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Final Operability and Chassis Emissions Results from a Fleet of Class 6 Trucks Operating on Gas-to-Liquid Fuel and Catalyzed Diesel Particle Filters

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ABSTRACT

Six 2001 International Class 6 trucks participated in a project to determine the impact of gas-to-liquid (GTL) fuel and catalyzed diesel particle filters (DPFs) on emissions and operations from December 2003 through August 2004. The vehicles operated in Southern California and were nominally identical. Three vehicles operated “as-is” on California Air Resources Board (CARB) specification diesel fuel and no emission control devices. Three vehicles were retrofit with Johnson Matthey CCRT® (Catalyzed Continuously Regenerating Technology) filters and fueled with Shell GTL Fuel.

Two rounds of emissions tests were conducted on a chassis dynamometer over the City Suburban Heavy Vehicle Route (CSHVR) and the New York City Bus (NYCB) cycle. The CARB-fueled vehicles served as the baseline, while the GTL-fueled vehicles were tested with and without the CCRT filters. Results from the first round of testing have been reported previously (see 2004-01-2959).

The second round results were compared to the CARB specification diesel fuel baseline. Over the CSHVR cycle, the GTL Fuel (no filter) reduced oxides of nitrogen (NO_x), hydrocarbon (HC), and particulate matter (PM) emissions by 13%, 46%, and 21%, respectively, and increased carbon monoxide (CO) by 11%. The GTL Fuel and the CCRT filter virtually eliminated the HC, CO, and PM emissions and reduced NO_x emissions by 22%, a statistically significant reduction.

Testing over the NYCB cycle also revealed emission reductions are possible with GTL Fuel. Compared to the CARB specification diesel fuel, the GTL Fuel provided statistically significant reductions in NO_x, HC, and PM emissions by 11%, 58%, and 16%, respectively. A 10% increase in CO emissions was also noted, although not statistically significant. With the CCRT filter, the HC, CO, and PM emissions were reduced by over 95%. A statistically significant NO_x reduction of 20% was observed.

Reductions from round 2 were notably larger than those in round 1. To determine if the changes observed between rounds were “real”, a statistical analysis was performed. The analysis found that CO emissions were higher without the filter in round 2, while no changes were observed for HC or PM emissions. The NO_x emissions were significantly higher in round 1 for the NYCB cycle only.

The fleet was followed for operability for 6 months and accumulated ~20,000 miles. Driver feedback for the vehicles operating on the GTL Fuel and CCRT filters was very positive. An analysis determined that the fuel economy with the combination of GTL Fuel and CCRT filters decreased by 8%. Evaluation of the maintenance

records did not reveal any impact of the GTL fuel or CCRT filters on operability.

INTRODUCTION

GTL fuel (also referred to as Fischer-Tropsch diesel fuel) has been used in a variety of recent projects. Most of the projects have focused on the emissions benefits of the fuel. Emissions reductions in older model engines have been significant (1997 and older). Somewhat smaller emission reductions have been observed in newer engines (1998 and later).[1] Few studies have examined the longer-term impact of GTL fuel on the operability of heavy-duty vehicles.

The first portion of this study showed that emissions benefits can be achieved in real world vehicles with GTL fuel and catalyzed DPFs.[2] Emissions reductions were observed with GTL fuel, with and without the diesel particle filters. The overall project goal was to collect operability results from a fleet using GTL fuel and catalyzed DPFs over time, hence chassis emissions were collected at the start and end of the operability study. This paper contains the results from the second round of emissions testing and the operability results.

APPROACH

VEHICLES – Yosemite Waters in Fullerton, CA was selected as the fleet for this project. The Yosemite Waters fleet met the study requirements, such as having six nominally identical vehicles that operated out of a single, central location. Vehicle and engine specifications for the Yosemite Waters vehicles are given in Table 1.

Table 1. Vehicle and engine specifications for Yosemite Waters test fleet.[2]

Vehicle	
Manufacturer	International
Model number	4300-DT466
Body manufacturer	Hackney
Vehicle activity	Pickup and delivery
Transmission type	5-speed automatic
Transmission manufacturer	Allison
Transmission Model	2000
Engine	
Manufacturer	International
Engine	DT466
Configuration	Inline 6 cylinder
Model year	2001
Peak Power	195 hp @ 2,300 rpm
Peak Torque	520 ft-lb

The six Yosemite Waters vehicles were divided into "baseline" or "test" vehicles. The criteria and details of the division were discussed previously.[3] The vehicles operate on dedicated 10-day routes. Each 10-day cycle is composed of varying degrees of highway and city driving. Table 2 shows the percentage of highway driving for each vehicle over the 10-day route.

Table 2. Driving characteristics for test vehicles in Yosemite Waters fleet.[2]

Vehicle	Fuel/ Emission Control	% Highway Miles over 10-day cycle	Total Miles Driven over 10-day cycle
201	CARB, None	36	532
202	CARB, None	75	752
203	CARB, None	74	1,030
204	GTL, CCRT filter	61	680
205	GTL, CCRT filter	82	667
206	GTL, CCRT filter	77	837

FUEL – Vehicles 204-206 operated on GTL fuel for the project duration. Shell Global Solutions (US) Inc. provided the GTL Fuel. The fleet purchased the CARB specification diesel fuel on an as-needed basis at various commercial stations. The CARB specification diesel fuel and GTL Fuel were analyzed during each round of emission testing. Table 3 lists the fuel properties.

The CARB specification diesel fuel properties were somewhat different between rounds, especially sulfur and aromatic content. The differences between the CARB specification diesel fuels are due to the varying origins of the fuels. In round 2 in particular, the CARB specification diesel fuel had a high cetane number, coupled with low aromatic content (56 and 12%, respectively).

AFTERTREATMENT – The Johnson Matthey CCRT filter was selected for this project. The CCRT filter is a combination catalyzed filter and diesel oxidation catalyst. The CCRT filter is used in challenging applications with low exhaust temperatures (200ºC-250ºC). Figure 1 features a photograph of the CCRT filter.

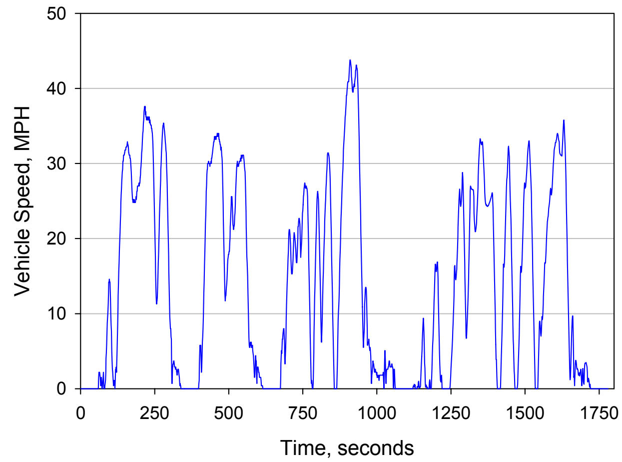
The CCRT filters were installed with data loggers to record the exhaust temperature and back pressure during the project. The data loggers were used to monitor the exhaust back pressure to determine if filter maintenance was needed.

Table 3. Fuel property analysis results.

Property	Method	Shell GTL Fuel		CARB Specification Diesel Fuel	
		Round 1	Round 2	Round 1	Round 2
Density, g/mL	ASTM D4052	0.7850	0.7847	0.8308	0.8312
Viscosity @ 40ºC, mm^2/s	ASTM D445	3.506	3.519	2.297	2.539
Flash Point, ºC	ASTM D93	97	99	60	70
Pour Point, ºC	ASTM D97	-3	-3	-18	-27
Sulfur, ppm	ASTM D5453	0.3	0.2	222.9	70.5
Distillation, ºC	ASTM D86				
IBP		212	214	168	183
T50		294	295	245	253
T90		323	334	317	315
FBP		352	353	348	346
Ash, mass%	ASTM D482	<0.001	<0.001	<0.001	<0.001
Heat of Combustion, BTU/lb	ASTM D240				
Gross		20,232	20,297	19,672	18,145
Net		18,856	18,908	18,430	16,879
Carbon/Hydrogen Ratio	ASTM D5291	2.13	2.13	1.87	1.92
Cloud Point, ºC	ASTM D2500	-1	0	-11	-15
SFC Aromatics, mass%	ASTM 5186				
Monoaromatics		1.3	2.1	15.2	10.7
Polynuclear Aromatics		1.7	0.2	3.0	1.4
Total Aromatics		3.0	2.3	18.2	12.1
Hydrocarbon Types, vol%	ASTM D1319				
Aromatics		0.6	1.1	18.7	12.4
Olefins		0.6	1.1	0.8	1.3
Saturates		98.8	97.8	80.5	86.3
Cetane Number	ASTM D613	>76	>76	53	56
Water & Sediment	ASTM D2709	0.005	0.01	0.005	0.01
Carbon Residue, mass%	ASTM D524	0.05	0.04	0.09	0.06
Copper Corrosion	ASTM D130	1A	1A	1A	1A
SLBOCLE, g	ASTM D6078	2,750	3,550	2,550	2,750
HFRR, mm	ASTM D6079	0.395	0.355	0.360	0.590

Figure 1. The Johnson Matthey CCRT filter.

Figure 2. Schematic of the CSHVR cycle.[4]



TEST MATRIX – Vehicles 204-206 were tested with the Shell GTL Fuel, with and without the CCRT filters, to isolate the fuel effects from the combined effect of the fuel and filter. Testing was conducted over the CSHVR (see Figure 2) and NYCB cycle (see Figure 3). For details on the development of the CSHVR cycle see Reference 4. These cycles were selected to simulate higher speed arterial driving and lower speed city driving. Table 4 shows the vehicle test matrix for each round of emission testing. The designation "(2)" indicates that the cycle was run twice, back to back, to ensure sufficient PM was collected.

Two vehicles were tested twice in round 2. The vehicle retests were used to insure that lab operation was as expected due to the recent move of the facility. These results have been included in all subsequent discussions.

Figure 3. Schematic of the NYCB cycle.

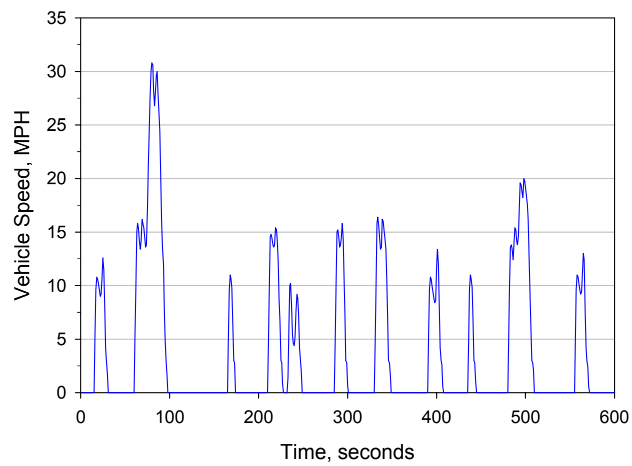


Table 4. Vehicle test matrix for emission testing.

Round 1			**Round 2**		
Vehicle	**Fuel/Filter**	**Test Cycle**	**Vehicle**	**Fuel/Filter**	**Test Cycle**
201	CARB, None	NYCB, CSHVR	204	GTL, CCRT	CSHVR(2)
202	CARB, None	NYCB, CSHVR		GTL, None	NYCB, CSHVR
203	CARB, None	NYCB, CSHVR		GTL, CCRT	NYCB(2)
205	GTL, CCRT	NYCB(2), CSHVR(2)	205	GTL, CCRT	NYCB(2), CSHVR(2)
	GTL, None	NYCB, CSHVR		GTL, None	NYCB, CSHVR
206	GTL, CCRT	CSHVR(2), NYCB(2)	203	CARB, None	NYCB, CSHVR
	GTL, None	NYCB, CSHVR	206	GTL, CCRT	NYCB(2), CSHVR(2)
204	GTL, CCRT	CSHVR(2), NYCB(2)		GTL, None	NYCB, CSHVR
	GTL, None	NYCB, CSHVR	201	CARB, None	CSHVR, NYCB
			202	CARB, None	NYCB, CSHVR
			203	CARB, None	NYCB, CSHVR
			204	GTL, None	NYCB, CSHVR

CHASSIS FACILITY – Researchers at West Virginia University (WVU) performed the chassis testing. Details of the laboratory facility have been previously reported.[5,6,7]

DATA AND RESULTS

DATA LOGGERS – The CCRT filters were installed with data loggers to monitor exhaust temperature and back pressure. Data was collected throughout the study period for all three vehicles. During filter removal and shipment back to Johnson Matthey, the data logger for vehicle 205 was damaged and the data lost.

The data for vehicle 204 represent 18 months or 1,291 hours of engine operation (January 2003 through July 2004). As shown in Figure 4, the back pressure remained stable throughout the project, indicating the filter was not plugging with ash when the project was completed. Additionally, the temperature profile shows the average exhaust temperature above 210ºC for roughly 40% of the total operating time (Figure 5).

Figure 4. Exhaust back pressure histogram for vehicle 204.[2]

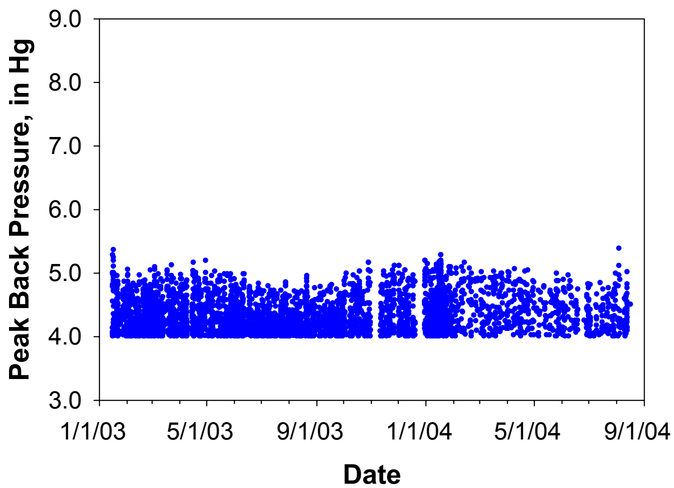
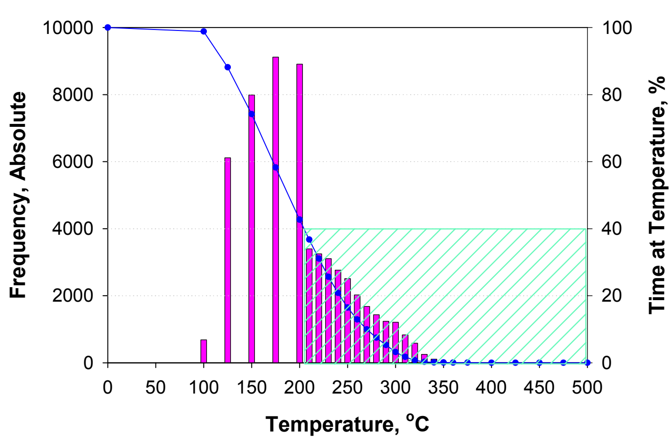


Figure 5. Exhaust temperature profile for vehicle 204.[2]



The data for vehicle 206 represent 8 months or 395 hours of engine operation (December 2003 through July 2004). Figure 6 shows the peak back pressure; the back pressure remained stable throughout the project, indicating the filter was operating satisfactorily.

The temperature data (Figure 7) show a higher average exhaust temperature for vehicle 206 compared to vehicle 204. Forty percent of the time, the exhaust temperature was greater than ~240ºC. The reason for the higher exhaust temperature is the higher percentage of highway miles for vehicle 206 (see Table 2).

Figure 6. Exhaust back pressure histogram for vehicle 206.[2]

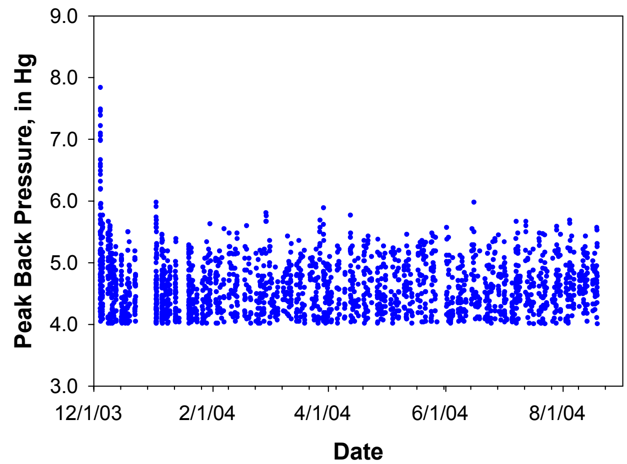
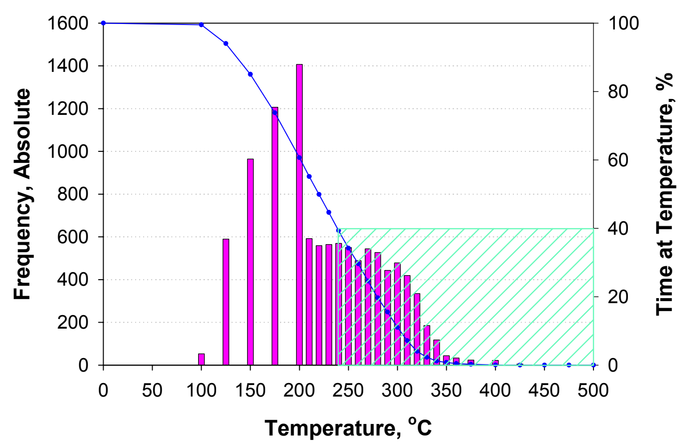


Figure 7. Exhaust temperature profile for vehicle 206.[2]



EMISSIONS – Chassis emission testing was conducted over the CSHVR and NYCB cycles. Vehicles 201-203 were tested only with CARB specification diesel fuel and no emission control devices. Vehicles 204-206 were tested with the Shell GTL Fuel with and without the CCRT filters. All results are compared to the CARB specification diesel fuel baseline. Appendix A-1 presents detailed test results from both rounds.

The calculated nitrogen dioxide (NO_2) results presented here are based on the difference in nitric oxide (NO) and NO_x emissions as measured by two tandem analyzers, using a previously described technique.[8] The NO_2 calculation technique is not robust enough to allow a statistical comparison between the CARB specification diesel and the Shell GTL Fuel (no filter). The results are simply presented for completeness.

The error bars on the figures are one confidence interval, which were generated using the statistical procedure outlined previously.[2] Statistical significance should not be inferred by overlapping error bars on the figures and will be discussed in further detail.

CSHVR Cycle – The change from CARB specification diesel fuel to the Shell GTL Fuel (no filter) resulted in reductions in the HC, PM, and NO_x emissions (46%, 21%, and 13%, respectively). Only the reduction in HC was statistically significant. An 11% increase in the CO emission was observed, but was not statistically significant. Figure 8 presents the results.

With the Shell GTL Fuel and the CCRT filter, the PM, HC, and CO reductions were all greater than 99% compared to the CARB specification diesel fuel. The NO_x emission was reduced by 22% compared to the baseline, which was statistically significant. The additional NO_x reduction with the filters is likely due to the conversion of NO_2 to N_2 over the CCRT filter.[9]

Figure 8. Regulated emissions from CSHVR cycle.

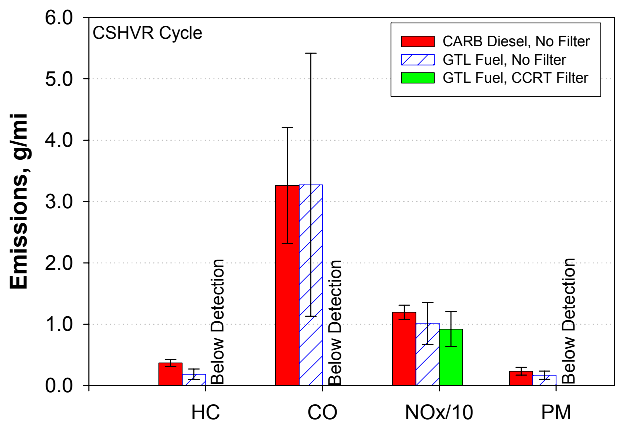


Figure 9 presents the calculated NO_2 emission results. The left bar is the NO_x emission and the right bar is the calculated NO_2 emission. As shown, the NO_2 emission composes roughly 50% of the NO_x emission with the CCRT filter and GTL fuel. Previous work has found similar percentages of NO_2 in the NO_x emission with DPFs.[8]

In chassis testing, the fuel economy is measured using a mass balance method outlined in the Code of Federal Regulations.[10] Figure 10 shows the fuel economy over the CSHVR test cycle. The slight changes in fuel economy with the various fuel/filter technologies are not statistically significant. No explanation is offered for the slight increase in fuel economy with the Shell GTL Fuel, either with or without the CCRT filter. The differences are likely due to vehicle-to-vehicle variability.

Figure 9. NO_x and calculated NO_2 emissions over the CSHVR cycle.

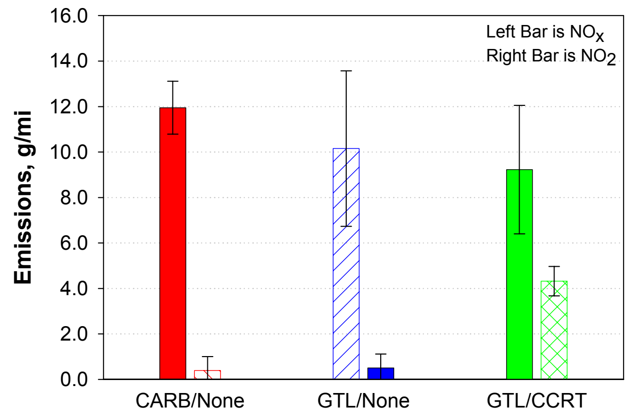
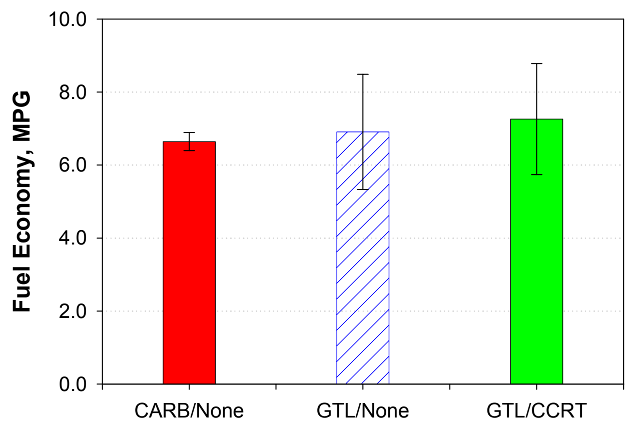


Figure 10. Fuel economy measured over the CSHVR cycle.



NYCB Results – Testing the Shell GTL Fuel (no filter) over the lower speed NYCB cycle resulted in reductions in the HC, PM, and NO_x emissions. These reductions—58% in HC, 16% in PM, and 11% in NO_x—were statistically significant. A 10% increase in CO emissions was observed, but was not statistically significant. Figure 11 graphically presents the emissions.

The Shell GTL Fuel and the CCRT filter reduced the HC, CO, and PM emissions by over 98% compared to the CARB specification diesel fuel baseline. These reductions were statistically significant. The NO_x emission was reduced by 20%, a statistically significant reduction.

Figure 11. Regulated emissions from NYCB cycle.

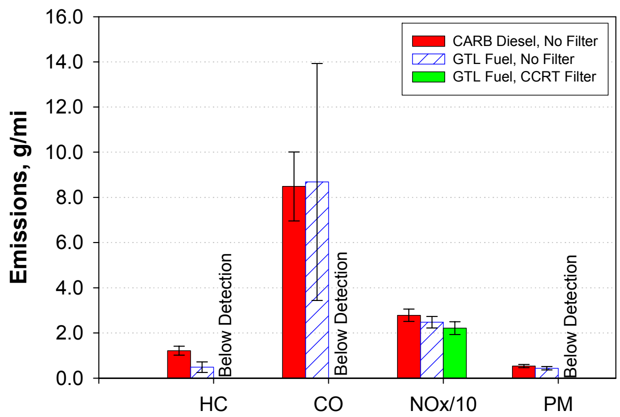


Figure 12 shows the calculated NO_2 emission results along with the NO_x emissions. As with the CSHVR cycle, the calculated NO_2 emissions are roughly 50% of the total NO_x emissions with the Shell GTL Fuel and CCRT filter.

Figure 12. NO_x and calculated NO_2 emissions over the NYCB cycle.

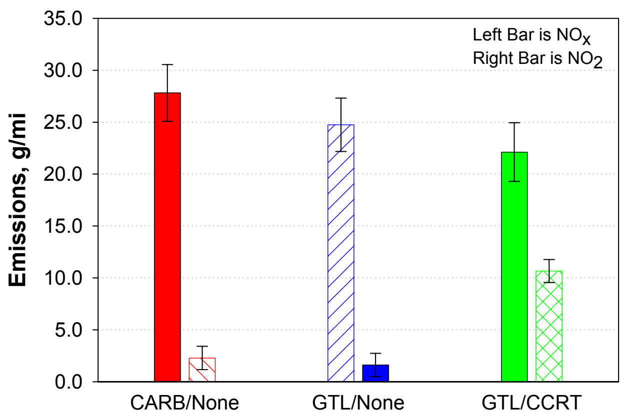
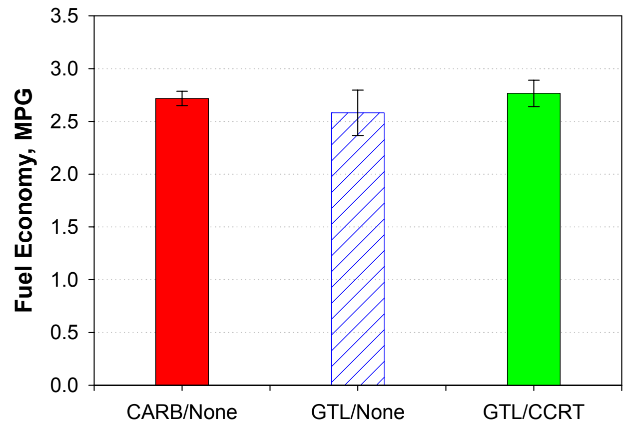


Figure 13 presents the measured fuel economy over the NYCB cycle. The small differences in the fuel economy between the vehicles are not statistically significant.

The emission reductions observed with the Shell GTL Fuel, with and without the CCRT filters, were compared to a high quality reference diesel fuel. The CARB specification diesel fuel in round 2 had a high cetane number and a low aromatic content. These properties are conducive to low emissions from diesel engines.

Figure 13. Measured fuel economy over NYCB cycle.



EMISSIONS COMPARISON BETWEEN TEST ROUNDS – The West Virginia University (WVU) chassis dynamometer facility changed locations between the first and second rounds of testing. In the first round, the WVU facility was at a local grocery distribution site in Riverside, CA. For the second round of testing, the WVU facility relocated to the University of California -Riverside campus.

Table 5 highlights the differences in emissions between the two rounds of testing over the CSHVR cycle. A statistical analysis was conducted on the emissions in each round of testing. The table shows the emission, whether there was a difference between round 1 and round 2, and whether the difference was statistically significant. Similar results are presented in Table 6 for the NYCB cycle.

Previous work has shown that increases in the CO emission over time can be related to engine deterioration.[11] However, over the course of this study, the vehicles accumulated approximately 20,000 miles, and engine deterioration is unlikely. More likely is that the testing was performed with a very small vehicle set (6 vehicles) and the differences are an example of vehicle to vehicle variability.

Table 5. Comparison of emissions between test rounds for the CSHVR cycle.

Emission	Difference	Statistically Significant?
HC	Higher for CARB diesel fuel in Round 2	No
CO	Higher for CARB diesel fuel and GTL Fuel in Round 2	Yes
NO_x	Decreased with GTL Fuel and GTL Fuel with CCRT filter in Round 2	No
PM	Increased for the CARB diesel fuel and GTL Fuel in Round 2	Yes for the CARB diesel fuel, No for the GTL Fuel
Fuel Economy	Decreased with CARB diesel fuel in Round 2	Yes

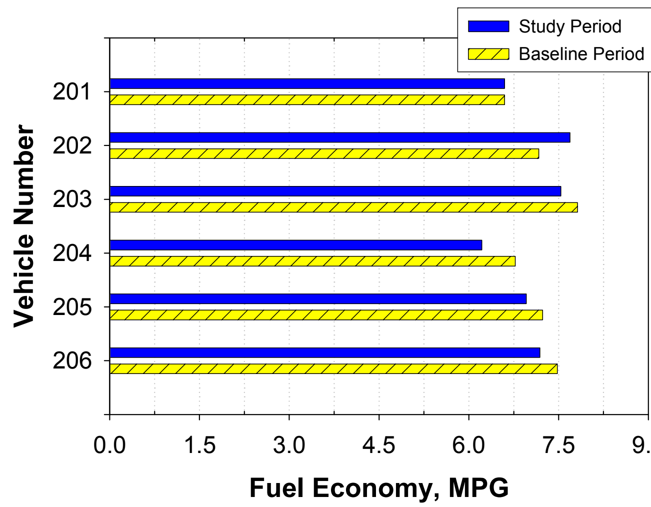
Table 6. Comparison of emissions between test rounds for the NYCB cycle.

Emission	Difference	Statistically Significant?
HC	Round 1 emissions were higher for the CARB diesel fuel	Yes
CO	Higher with CARB diesel fuel and GTL Fuel in Round 2	Yes
NO_x	Higher in Round 1 for all fuel/filter combinations	Yes
PM	Higher for CARB diesel fuel in Round 1	Yes
Fuel Economy	Higher with the CARB diesel fuel and the GTL Fuel with CCRT filter in Round 2	Yes

OPERABILITY RESULTS – NREL worked with the fleet to collect operability data during the project period. A separate operability report has been published. The benefit of the operability data collection is a quantitative measure of the impact of the fuel and filter technology on fleet operations.

Fuel Economy – Although fuel economy data were collected over the chassis dynamometer testing, this is not representative of the fuel economy experienced by the fleet. The "real world" fuel economy was determined by mileage and fueling data. Figure 24 shows the fuel economy for the Yosemite Waters vehicles over a baseline period and the study period.

Figure 24. "Real world" fuel economy for Yosemite Waters vehicles over study period.



The "real world" fuel economy is much more difficult to understand compared to chassis dynamometer results. The number of variables present in the real world can confound or even obscure trends. One example that is likely present in this fleet is the nature of the business. Yosemite Waters delivers water to residential and commercial customers. The demand for bottled water increases in the warmer summer months, resulting in heavier truck loading. Thus, some impact on fuel economy because the vehicles are carrying heavier loads. The "real world" fuel economy for the Yosemite Waters vehicles did not change over the study period compared to the baseline period. Although there was an 8% decrease in fuel economy, the change was not statistically significant. Previous fleet studies have shown that small changes in fuel economy are not statistically significant over the long-term.[8]

Maintenance – The maintenance costs for the Yosemite Waters fleet were tracked prior to and during the study period. The pre-study period, where all 6 trucks are operating on CARB specification diesel fuel, had maintenance costs of $0.02/mile. The diesel control vehicles (201-203) had maintenance costs of $0.025/mile during the study period. The maintenance costs for the GTL fueled vehicles with the CCRT filters (204-206) were $0.049/mile. The costs for the GTL vehicles were biased high by one event on vehicle 206—the starter was replaced twice. By omitting this event, the maintenance costs for the GTL fueled vehicles are much closer to the diesel vehicles at $0.019/mile.

Aside from the starter repair on 206, the data do not reveal much in the way of maintenance over the study period. Beyond preventative maintenance, the major repairs were:

- 201 – leaky oil pump, warranty repair
- 203 – leaky oil pump, warranty repair
- 206 – fuel leak, warranty repair
- 206 – oil leak, warranty repair

It should be noted that vehicle 206 experienced a fuel leak during the study period. It is unknown what caused this fuel leak and whether it was related to the GTL Fuel or not. Vehicles 204 and 205 did not report any fuel system problems during the study period. Vehicle 204 operated on GTL Fuel from January 2002 until July 2004, a significant period of time.

Drivability – The drivability of a vehicle is a qualitative measure. The drivers of the vehicles did not perceive any difference between the study vehicles before or during the study. No complaints were noted about issues like lack of power or poor acceleration.

CONCLUSIONS

Three Class 6 trucks were fueled with Shell GTL Fuel and retrofit with Johnson Matthey CCRT filters. The vehicles were part of an emissions and operability study which included three baseline vehicles. All the vehicles were chassis emission tested and followed for 6 months to gather operability data.

Two rounds of emission testing were completed, with the first round in December 2003 and the second round in July 2004. Testing was conducted over the CSHVR and NYCB cycles to simulate the types of driving experienced by the fleet. Results from the testing showed regulated emission reductions with the Shell GTL Fuel alone. Further reductions in emissions were possible with the CCRT filter and the Shell GTL Fuel.

The drivers of the vehicles fueled with the Shell GTL Fuel and the CCRT filters were interviewed to gauge their impression of the vehicles. Their experiences with the fuel and filter combinations were very positive. The drivers reported similar acceleration, power and drivability as the control vehicles.

An operability analysis revealed that the combination of the GTL Fuel and the CCRT filters reduced fuel economy by 8% compared to the baseline vehicles. This reduction was not statistically significant. The maintenance costs were similar for the test and baseline vehicles over the study period, showing that GTL Fuel and CCRT filters did not impact fleet operating costs during this study.

ACKNOWLEDGMENTS

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DEFINITIONS

ASTM: American Society of Testing and Materials
BTU/lb: British Thermal Units per pound
ºC: Degrees Celsius
CARB: California Air Resources Board
CCRT®: Catalyzed Continuously Regenerating Technology
CO: carbon monoxide
CO_2: carbon dioxide
CSHVR: City Suburban Heavy Vehicle Route
DPF: diesel particle filter
FBP: final boiling point
ft-lb: foot pounds
g: grams
g/mL: grams per milliliter
GTL: Gas-to-liquid
HC: Hydrocarbons
HFRR: High Frequency Reciprocating Rig
hp: horsepower
IBP: initial boiling point
mass%: Percentage by mass
mL: milliliter
mm: millimeter
mm^2/s: square millimeters per second
MPG: miles per gallon
NO: nitric oxide
NO_2: nitrogen dioxide
NO_x: nitrogen oxides
NYCB: New York City Bus
PM: particulate matter
ppm: parts per million
rpm: revolutions per minute
SLBOCLE: Scuffing Load Ball-On-Cylinder Lubricity Evaluator
vol%: Percentage by volume
WVU: West Virginia University

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APPENDIX A-1.

Yosemite Waters Vehicles Emission Test Results.

Vehicle	Round	Cycle	Fuel	Filter	Run #	CO, g/mi	NO_x, g/mi	NO_2, g/mi	HC, g/mi	PM, g/mi	CO_2, g/mi	Fuel Economy, MPG
201	1	CSHVR	CARB	None	2793-1	2.00	11.5		0.42	0.19	1461	6.86
					2793-2	1.91	11.6	1.3	0.48	0.19	1455	6.88
					2783-3	1.89	11.1	1.1	0.45	0.17	1414	7.09
					Average	**1.93**	**11.4**	**1.2**	**0.45**	**0.18**	**1443**	**6.94**
201	2	CSHVR	CARB	None	20073-1	3.17	13.0		0.37	0.23	1495	6.69
					20073-2	3.76	13.1	0.3	0.39	0.24	1513	6.61
					20073-3	3.78	12.6	0.5	0.36	0.24	1484	6.74
					Average	**3.57**	**12.9**	**0.4**	**0.37**	**0.24**	**1497**	**6.68**
202	1	CSHVR	CARB	None	2798-1	1.90	11.9		0.45	0.17	1417	7.07
					2798-2	2.15	11.6	1.1	0.52	0.17	1396	7.17
					2798-3	2.80	11.6	0.9	0.47	0.16	1403	7.14
					Average	**2.28**	**11.7**	**1.0**	**0.48**	**0.17**	**1405**	**7.13**
202	2	CSHVR	CARB	None	20080-1	3.31	12.2		0.41	0.26	1545	6.48
					20081-2	3.67	12.7	0.8	0.39	0.28	1585	6.31
					20081-3	3.67	12.6	0.6	0.39	0.27	1564	6.40
					Average	**3.55**	**12.5**	**0.7**	**0.40**	**0.27**	**1565**	**6.40**
203	1	CSHVR	CARB	None	2805-1	1.39	12.1		0.43	0.16	1476	6.79
					2805-2	1.36	11.7	1.1	0.47	0.15	1422	7.05
					2805-3	1.53	11.6	0.9	0.43	0.15	1408	7.12
					Average	**1.43**	**11.8**	**1.0**	**0.44**	**0.15**	**1435**	**6.99**
203	2	CSHVR	CARB	None	20056-1	2.56	10.7		0.32	0.19	1453	6.89
					20056-2	2.55	11.0	0.7	0.31	0.19	1450	6.90
					20056-3	2.50	10.7	0.4	0.31	0.19	1400	7.15
					Average	**2.54**	**10.8**	**0.5**	**0.31**	**0.19**	**1434**	**6.98**
203	2	CSHVR	CARB	None	20108-1	3.17	11.0		0.38	0.23	1510	6.63
					20108-2	2.92	10.9	0.2	0.37	0.21	1494	6.70
					20108-3	2.96	11.3	-0.5	0.35	0.22	1497	6.69
					Average	**3.02**	**11.1**	**-0.1**	**0.37**	**0.22**	**1500**	**6.67**
204	1	CSHVR	GTL	None	2837-2	2.33	11.1	0.1	0.24	0.16	1341	6.86
					2837-3	2.11	10.9	-0.4	0.24	0.15	1318	6.98
					2837-4	2.45	11.2		0.24	0.14	1312	7.01
					Average	**2.30**	**11.07**	**-0.15**	**0.24**	**0.15**	**1324**	**6.95**
204	2	CSHVR	GTL	None	20032-1	4.45	10.3		0.23	0.23	1363	6.73
					20032-2	5.05	10.3	0.6	0.22	0.22	1368	6.71
					20032-3	5.13	10.2	0.7	0.23	0.23	1329	6.9
					Average	**4.88**	**10.3**	**0.65**	**0.23**	**0.23**	**1353**	**6.78**
204	2	CSHVR	GTL	None	20135-1	4.04	9.9		0.22	0.24	1429	7.00
					20135-2	4.36	10.3	0.40	0.20	0.23	1421	7.03
					20135-3	4.23	10.4	0.70	0.20	0.21	1443	6.93
					Average	**4.21**	**10.20**	**0.55**	**0.21**	**0.23**	**1431**	**6.99**

APPENDIX A-1. CONTINUED

Vehicle	Round	Cycle	Fuel	Filter	Run #	CO, g/mi	NO_x, g/mi	NO_2, g/mi	HC, g/mi	PM, g/mi	CO_2, g/mi	Fuel Economy, MPG
205	1	CSHVR	GTL	None	2820-1	1.26	9.5		0.16	0.10	1248	7.38
					2820-2	1.27	9.2	0.7	0.15	0.08	1208	7.63
					2820-3	1.32	9.2	0.6	0.14	0.09	1218	7.57
					Average	**1.28**	**9.3**	**0.6**	**0.15**	**0.09**	**1225**	**7.53**
205	2	CSHVR	GTL	None	20051-1	1.85	8.2		0.15	0.11	1156	7.97
					20051-2	2.11	8.6	0.4	0.16	0.11	1177	7.82
					20051-3	2.18	8.4	0.4	0.16	0.11	1155	7.97
					Average	**2.05**	**8.4**	**0.4**	**0.16**	**0.11**	**1163**	**7.92**
206	1	CSHVR	GTL	None	2828-1	1.55	11.6		0.15	0.11	1369	6.73
					2828-2	1.39	11.6	0.4	0.20	0.10	1375	6.70
					2828-3	1.45	11.2	0.3	0.21	0.09	1353	6.81
					Average	**1.46**	**11.5**	**0.4**	**0.19**	**0.10**	**1366**	**6.75**
206	2	CSHVR	GTL	None	20069-1	2.95	11.7		0.20	0.17	1583	5.82
					20069-2	2.73	11.9	0.5	0.18	0.15	1544	5.96
					20069-3	3.04	12.2	0.4	0.19	0.16	1559	5.90
					Average	**2.91**	**11.9**	**0.4**	**0.19**	**0.16**	**1562**	**5.89**
204	1	CSHVR	GTL	CCRT	2830-1	0.00	10.8		0.00	0.00	1364	6.77
					2830-2	0.08	10.8	5.9	0.00	0.00	1321	6.97
					2830-3	0.00	10.7	5.4	0.00	0.00	1321	6.99
					Average	**0.03**	**10.8**	**5.7**	**0.00**	**0.00**	**1335**	**6.91**
204	2	CSHVR	GTL	CCRT	20027-1	0.00	9.2		0.00	0.00	1340	6.89
					20027-2	0.00	9.2	4.5	0.00	0.00	1332	6.93
					20027-3	0.00	9.6	4.6	0.00	0.00	1322	6.99
					Average	**0.00**	**9.3**	**4.6**	**0.00**	**0.00**	**1331**	**6.94**
205	1	CSHVR	GTL	CCRT	2813-1	0.00	9.1		0.00	0.00	1268	7.29
					2813-2	0.00	8.7	4.5	0.00	0.00	1224	7.55
					2813-3	0.00	8.7	4.4	0.00	0.00	1220	7.57
					Average	**0.00**	**8.8**	**4.5**	**0.00**	**0.00**	**1237**	**7.47**
205	2	CSHVR	GTL	CCRT	20045-2	0.00	7.3	3.4	0.00	0.0016	1087	8.5
					20045-3	0.00	7.6	3.4	0.00	0.0010	1129	8.18
					20045-4	0.00	7.5		0.00	0.0007	1079	8.56
					Average	**0.00**	**7.5**	**3.4**	**0.00**	**0.0011**	**1098**	**8.41**
206	1	CSHVR	GTL	CCRT	2822-1	0.00	10.6		0.00	0.00	1409	6.56
					2822-2	0.00	10.3	5.8	0.00	0.00	1371	6.74
					2822-3	0.00	10.5	6.1	0.00	0.00	1369	6.75
					Average	**0.00**	**10.5**	**6.0**	**0.00**	**0.00**	**1383**	**6.68**
206	2	CSHVR	GTL	CCRT	20064-1	0.0125	10.2		0.00	0.0010	1413	6.54
					20064-3	0.0000	11.3	5.00	0.00	0.0008	1477	6.26
					20064-4	0.0042	11.1	5.00	0.00	0.0002	1425	6.48
					Average	**0.0056**	**10.9**	**5.00**	**0.00**	**0.001**	**1438**	**6.43**

APPENDIX A-1. CONTINUED

Vehicle	Round	Cycle	Fuel	Filter	Run #	CO, g/mi	NO_x, g/mi	NO_2, g/mi	HC, g/mi	PM, g/mi	CO_2, g/mi	Fuel Economy, MPG
201	1	NYCB	CARB	None	2792-1	5.09	31.9		1.56	0.61	3890	2.57
					2792-2	5.52	32.3	4.0	1.37	0.55	3856	2.69
					2792-3	6.18	30.7	3.2	1.54	0.56	3940	2.54
					Average	**5.60**	**31.6**	**3.6**	**1.49**	**0.57**	**3895**	**2.60**
201	2	NYCB	CARB	None	20074-1	10.68	32.2		1.31	0.62	3826	2.61
					20074-2	8.95	30.3	2.4	1.35	0.53	3657	2.73
					20074-3	9.79	31.6	1.8	1.33	0.49	3789	2.64
					Average	**9.81**	**31.37**	**2.10**	**1.33**	**0.55**	**3757**	**2.66**
202	1	NYCB	CARB	None	2797-1	6.26	33.3		1.48	0.67	3932	2.55
					2797-2	6.92	34.5	3.2	1.34	0.63	4073	2.46
					2797-3	9.35	32.3	3.9	1.33	0.80	3857	2.59
					Average	**7.51**	**33.4**	**3.6**	**1.38**	**0.70**	**3954**	**2.53**
202	2	NYCB	CARB	None	20079-1	8.18	27.3		1.38	0.55	3644	2.74
					20079-2	7.93	26.9	3.5	1.23	0.54	3595	2.78
					20079-3	8.50	26.7	3.1	1.20	0.57	3556	2.81
					Average	**8.20**	**27.0**	**3.3**	**1.27**	**0.55**	**3598**	**2.78**
203	1	NYCB	CARB	None	2802-1	4.68	32.1		1.56	0.80	3988	2.51
					2802-2	5.41	31.9	3.3	1.87	0.65	3997	2.50
					2802-3	6.25	32.0	2.9	1.84	0.65	4072	2.46
					Average	**5.45**	**32.0**	**3.1**	**1.76**	**0.70**	**4019**	**2.49**
203	2	NYCB	CARB	None	20055-1	6.80	26.1		1.03	0.45	3681	2.72
					20055-2	6.94	26.7	2.4	1.00	0.49	3593	2.79
					20055-3	7.13	26.5	1.5	1.10	0.51	3697	2.71
					Average	**6.96**	**26.4**	**1.95**	**1.04**	**0.48**	**3657**	**2.74**
203	2	NYCB	CARB	None	20107-1	9.52	26.8		1.31	0.56	3747	2.67
					20107-2	9.02	26.1	2.3	1.33	0.56	3671	2.72
					20107-3	8.38	26.3	0.3	1.00	0.50	3719	2.69
					Average	**8.97**	**26.4**	**1.3**	**1.21**	**0.54**	**3712**	**2.69**
204	1	NYCB	GTL	None	2835-1	7.55	28.3		0.55	0.92	3650	2.52
					2835-2	8.76	29.4	2.9	0.65	0.63	3617	2.54
					2835-3	8.94	28.0	1.3	0.63	0.61	2561	2.58
					Average	**8.4**	**28.6**	**2.1**	**0.6**	**0.7**	**3276**	**2.5**
204	2	NYCB	GTL	None	20031-1	10.3	23.0	1.2	0.62	0.55	3401	2.70
					20031-2	12.5	24.4		0.62	0.54	3474	2.64
					20031-3	11.1	23.9	2.1	0.59	0.51	3367	2.73
					Average	**11.3**	**23.8**	**1.65**	**0.61**	**0.53**	**3414**	**2.69**
204	2	NYCB	GTL	None	20134-1	11.2	24.2		0.50	0.55	3620	2.54
					20134-2	11.5	25.0	1.7	0.47	0.55	3674	2.5
					20134-3	11.1	24.3	2.2	0.65	0.57	3523	2.61
					Average	**11.27**	**24.50**	**1.95**	**0.54**	**0.56**	**3606**	**2.55**
205	1	NYCB	GTL	None	2819-1	5.56	26.6		0.28	0.37	3479	2.65
					2819-2	4.91	26.3	2.4	0.36	0.36	3494	2.64
					2819-3	5.33	26.8	1.9	0.42	0.30	3588	2.57
					Average	**5.27**	**26.57**	**2.15**	**0.35**	**0.34**	**3520**	**2.62**
205	2	NYCB	GTL	None	20050-1	8.04	24.1		0.39	0.35	3466	2.65
					20050-2	7.26	24.2	1.7	0.43	0.33	3419	2.69
					20050-3	6.93	23.9	1.3	0.40	0.33	3402	2.71

					Average	**7.41**	**24.1**	**1.5**	**0.41**	**0.34**	**3429**	**2.68**

APPENDIX A-1. CONTINUED

Vehicle	Round	Cycle	Fuel	Filter	Run #	CO, g/mi	NO_x, g/mi	NO_2, g/mi	HC, g/mi	PM, g/mi	CO_2, g/mi	Fuel Economy, MPG
206	1	NYCB	GTL	None	2826-1	4.58	27.8		0.33	0.48	3572	2.58
					2826-2	5.59	29.0	1.5	0.54	0.46	3701	2.49
					2826-3	4.89	29.8	1.6	0.54	0.40	3856	2.39
					Average	**5.02**	**28.9**	**1.6**	**0.47**	**0.45**	**3710**	**2.49**
206	2	NYCB	GTL	None	20068-1	7.32	26.2		0.45	0.37	3799	2.42
					20068-2	6.94	26.2	1.9	0.47	0.33	3771	2.44
					20068-3	7.35	27.0	1.3	0.52	0.38	3838	2.40
					Average	**7.20**	**26.5**	**1.6**	**0.48**	**0.36**	**3803**	**2.42**
204	1	NYCB	GTL	CCRT	2833-1	0.00	28.2		0.00	0.01	3229	2.62
					2833-2	0.00	28.6	15.9	0.00	0.01	3615	2.56
					2833-3	0.00	27.1	15.3	0.00	0.00	3535	2.61
					Average	**0.00**	**27.97**	**15.60**	**0.00**	**0.01**	**3460**	**2.60**
204	2	NYCB	GTL	CCRT	20026-1	0.00	20.40		0.03	0.00	3261	2.83
					20026-2	0.21	20.10	11.00	0.00	0.00	3215	2.87
					20026-3	0.00	19.20		0.01	0.00	3098	2.98
204	2	NYCB	GTL	CCRT	20036-1	0.043	21.3		0.00	0.0077	3394	2.72
					20036-2	0.000	21.5	11.6	0.00	0.0044	3364	2.75
					20036-3	0.000	21.8		0.00	0.0056	3318	2.78
					Average	**0.014**	**21.5**	**11.6**	**0.00**	**0.0059**	**3359**	**2.75**
205	1	NYCB	GTL	CCRT	2809-1	0.00	25.9		0.00	0.0510	3609	2.56
					2809-2	0.00	25.7	12.5	0.00	0.0170	3595	2.57
					2809-3	0.00	24.8	11.1	0.00	0.0170	3520	2.62
					Average	**0.00**	**25.5**	**11.8**	**0.00**	**0.0283**	**3575**	**2.58**
205	2	NYCB	GTL	CCRT	20041-1	0.00	21.2		0.00	0.0046	3239	2.85
					20041-2	0.00	21.9	8.9	0.00	0.0045	3339	2.77
					20041-3	0.00	22.0	10.1	0.00	0.0073	3267	2.83
					Average	**0.00**	**21.7**	**9.5**	**0.00**	**0.0055**	**3282**	**2.82**
206	1	NYCB	GTL	CCRT	2823-1	0.00	25.80		0.00	0.007	3388	2.73
					2823-2	0.00	27.80	13.4	0.00	0.002	3593	2.57
					2823-3	0.00	27.40	12.2	0.00	0.061	3516	2.63
					Average	**0.00**	**27.00**	**12.8**	**0.00**	**0.023**	**3499**	**2.64**
206	2	NYCB	GTL	CCRT	20060-2	0.00	25.40		0.00	0.014	3538	2.61
					20060-3	0.00	25.50	11.4	0.00	0.012	3572	2.59
					20060-4	0.00	25.00	10.9	0.00	0.015	3454	2.61
					Average	**0.00**	**25.30**	**11.2**	**0.00**	**0.014**	**3521**	**2.60**