over our conventional units.

It was noted that the comparisons done were not with the same model YEAR trucks.
The Parker-Run Wise Hybrid trucks are 2012 and the comparison vehicles were 2008 and 2009. The City does not have a fully-automated side loader truck that is any newer than 2009. The INFOWEDGE consultant tried to make comparisons with same Tier level vehicles using data collected by other sources. Based on his data collection comparing the same Tier level vehicles the fuel savings measured about 39%. The NOx and PM emissions benefits were both modeled to be greater than 39%.

One of the major stumbling blocks with the two hybrid trucks has been reliability. The maintenance issues have been much more than we experience when purchasing a new conventional truck. Both vehicles have had to be towed. Unit 2079 was towed from our green waste disposal facility in Lathrop back to our Corp Yard one day. The mechanics thought the problem was fixed. It went out the next day; had the same problem and was towed to Sacramento. Vehicle 2080 experienced the same problem and was towed back to your Corp Yard. Both trucks had an 0-ring failure which required major work to be done and the truck to be done for an extended period of time.

The Parker-RunWise system on these trucks have had major failures with pumps, speed sensors, pressure sensors and o-rings. There have been minor problems with loose wires, fuse panels, lights, gaskets and hydraulics. There have been minimal issues with the bodies and arms of the vehicles. Fortunately the trucks have been under warranty so the costs have been minimal. The unfortunate part is the down time. When these trucks are not operating it makes it difficult to continue our daily operations.

All collection vehicles experience some mechanical issues, usually hydraulic in nature. We have many trucks in our fleet that are 12-13 years old. They are not in the shop for more than a day when it comes to repairs. We have these two Parker Run Wise Hybrid trucks that spend more time in the repair shop than the much older conventional trucks on a weekly basis.

Another major issue that we had with these two trucks, which was probably an oversight when the trucks were ordered, were crusher panels. Every conventional truck in our fleet has crusher panels. These two trucks did not have them when we got them. The drivers had to climb into the bodies and smash down the recycling at every few stops to prevent materials from flying out. We had the panels put in but the trucks were down for two weeks and the equipment cost was $17,000 each.

The Parker Run Wise system is located on the bottom of each truck. It basically hangs underneath. Given that our conventional trucks take our MSW to a landfill which is often very bumpy, hilly, rocky and otherwise unstable, this presented a problem for us as well. The fear of hitting that black box underneath the truck was ever present. Not wanting to take the chance, we opted to dispose of MSW picked up in the Hybrid trucks at the local transfer station instead. The transfer station is all concrete, level and indoors. The problem now being is cost. The disposal fee at the landfill is $ 44.17 per ton. The disposal fee at the transfer station is $56.27 per ton (going up to $57.20). We have been paying $12.10 more per ton with each vehicle. On average, each vehicle disposes of 6 tons of MSW each day. That being said, we are paying an

average of $150.00 more per day for the Hybrid trucks to go the transfer station rather than the landfill.

SUMMARY OF TASKS:

Task 1. Contracting and Procurement.
Contract between City of Manteca and InfoWedge approved
E3-Parker Run-Wise Hybrid Trucks Ordered
E3-Parker Run-Wise Hybrid Truck Delivered (November 14, 2012)

Task 2. Drive Cycle Characterization.
Identify a conventional vehicle to be used for comparison
Install data collection equipment
Operate conventional vehicle for 30 days and record drive cycle parameters
Collect recorded data. Analyze data.

Task 3. Install data collection equipment in E3 Parker Run Wise vehicle
Operate E3 Parker Run Wise vehicle for 30 days and record drive cycle parameters
Collect recorded data. Analyze data.

Task 4. Emissions testing of E3 and Conventional Refuse Vehicles
Install equipment in a conventional vehicle and run emissions testing.
Collect data.
Install equipment in E3 Parker Run Wise vehicle and run emissions testing.
Collect data.
Analyze data to determine emission and fuel consumption benefits of E3 Parker Run Wise versus Conventional vehicles.
Compile data analysis and prepare final reports for conventional and RunWise

Task 5. Demonstration of E3 Hybrid Refuse Vehicle
Operate RunWise vehicle and record usage, fuel consumption and maintenance data.

manteca

Finding and Results of Tasks:

Tasks 1, 2, 3 and 4 were done by INFOWEDGE. Their findings are attached. Their basic conclusion is that the E3 Run Wise vehicles could save the City of Manteca about 39% in fuel over the conventional collection trucks. They also concluded that the E3 Run Wise reduces particulate matter and NOx by at least 39% compared to our conventional trucks.

The City of Manteca Solid Waste Division completed Task 5. Our analysis of fuel consumption shows that the E3 Parker Run Wise vehicles get an average of 2.4 miles to the gallon and our conventional trucks get an average of 1.9 miles to the gallon. The fuel consumption is a savings but thus far the maintenance time and costs have not.

Conclusion:

The fuel savings are a benefit.

The NOx and particulate matter are reduced.

Drivers prefer to operate the E3 Parker Run Wise vehicles.

Purchase costs and maintenance costs are significantly higher than conventional vehicles.

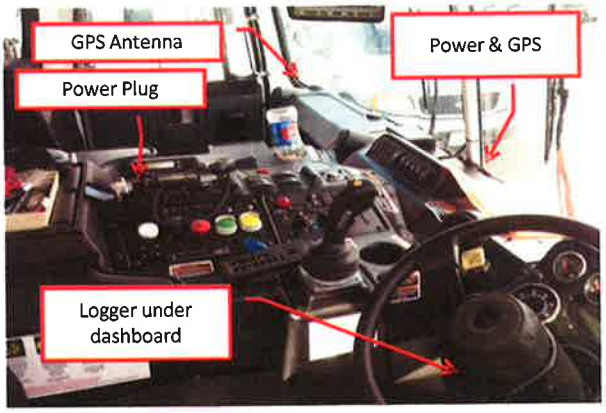
Disposal costs are more because we take the E3 vehicles to the transfer station rather than the landfill.

infoWedge

February 11, 2013

Interim Report: Update on data collection for Manteca Trash Haulers

On February 1, 2013 an activity datalogger was installed onto a hydraulic hybrid trash hauler (City of Manteca unit number 20-2080). The figure below shows a front-view photo of the vehicle. The logger was a UniCAN Pro with custom programming and features to allow second-by-second collection of CAN (SAE J1939) and GPS data. The logger was connected to the vehicle's CAN network using a custom fabricated "Y" cable that allowed other CAN loggers and telemetrics systems to communicate simultaneously. None of the vehicle's other logger or telemetrics systems were affected by the presence of the UniCAN logger. An overview of the installation is shown in a photograph below to demonstrate how the installation was not obtrusive and did not affect operator interaction with the vehicle.



After installation, the vehicle was driven a short distance to allow a download and quality assurance of the data. Two partially full trash cans were also dumped to show that the engine power and vehicle speed data could be used to determine when trash can dumps occured. The vehicle was not used for trash hauling until February 6, 2013. It was also used for trash hauling on February 7th and 8th.

On the afternoon of February 8, 2013, the installation was checked for soundness and the data collected during the previous three days was downloaded and quality assured. No adjustment of the installation was necessary and it was left "as is." The short report gives an overview of the above data. Further analysis is ongoing to describe how the vehicle was driven during trash collection, driving to the landfill, etc.

The plots in the worksheets named "Feb6Graphs," "Feb7Graphs," and "Feb8Graphs" show overviews of the vehicle speed (km/hr), vehicle altitude (m), engine speed (RPM), engine load (%), engine coolant temperature (°C), and Fuel Rate (L/hr). The vehicle speeds are comparable for all three days, ranging from residential street speeds (during trash collection) to highway speeds (most likely during trips to facilities where trash was dumped and back to the Manteca Fleet Yard). On a first inspection, it appears the vehicle was driven a bit more aggressively on February 6th than on the other two days. Altitude readings are accurate enough to show that all driving was on flat terrain (i.e., none was in the Sierra foothills). Engine parameters seem comparable on all three days., with Fuel Rate seeming a bit higher on the 6th than on the 7th and 8th.

The graphics in the worksheets named "FEb6Track," "Feb7Track," and "Feb8Track" show where the vehicle was driven on each of those days (using Google Maps). By flipping between these worksheets one can easily see that trash was collected in different neighborhoods on each day. It can also be seen that the same two remote facilities were also visited on each day.

The plots in the worksheet named "Weather" were copied from the "Weather Underground" website. They show that the weather on all three days was very similar. Therefore, we do not expect ambient conditions to play any role in differences found between the data from collected on these three days.

TASK #2
PART of IT

DRIVE CYCLE MIMICS REAL DATA

SummaryText

2063

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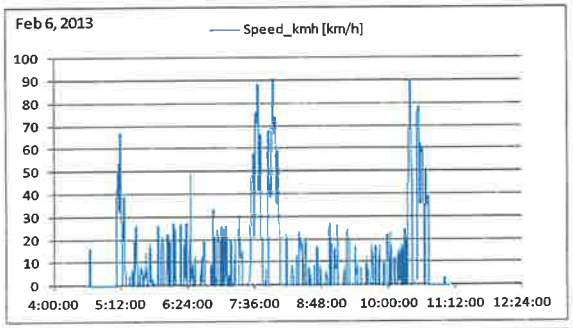
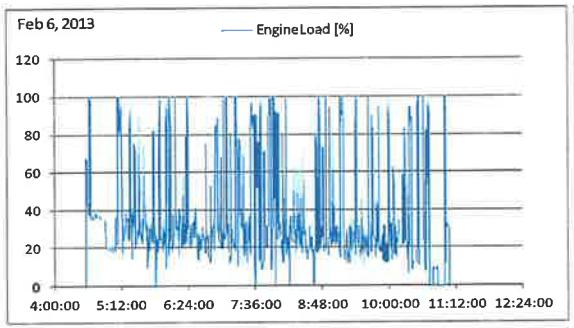
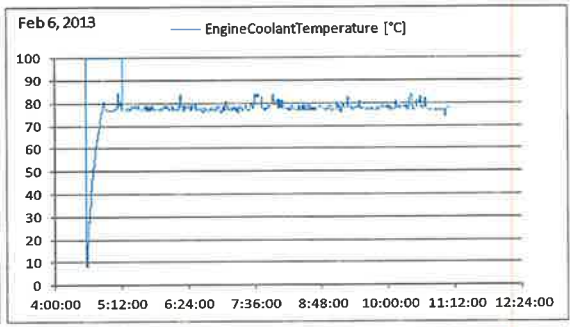
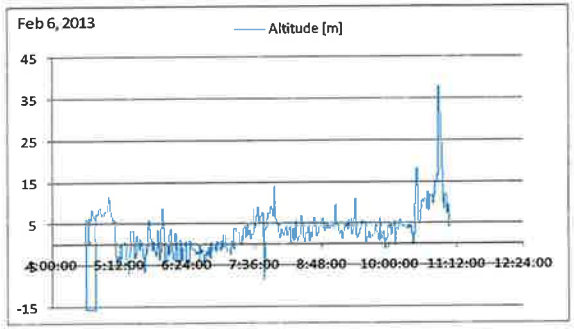
February 11, 2013

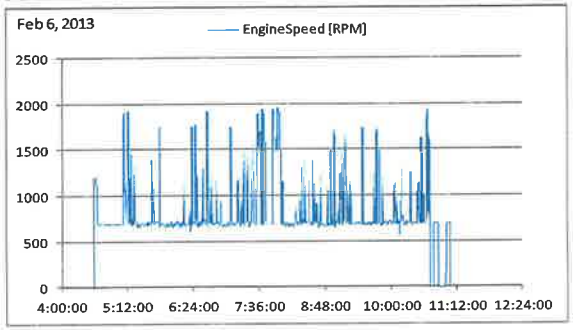
Interim Report: Update on data collection for Manteca Trash Haulers

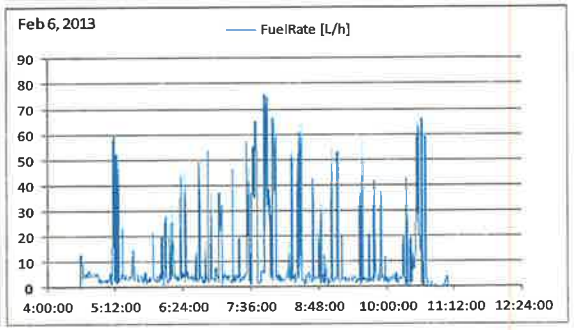












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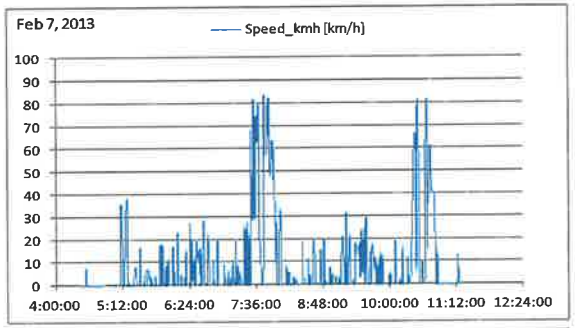

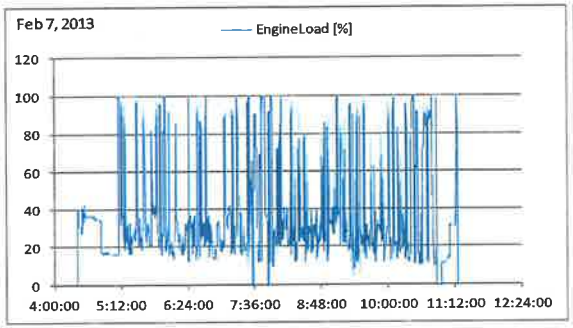

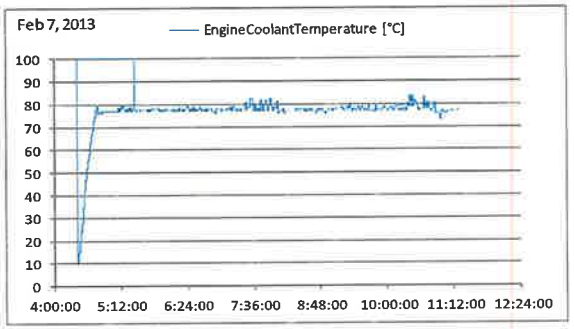

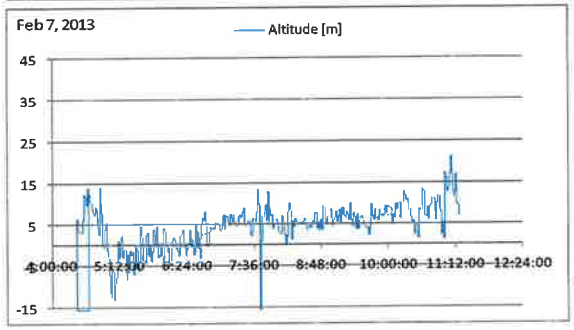

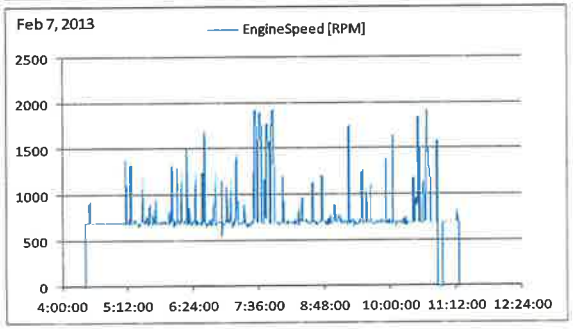

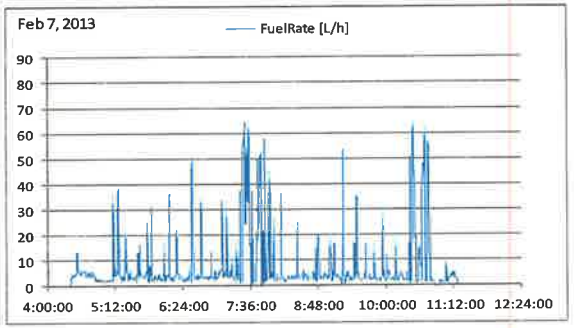

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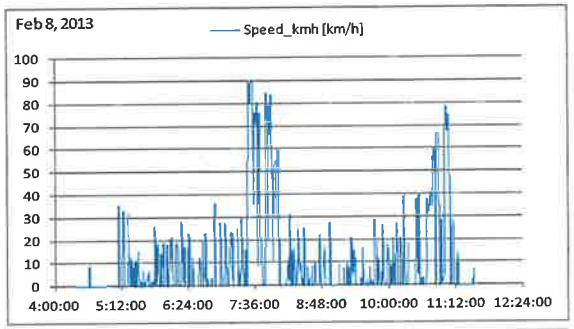

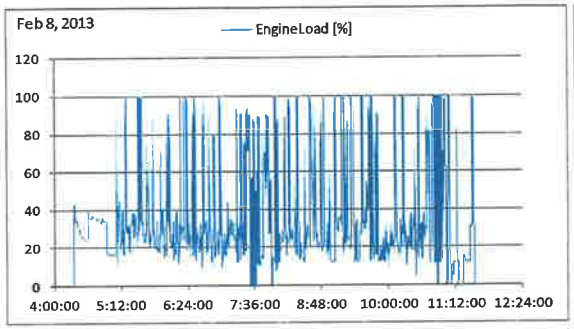

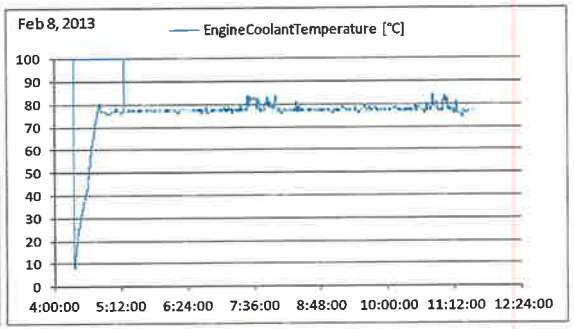

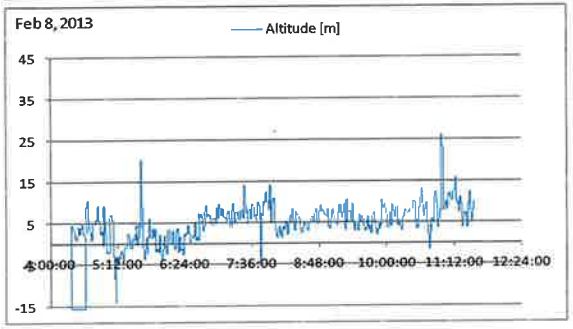

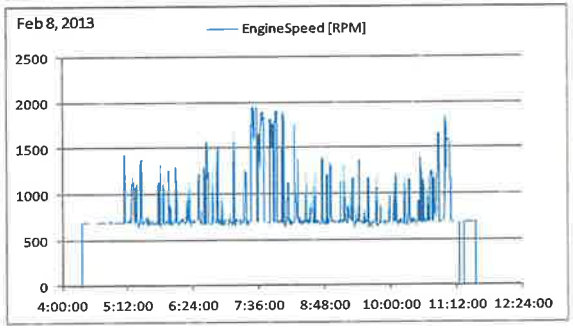

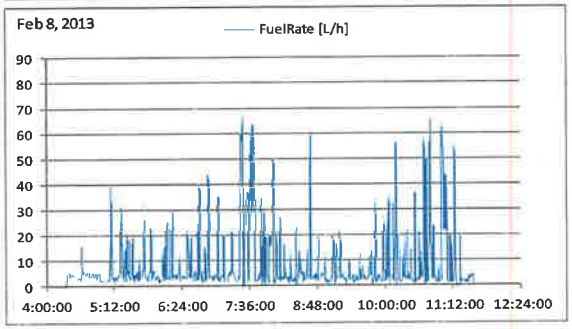

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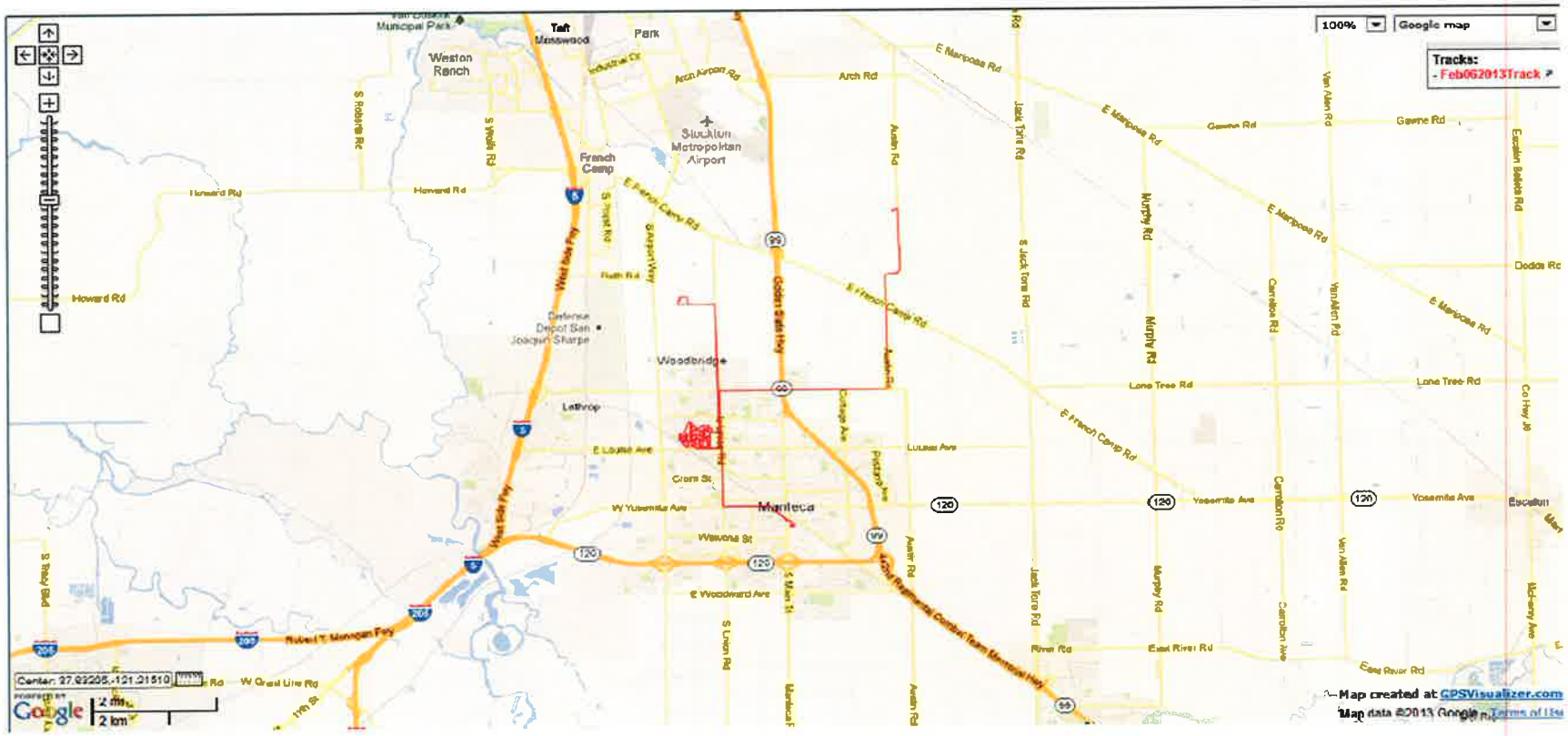
February 11, 2013

Interim Report: Update on data collection for Manteca Trash Haulers



Feb6Track

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February 11, 2013

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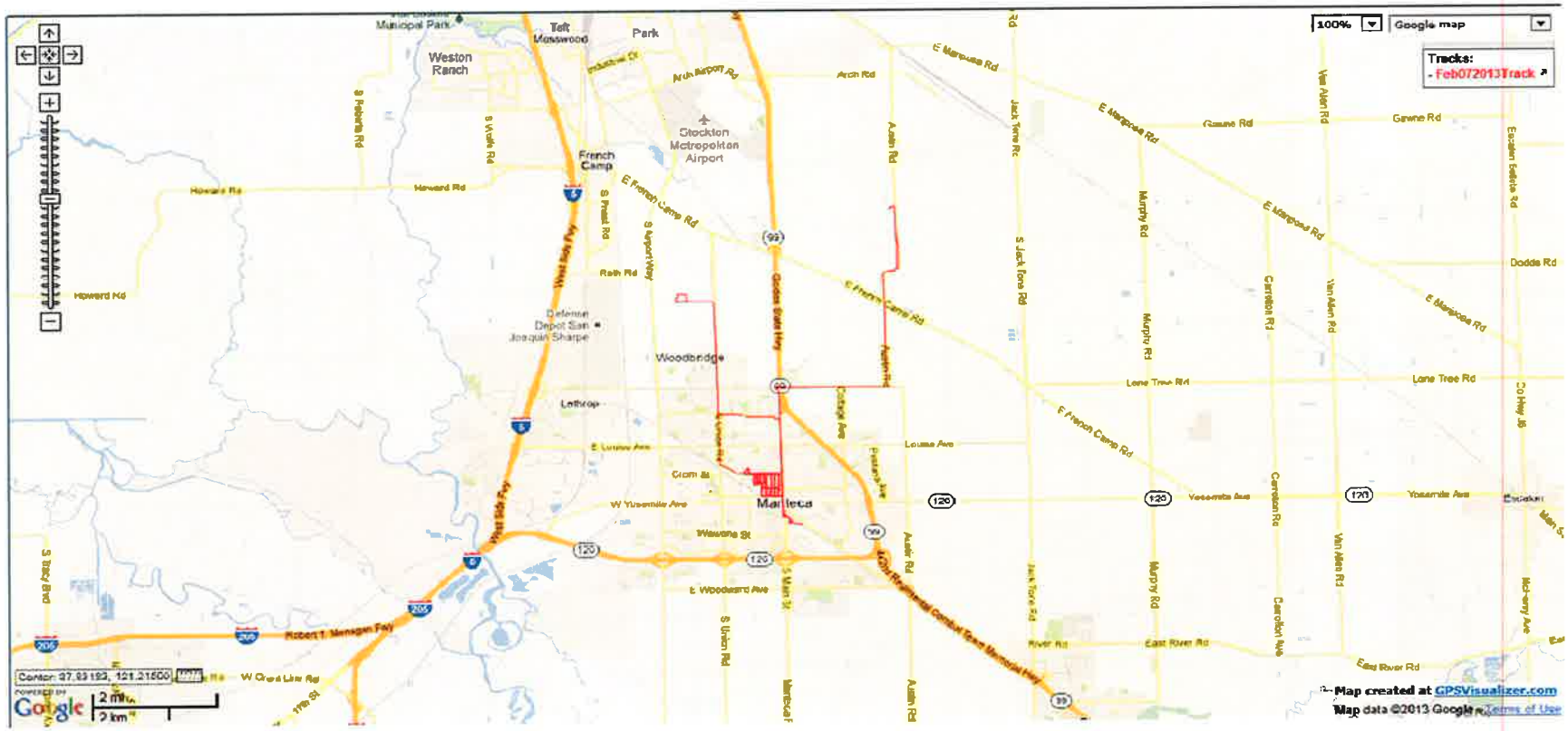

Feb7Track

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February 11, 2013

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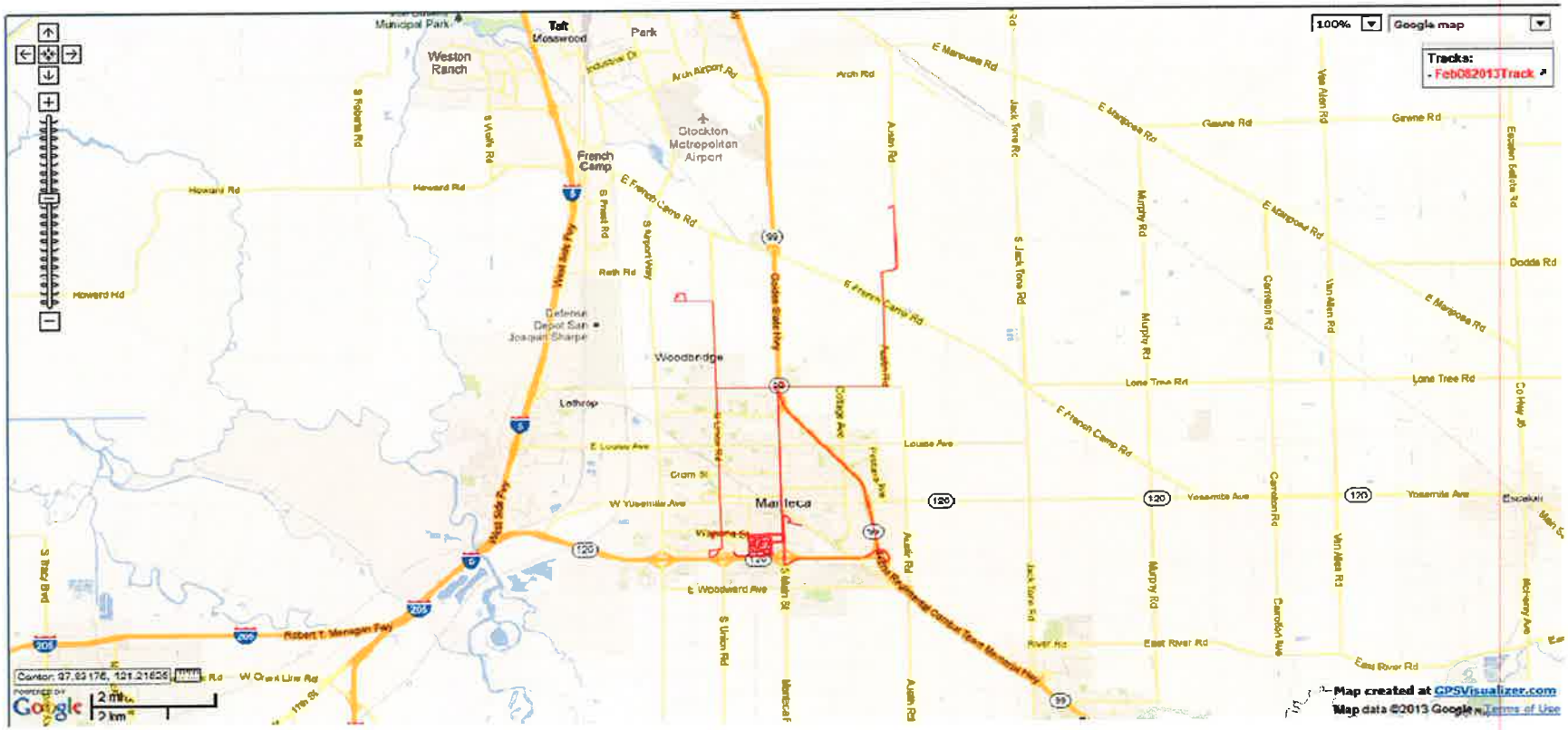
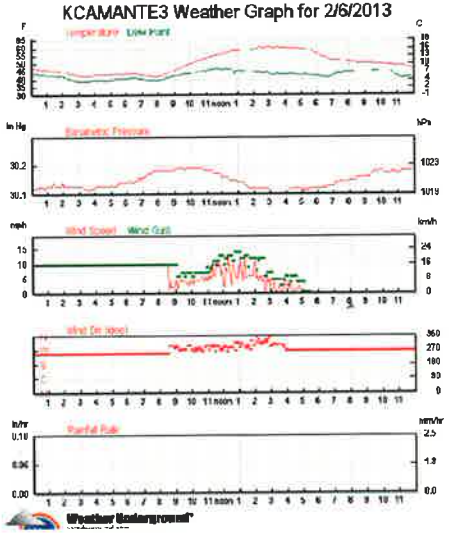
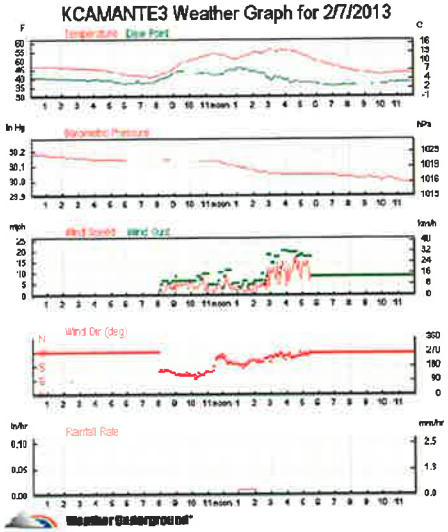


Feb8Track

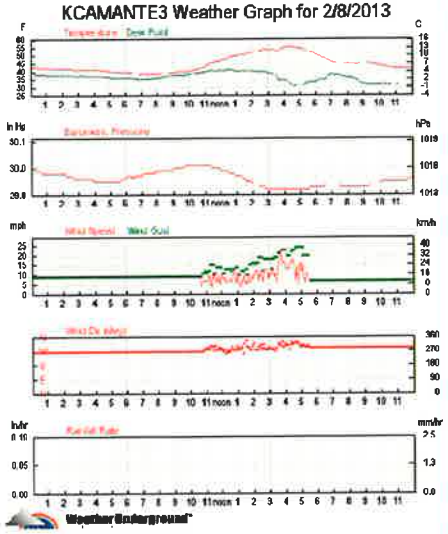
KCAMANTE3 Weather Graph for 2/6/2013



KCAMANTE3 Weather Graph for 2/7/2013



KCAMANTE3 Weather Graph for 2/8/2013



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TEST REPORT FROM:
Andrew D. Burnette

4903 Alondra Court, El Dorado Hills, CA 95762
tel: 916.760.8474 email: andrew.burnette@infowedge.com cell: 916.221.8159

TO: Rexie LeStrange, Superintendent, Solid Waste Div., City of Manteca.
SUBJECT: **Task 2 Executive Summary Report: CIP Project No. 11078, SJV APCD Grant**

As part of a grant-funded demonstration project, the City of Manteca contracted infoWedge to determine the actual fuel and emissions savings of operating the new, RunWise hydraulic hybrid refuse haulers as compared to the conventional Autocar trash haulers. Task 2 of the project involved documenting how the trash haulers are operated and using the data to develop a test protocol that would allow a fair, "apples-to-apples" comparison of the two types of refuse haulers. This executive summary report covers the Task 2 effort and results.

Project Description and Preliminary Discussion

Two trash haulers were identified as appropriate for developing a representative duty cycle. Unit 2063 was the conventional refuse hauler and unit 2080 was the hybrid. A photo of each is shown below.

Unit 2063 – Autocar Conventional

Unit 2080 – RunWise Hybrid

Data logging equipment was installed on both of the trash haulers and activity and engine data were logged for at least 30 days on each unit. The data logging equipment communicated with the main computer that controls the engine and power train of each refuse hauler, recording important engine and vehicle parameters (such as engine load, estimated fuel consumption, engine speed, etc.) every second. It also independently logs the location of the vehicle every second using a GPS system. A photo of the main part of the data logger, installed under the dashboard of one of the units, is shown below.

CAN data logger installed

The recorded data from both units was archived and field-checked for quality periodically, as it was being collected. Once the minimum required amount of data had been confirmed and archived, the data were analyzed to determine a representative duty cycle and how best to collect the required emissions and fuel consumption data during a later task of the project.

Through the resulting analysis and through interviews with Solid Waste Division personnel, infoWedge determined that the best way to emissions test these units would be during actual trash and green waste collection routes. The routes would be as similar to each other as possible, but would not be identical. Therefore, a hypothetical duty-cycle would not be used to collect the emissions and fuel consumption data. Instead, a hypothetical duty-cycle would be used during analysis of the data. This approach to comparing the emissions from two vehicles is often called "Modal Analysis."

Modal Analysis categorizes the emissions and fuel consumption data into similar categories, based upon the type of activity the vehicle is performing. Then an average emissions and fuel consumption rate for each of the categories of activity is determined. Then those averages are recombined into an "overall" average that represents a typical day's worth of activity for each vehicle. This approach ends up comparing the two vehicles over the exact same duty-cycle that has been assembled from the Modal Analysis results – after the emissions data are collected, instead of in advance.

Final Test Cycle

After having analyzed the logged activity data, we have determined that the emissions and fuel consumption data should be collected as the refuse haulers are actually performing their normal work duties. The two units will be tested on successive days as they collect normal trash and green-waste

over similar routes. If different parts of the routes are not sufficiently similar, then accommodations will be made to make them as similar as possible. For example, we expect that the RunWise hybrid unit will not be allowed to dump at the land fill, but will have to dump at a transfer station instead. Therefore, after having dumped at the transfer station, the RunWise unit will travel to the landfill and simply turn around and perform the rest of its normal route. This accommodation will ensure that the test units travel similar distances on the highway.

Preliminary Modal Analysis of Logged Engine Control Unit Data

As a step in designing the emissions testing protocol and data analysis, we performed a preliminary Modal Analysis of the data collected during Task 2. As shown in the table of typical refuse hauler service below, the activity data were categorized into driving modes based upon the type of loads on the engine of the vehicle. The modes were: Idling, Start/Stop driving, Urban driving, Highway driving, and Off. Specific speed and duration parameters were defined so that each second of the logged data could be classified as having fallen into one of the above driving modes.

Manteca refuse hauler typical daily service:

	Activity	Driving Mode
1	Start truck and warm up	Idling
2	Drive to pick up trash	Urban driving
3	Pick up trash (route 1)	Start/stop/pickup bin, etc.
4	Drive to dump trash at land fill	Urban and highway driving
5	Dump trash at land fill	Idling, start/stop, urban
6	Drive to pick up recycling/yard waste	Highway and urban driving
7	Pick up recycling/yard waste (same route 1)	Start/stop/pickup bin, etc.
8	Drive to dump at recycling/yard waste facility	Urban and highway driving
9	Dump at recycling/yard waste facility	Idling, start/stop
10	Drive back to truck yard	Highway and urban driving
11	Refill fuel and clean truck	Off, start/stop
12	Park	Off

Note: The above route order is for "yard waste" days. On recycling days the recycling route is run before the trash route.

After the logged data had been categorized into driving modes, averages were calculated for key data that would help determine how the vehicles are used and how much fuel was consumed (according the engine control computer), without any emissions testing. The series of tables below show the resulting analysis that compares the two refuse haulers. The "Off" driving mode has been excluded since no fuel is consumed during that mode.

TO: Rexie LeStrange

Task 2 Exec. Sumry. Report, SJV APCD Grant

Average Daily Modal Time & Distance

	Conventional		Hybrid		Average	
	Daily Time (hr)	Daily VMT (mi)	Daily Time (hr)	Daily VMT (mi)	Daily Time (hr)	Daily VMT (mi)
Idle	1.25	0.0	1.14	0.1	1.19	0.1
StartStop	3.22	11.4	4.01	15.4	3.62	13.4
Urban	0.97	16.4	0.67	11.2	0.82	13.8
Highway	0.58	18.0	0.59	23.1	0.59	20.5

	Average ECM fuel consumption rates			Avg. Daily Time or Distance		Daily ECM fuel consumption amounts		Fuel Savings
	Convntnl	Hybrid				Convntnl	Hybrid	
	gal/hr	gal/hr		hr		gal	gal	
Idle	0.89	0.99	X	1.19	=	1.06	1.18	-12%
	gal/mi	gal/mi		mi				
StartStop	1.03	0.50	X	13.4	=	13.74	6.64	52%
Urban	0.35	0.26	X	13.8	=	4.767	3.577	25%
Highway	0.30	0.19	X	20.5	=	6.163	3.854	37%
					Overall	25.73	15.26	41%

In the top tables the typical daily amount of time and distance traveled in each mode are shown for the two vehicles. These are averaged together, by mode, to give a typical "day in the life" of the Manteca refuse hauler. Since no distance is traveled during the Idle mode, its average is expressed in terms of time (hours). The rest of the driving modes are expressed in terms of distance (miles). For example, the data show that a Manteca refuse hauler spends about 1.19 hours idling each day and travels 13.4 miles in Start/Stop mode, 13.8 miles in Urban driving, and 20.5 miles in Highway driving.

In the bottom tables the average fuel consumption rates of the two refuse haulers are shown for each mode. These modal averages are then recombined into a typical daily amount of fuel consumed using the typical time spent at idle and the typical distances traveled in each of the other driving modes. Looking at the results for each mode, the hybrid actually uses about 12% more fuel idling during a typical day. However, the savings of the hybrid for each of the other driving modes more than makes up for the higher fuel consumption at idle.

As expected, the most savings from the hybrid system (52%) is seen during the "Start/Stop" driving mode, such as when they are pickup up trash. More modest amounts of fuel are saved by the hybrid during Urban driving (25%) and Highway driving (37%). When all of these results are combined into a typical daily use, we expect the hybrid system will realize a fuel savings of about 41% over the conventional refuse hauler. This result is preliminary and does not include any emissions testing. It only uses data produced by the engine control units of the vehicles and the GPS systems of the data logger.

infoWedge

TEST REPORT FROM:
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TO: Rexie LeStrange, Superintendent, Solid Waste Division, City of Manteca.

SUBJECT: **Task 4 Revised Executive Summary Report: CIP Project No. 11078, San Joaquin Valley Air Pollution Control District Grant**

As part of a grant-funded demonstration project, the City of Manteca contracted infoWedge to determine the actual fuel and emissions savings of operating the new, RunWise hydraulic-hybrid refuse haulers as compared to the conventional Autocar refuse haulers. Task 4 of the project involved performing emissions tests on two, representative refuse haulers, one a hydraulic-hybrid diesel and the other conventionally powered, from the Manteca fleet using the test protocol developed during Task 2 of the project. It then required that a fair, "apples-to-apples" comparison of the two types of refuse haulers be reported, based upon the results of the testing. This executive summary report covers the Task 4 effort and results. As later requested by the San Joaquin Air Pollution Control District, it also discusses additional analyses comparing the hybrid model to similar conventional models of the same model year, based upon emissions standards and estimated fuel efficiency differences.

Project Description and Preliminary Discussion

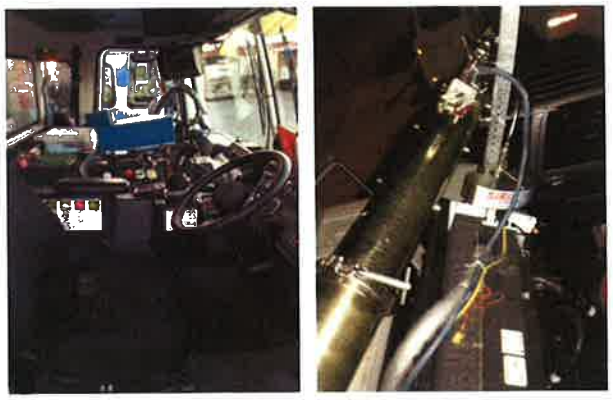
Two refuse haulers were identified as appropriate for emissions measurement using the test protocol developed in Task 2. Unit 2074 was the conventional refuse hauler and unit 2079 was the hybrid. A photo of each is shown below. Notice that the photos were taken as the emissions testing equipment was being installed (see the flow meter and sample lines coming from the exhaust pipes).

Unit 2074 – Autocar Conventional

Unit 2079 – RunWise Hybrid

Emissions testing equipment was installed on both of the refuse haulers and their emissions and fuel consumption were measured as had been planned in Task 2. On the morning of July 17 the conventional vehicle was testing and the hybrid was tested the following morning. The gaseous emissions testing equipment was a system manufactured by Sensors, Inc., named the SEMTECH-DS. It

has been approved by EPA for in-use compliance testing of on-road trucks in accordance with 40 CFR 1065. The particulate measurement system is manufactured by ProcessMetrix (named Siris) and is based upon the two-angle measurement of laser light scattered by the particles in the exhaust. The Siris has been shown to correlate exceptionally well with "gold-standard" gravimetric systems[1] and other on-board PM measurement systems that are pre-approved by EPA for in-use compliance testing. Photos of the SEMTECH-DS and the Siris installed are shown below.



SEMTECH-DS and Siris measurement systems

As the vehicles were driving over their normal routes, we followed the refuse hauler and monitored the data remotely to make sure the data were being collected properly and were of appropriate quality. After the units returned to the fleet yard and were refueled and parked, the data were downloaded and checked for completeness. Then the emissions measurement instruments were removed and the trucks were returned to "as received" condition.

The San Joaquin Valley Air Pollution Control District (SJVAPCD) requested that, if possible the hybrid refuse haulers should be compared to conventional vehicles that conform to the same emissions standards as the hybrid. However, since no conventional refuse haulers of the same model year or emissions standards as the new hydraulic-hybrids were available for in-use testing, the SJVAPCD requested that additional analyses be done. These analyses were to compare the likely emissions benefits of using the hydraulic-hybrid refuse haulers as compared to a similar truck of the same model year, but of conventional diesel propulsion. The comparison was to be done based upon certified emissions standards and with the observed emissions of the in-use hydraulic-hybrid taken into account as best as possible. The results of these analyses are discussed after the test results section below.

[1] Donald J. Holve, Jessica Chapman & Rob Graze (2011): Two-Angle Ratio Scattering (STAR) Method for Real-Time Measurement of Agglomerate Soot Concentration and Size: Experimental Measurements, Aerosol Science and Technology, 45:11, 1400-1407

TO: Rexie LeStrange
City of Manteca

Task 4 Revised Exec. Sumry. Report for
San Joaquin Valley APCD Grant Project

Modal Analysis of Measured Fuel and Emissions Data

As described in the Task 2 report, Modal Analysis categorizes the emissions and fuel consumption data into similar categories, based upon the type of activity the vehicle is performing. Then an average emissions and fuel consumption rate for each of the categories of activity is determined. Then those averages are recombined into an "overall" average that represents a typical day's worth of activity for each vehicle. This approach ends up comparing the two vehicles over the exact same duty-cycle that has been assembled from the Modal Analysis results of Task 2.

A comparison of the fuel and emissions results is shown below in three tables: one each for fuel consumption, NOx emissions and PM emissions. Each table is set up as a calculation. Modal emission factors on the left are multiplied by daily modal activity (time or distance) to yield daily results for each mode (on the right). The modes are then summed to give typical daily amounts for each vehicle.

	Average fuel consumption rates			Avg. Daily Time or Distance		Daily fuel consumption amounts		Fuel Savings
	Convntnl	**Hybrid**				**Convntnl**	**Hybrid**	
	gal/hr	gal/hr		hr		gal	gal	
Idle	0.93	0.88	X	1.19	=	1.12	1.05	**6%**
	gal/mi	gal/mi		mi				
StartStop	1.29	0.62	X	13.4	=	17.26	8.32	**52%**
Urban	0.31	0.22	X	13.8	=	4.273	3.027	**29%**
Highway	0.28	0.20	X	20.5	=	5.740	4.035	**30%**
					Overall	**28.39**	**16.43**	**42%**

Calculation of "typical route" fuel savings: the hybrid compared to the conventional refuse hauler

	Average NOx emission rates			Avg. Daily Time or Distance		Daily NOx emission amounts		NOx Reduction
	Convntnl	**Hybrid**				**Convntnl**	**Hybrid**	
	g/hr	g/hr		hr		g	g	
Idle	7.55	2.38	X	1.19	=	9.02	2.84	**69%**
	g/mi	g/mi		mi				
StartStop	38.35	1.82	X	13.4	=	512.80	24.32	**95%**
Urban	2.88	0.22	X	13.8	=	39.738	2.985	**92%**
Highway	1.69	0.12	X	20.5	=	34.675	2.536	**93%**
					Overall	**596.2**	**32.7**	**95%**

Calculation of "typical route" NOx reduction: the hybrid compared to the conventional refuse hauler

TO: Rexie LeStrange
City of Manteca

Task 4 Revised Exec. Sumry. Report for San Joaquin Valley APCD Grant Project

	Average PM emission rates			Avg. Daily Time or Distance		Daily PM emission amounts		PM
	Convntnl	Hybrid				Convntnl	Hybrid	Reduction
	g/hr	g/hr		hr		g	g	
Idle	0.00031	0.00305	X	1.19	=	0.00036	0.00364	-897%
	g/mi	g/mi		mi				
StartStop	0.01331	0.00079	X	13.4	=	0.17794	0.01058	94%
Urban	0.00088	0.00015	X	13.8	=	0.01212	0.00204	83%
Highway	0.00360	0.00015	X	20.5	=	0.07386	0.00318	96%
					Overall	0.2643	0.0194	93%

Calculation of "typical route" PM reduction: the hybrid compared to the conventional refuse hauler

The test results show that over a typical day of use in the Manteca fleet, the hybrid RunWise test unit will save approximately 42% in fuel and more than 90% in both NOx and PM emissions over the conventional test unit. We found that both units most likely conform to their in-use test (i.e., Not To Exceed or NTE) emissions limits as defined by EPA for Tier 3 (conventional) and Tier 4 (hybrid) highway trucks.

Modeled Benefit of Hydraulic-Hybrid Compared to Conventional Refuse Hauler Meeting the Same, Tier 4 Emissions Standards

Basis of Modeling Assumptions

As was done in this project, a small sample can be used to measured a realistic average emissions benefit of using a late-model hydraulic-hybrid propulsion diesel refuse hauler as opposed to a similar, but older conventional propulsion truck meeting previous emissions standards. In this case, small sample sizes are feasible because expected emissions differences are relatively large and the cohort of older vehicles in the Manteca fleet is well maintained (so it is reasonable to expect that the true average emissions of the older vehicle cohort are similar to the measured average emissions of the older test vehicle). In other words, the average emissions differences between old and new vehicles in this case can be shown to be statistically significant (i.e., not due to natural, expected variability in emissions) using a small sample size.

However, when expected emissions differences are relatively small – as would be the case when comparing similar engines that meet the same emissions standards – larger, replicate sample sizes of each vehicle type will typically be necessary to calculate a statistically significant, average emissions benefit of one engine/propulsion combination over another. This is because the natural, test-to-test variability in emissions (due to test-to-test differences of in-use loads, driver repeatability, vehicle-to-vehicle differences, etc.) is relatively large compared to the expected average emissions differences. Larger test samples result in tighter statistical confidence intervals for the calculated averages. And the

tighter the confidence intervals, the closer the actual average differences can be while still resulting in a statistically significant.

As implied above, since emissions standards are expressed in terms of "work-specific" emissions (e.g., grams of pollutant per brake horsepower-hour of engine work, or g/bHP-hr), we expect that engines meeting the same standard will produce comparable pollutant emissions for a given amount of work (e.g., for the same route). (We know from experience that engine manufacturers do not over-comply with the emissions standards unless there is some kind of market advantage for doing so.) In other words, if we had several conventional refuse haulers powered by similar, Tier 4 diesel engines and performing the same work over the same route, we expect they would produce very similar (but slightly different) average emissions levels. In fact, to see whether the small average differences we observed were statistically significant (and not just a result of natural, test-to-test variations), we would expect to have to test the same vehicles multiple times (at least 3, and probably more) over the same route so that we could estimate the test-to-test variability of their emissions and calculate appropriate statistical confidence intervals for the calculated averages.

Since engines meeting the same standard produce similar emissions for the same amount of work, we expect that the majority of the benefit from using a Tier 4-final hydraulic-hybrid refuse hauler versus a similar Tier 4-final conventional unit will be due to the substantially reduced work done by the engine in the hybrid unit for a given route. Since for similar engines, fuel consumption is proportional to engine work, this reduced engine work shows up in substantially reduced fuel consumption by the hybrid units as compared to similar conventional units. Although there may be minor additional emissions benefits due to the reduced transient loads on hydraulic-hybrid engines, these benefits are most likely small compared to those derived from the reduced fuel consumption.

The extremely low, Tier 4 emissions levels these engines conform to are made possible by exhaust "after-treatment" systems. All medium-duty and heavy-duty diesel engines conforming to the Tier 4-final standards, and used in these refuse haulers, require a diesel particulate filter (DPF) and a selective catalytic reduction (SCR) system. These after-treatment systems reduce "engine-out" emissions of particulate and NOx by 95% or more and are tuned to maintain low emissions during the extremely aggressive (transient) certification test cycle used for these engines. The table below lists the two Cummins engines commonly used in the Manteca conventional and hybrid refuse haulers and compares them to similar engines (same power, fuel, etc.) offered by other OEMs in the California market. Notice that some of the emissions levels are listed in the executive orders as numerically "0." This does not mean "no emissions." Rather it means that the measured emissions were sufficiently lower than the standard that when rounded to the significant digit below standard the result was 0.

Certification Levels for Conventional Propulsion Engines Similar to the Hybrid Engine

Manuf	Engine	Family	Displ L	Propulsion	Executive Order Certification Emissions NMHC g/bhp-hr	NOx g/bhp-hr	CO g/bhp-hr	PM g/bhp-hr
Cummins	ISL9-380	ACEXH0540LAQ	8.9	Hybrid	0.0004-	0.22	0.04-	0.004-
Cummins	ISL9-380	ACEXH0540LAQ	8.9	Conventional	0.0004-	0.22	0.04-	0.004-
Navistar	MaxxForce 11	ANVXH06410GA	10.5	Conventional	0.110	0.48	0.9	0.004
Volvo	MP7 395	AVPTH10.8S02	10.8	Conventional	0.094-	0.12	*	0.001

Notes: 0.04- was listed as 0.0 in the Executive Order, 0.004- listed as 0.00, etc.
* means the value was not listed in the EO

Because the extremely low emissions from Tier 4-final vehicles are obtained using exhaust after-treatment systems, the possible impacts of the less severe duty-cycle on the hybrid engine (as compared to the conventional one) are mitigated. In other words, if the "engine out" emissions of the hybrid are reduced by say 10% due to a less transient duty-cycle, the exhaust after-treatment system will reduce this impact to less than 1% because it reduces the "engine out" PM and NOx emissions by over 90% before they are released to the atmosphere. Even though they are relatively small, we should not ignore the possible impacts of less transient operation of hybrid engines. Rather, we should assume that the modeled emissions benefits of the hydraulic-hybrids described are "conservative" estimates based only upon fuel consumption differences, and may in fact be slightly better if the effects of duty-cycle differences could have also been modeled.

Modeled Benefits of Tier 4 Hydraulic-Hybrid Versus Tier 4 Conventional

The majority of emissions benefits of using the hydraulic-hybrid as compared to a similar Tier 4-final conventional will be modeled as the percent impact on fuel consumption applied to the emission factors determined from the test program. Expressed simplistically – if the Tier 4 hybrid system uses 40% less fuel than a Tier 4 conventional, it will emit 40% less pollution as well. As described above, this approach will estimate a conservative benefit which may in reality be slightly better due to the effects of reduced transient loads on the engine in the hybrid system (e.g., during accelerations).

The fuel consumption benefit will be estimated as the measured benefit from this project (Tier 4 hybrid vs Tier 3 conventional) adjusted to what would have most likely been observed if the conventional unit had been a Tier 4 system. This slight adjustment is due to the fact that conventional Tier 4 systems are known to be slightly more fuel efficient than similar Tier 3 systems.

The engine OEMs have claim that their Tier 4-final engines are between 3% and 5% more fuel efficient than similar Tier 3 engines.[2] Vehicle dealers and fleet owners have reported fuel efficiency benefits

[2] http://www.fleetequipmentmag.com/Item/102605/scr_technology_lives_up_to_promises.aspx

ranging from zero to about 5% when comparing Tier 3 to Tier 4-final vehicles.[3] Based upon those ranges, we propose to use a middle-ground estimate of a 3% fuel efficiency benefit of the Tier 4-final conventional systems over the Tier 3 systems.

The measured fuel efficiency improvement of using the Tier 4 hybrid as opposed to the Tier 3 conventional on the typical Manteca route (vehicle duty-cycle) was 42%. Applying the Tier 3 to Tier 4 adjustment factor of 3% makes the expected fuel improvement measurement (if the Tier 3 test vehicle had been a Tier 4) equal to 42% - 3%, or 39%. This 39% is a conservative estimate of the "across the board," modeled benefit that would be realized for all emission factors if a Tier 4 hydraulic-hybrid refuse hauler were purchased by Manteca instead of a Tier 4 conventional refuse hauler.

Conclusions

The fuel consumption benefit realized by Manteca when they replace a Tier 3 refuse hauler with a Tier 4 hydraulic-hybrid unit was measured to be an average of 42%. The average NOx and PM emissions benefits were both measured at higher than 93%.

The fuel consumption benefits realized by Manteca by purchasing a Tier 4 hydraulic-hybrid instead of a Tier 4 conventional refuse hauler were modeled to be about 39%. The NOx and PM emissions benefits for such a purchase were both modeled to be greater than 39%.

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[3] Patrick Calpin, Esteban Plaza-Jennings, "A Look Back at EPA's Cost and Other Impact Projections for MY 2004-2010 Heavy-Duty Truck Emissions Standards," American Truck Dealers, February 2012. http://www.nadafrontpage.com/upload/wysiwyg/NADA-ATD-A%20Look%20Back%20at%20EPA%E2%80%99s%20Cost%20and%20other%20Impact%20Projections%20for%20MY%202004-2010%20Heavy-Duty%20Truck%20Emissions%20Standards.pdf

QUARTERLY REPORT #7-OCTOBER 31, 2013			
CITY OF MANTECA-HYBRID REFUSE COLLECTION VEHICLE			
GRANT AGREEMENT NO: C-15655-A			
Results of 6 Week Comparison Test conducted by Solid Waste Staff			
	(Done on Monday, Wednesday and Friday)		
TASK:	Compare Hybrid Vehicle to Standard Collection Vehicle for 3 Weeks		
	Used same driver for each vehicle: Manny Santos	Miles Driven	Fuel Used
2070	Week 1: picked up recycling and MSW on Route 2	141	75.5
2070	Week 2: picked up green waste and MSW on Route 2	151	70.5
2070	Week 3: picked up recycling and MSW on Route 2	137	70.8
	Took the week off between testing		
2080	Week 4: picked up recycling and MSW on Route 2	136	59
2080	Week 5: picked up green waste and MSW on Route 2	151	54
2080	Week 6: picked up recycling and MSW on Route 2	141	49.4
	Hybrid Vehicle is Truck 2080		
	Standard Collection Vehicle is 2070		
	Route 2 is approximatly 450 homes		
	During the Testing the Standard Truck (2070) drove 429 miles		
	and used 216.8 gallons of fuel. Average 1.98 gallons/mile		
	During the Testing the Hybrid Truck (2080) drove 428 miles		
	and used 162.4 gallons of fuel. Average 2.64 gallons/mile		
	This is was a very crude test just conducted by Solid Waste staff		
	We were consistent in keeping the driver and routes the same		
	Thje only variable was the truck.		
	This test is consistent with the fuel reports by Vehicle Maintenance		
	reporting both hybrid trucks averaging 2.6 miles/gallon fuel usage.		