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SIMULATION OF HYBRID ELECTRIC BUSES

SECOND REPORT

submitted by

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and

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to

Jerusalem Transportation Master Plan

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1. EXECUTIVE SUMMARY

The Israel Ministry of Transportation (IMOT) will be introducing new hybrid electric buses onto various routes in Jerusalem and Haifa. Such purchases are being considered because of the need to conserve diesel fuel, because the hybrids produce significantly less air pollution and because these buses may offer savings in maintenance costs.

The purpose of the current project is to assist in that purchase by the simulation of various hybrids in order to choose an optimal one for operations in Israel. The simulation will be based on code which has been validated to compare well with tested vehicles. It will permit a variety of duty cycles to be employed so that various operations can be compared. In Section 2, below, we review the software that has been used and some results that have been obtained there. In Section 3 we look at the different duty/driving cycles used in this study and suggest how they may be effectively employed.

In this project and in conjunction with the IMOT, we have been be assessing four of the many possible hybrid electric buses available. These are all 60 ft, articulated vehicles:

NABI 60 LFW (diesel)
New Flyer DE60LF (hybrid)
New Flyer DE60LF-BRT (hybrid)
Wrightbus StreetCar RTV (hybrid)

This first was chosen so that a comparison of results with straight diesel could be obtained. The others were selected as typical of those available for purchase and for use in Israel. We worked with staff at the Jerusalem Transportation Master Plan to be sure that these are the best choices.

We should emphasize that many of the largest bus operators in the United States have now settled on the hybrid, both standard and articulated, as the vehicle of choice for the next ten to twelve years in order to meet increasingly stringent environmental emission regulations. These have come about because of the major performance improvements that have been seen in their simulation and subsequent testing over a long period. Much of this work has been documented before and is available in the literature. Typical of the reports are those in References 1, 2 and 3[1]. Some new results are just becoming available from recent testing in Westchester County, New York, and Seattle King County Metro Transit. The bus operators there have decided to deploy hybrid buses based on extensive testing of vehicles over the last years.These results, cited in Ref. 4 and 5, are under review by the Counties and are available publicly. Needless to say, the results confirm all earlier studies and indicate that even in the Counties duty cycle, with its many hills and difficult route structures, hybrid performance is excellent.

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[1] All references are provided at the end of this report.

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Following are presented executive summary evaluated and simulated results in this second report of typical hybrid BRT fuel economy (mpg-miles per gallon) improvement, emissions reduction (carbon dioxide CO2, carbon monoxide CO, nitrogen oxides NOx, particulate matter PM, and hydrocarbon HC) which are analyzed in next sections. Following it is also presented the formula how to convert the fuel economy improvement versus reduction in fuel consumption. The hybrid bus presented hereby are New Flyer buses and the conventional bus is the NABI diesel bus. The results obtained for the Manhattan, Orange County Transit Authorities (OCTA) and Central Business District (CBD) duty cycles are results obtained from chassis dynamometer test results, and the results for the Jerusalem duty cycle were evaluated from simulation as explained in next section, including definition of the Jerusalem duty cycle.

Fuel Economy of Buses on Various Duty Cycles:

	Manhattan	**OCTA**	**CBD**	**Jerusalem**
Conventional Bus Fuel Economy (mpg)	1.46	2.15	2.19	2.34
Hybrid Bus Fuel Economy (mpg)	2.56	3.24	3.25	3.26
Fuel Economy (mpg) % Increase w/Hybrid Bus	74.6%	50.6%	48.3%	39.3%

Average Values for Emission Results of Buses on Specified Duty Cycles

	Manhattan		**OCTA**		**CBD**		**Jerusalem**	
	Diesel	Hybrid	Diesel	Hybrid	Diesel	Hybrid	Diesel	Hybrid
NOx (gram/mile)	29.58	18.12	18.91	13.51	19.67	14.44	14.74	12.11
PM (gram/mile)	0.380	0.003	0.050	0.024	0.101	0.003	0.187	0.108
CO (gram/mile)	3.13ns	2.81ns	2.29	1.55	1.77	1.55	1.66	1.07
HC (gram/mile)	0.04ns	0.05ns	0.03ns	0.03ns	0.12	0.03	0.13	0.07
CO_2 (gram/mile)	6714	3771	4579	3001	4587	2991	3446	2614

ns – not statistically significant

Regarding the Wright bus Street Car RTV hybrid bus there are presented in the next section the preliminary Chassis Dynamometer test measurements according to MILLBROOK duty cycle. The achieved fuel economy was 5.59 mpg and the emissions results were quite good (see results there). However it is not possible for us to simulate the Street Car bus for the Jerusalem cycle

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due to lack of final information.

Following is the formula how to convert the fuel economy improvement (mpg) in % of hybrid bus versus diesel one, to fuel consumption (gal/100 miles) improvement in %.

X= % improvement in MPG
Y = equivalent % reduction in fuel consumption measured in gal/100 miles (or liter/100 km)
neg y = just a multiplier by -1 to avoid negatives on the graph

X	y	neg y	Equal
% Fuel Economy Improvement	% Fuel Consumption Reduction		
40	-28.6%	0.29	5

For the Jerusalem duty cycle the 40% fuel economy improvement presented above is converted to 30 % fuel consumption reduction.

As per indication following is presented the fleet summary statistics in Seattle of hybrid BRT regarding the reduction of consumed fuel cost, operating cost and maintenance cost. Important point to be emphasized is that the total operating cost of hybrid buses fleet is lower by 15% than the operating cost of diesel buses fleet.

Although this is not the final bus simulation report, and this report is not aiming to recommend to purchase any one of the tested/evaluated buses, it can presently be said that the hybrid buses with compare to equivalent diesel buses have benefits: about 40% fuel economy improvement, about 50% emission reduction, about 30% CO_2 (Greenhouse effect) reduction, about 15% operational cost reduction. Although these benefits are not necessarily cost effective in price with compare to diesel buses, they certainly provide a very good environmental option for hybrid BRT (bus rapid transit) with compare to LRT (light rail transit) where the price of the infrastructure is much more higher.

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King County Metro (Seattle, WA) Fleet Summary Statistics			
Evaluation Period Only			
Fleet Operations and Economics			
	Diesel	Hybrid	Hybrid
	Ryerson	Atlantic	South
Number of Vehicles	10	10	9
Period Used for Fuel Analysis	4/05—3/06	4/05—3/06	4/05—3/06
Total Number of Months in Period	12	12	12
Fuel Analysis Base Fleet Mileage	350,567	362,049	379,328
Period Used for Maintenance Op Analysis	4/05—3/06	4/05—3/06	4/05—3/06
Total Number of Months in Period	12	12	12
Maintenance Analysis Base Fleet Mileage	353,785	371,548	427,331
Average Monthly Mileage per Vehicle	2,948	3,096	3,957
Fleet Fuel Usage in Gal.	139,996	114,054	101,174
Representative Fleet MPG	2.50	3.17	3.75
Hybrid compared to Diesel		27%	50%
Average Fuel Cost as Reported	1.98	1.98	1.98
	per Gal D2	per Gal D2	per Gal D2
Average Fuel Cost per Energy Equivalent	1.98	1.98	1.98
Fuel Cost per Mile	0.791	0.624	0.528
Number of Total Road Calls	60	75	91
MBRC All Road Calls	5,896	4,954	4,696
Number of Propulsion System Road Calls	29	35	50
MBRC Propulsion System Road Calls	12,199	10,616	8,547
Total Scheduled Repair Cost per Mile	0.154	0.140	0.118
Total Unscheduled Repair cost per Mile	0.308	0.304	0.293
Total Maintenance Cost per Mile	0.462	0.444	0.411
Total Operating Cost per Mile	**1.252**	**1.068**	0.939
Maintenance Costs			
	Diesel	Hybrid	Hybrid
	Ryerson	Atlantic	South
Fleet Mileage	353,785	371,548	427,331
Total Parts Cost	32,555.04	39,319.89	28,181.55
Total Labor Hours	2615.4	2514.2	2946.9
Average Labor Cost	130,770.00	125,707.50	147,346.00
(@ $50.00 per hour)			
Total Maintenance Cost	163,325.04	165,027.39	175,527.55
Total Maintenance Cost per Mile	**0.462**	**0.444**	0.411

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2. SOFTWARE THAT HAS BEEN USED

Over the years, two software packages have been developed and tested to be used in the sorts of simulations to be undertaken in the current work. The first, called ADVISOR, was one which the project team used several years ago in our original simulations for hybrid vehicles in Israel. While this package is still available, a better and more useful one has been in developed in parallel and subjected to better and more accurate validation. This software, PSAT (Powertrain System Analysis Toolkit), running under the standard simulation packages of MATLAB, is the one chosen for this project.

Argonne National Laboratory of the United States Department of Energy (USDOE) undertook a collaborative effort to develop the Powertrain System Analysis Toolkit © (PSAT) under the direction of and with contributions from Ford, General Motors, and DaimlerChrysler. PSAT is sponsored by USDOE. After a thorough assessment, DOE selected PSAT as its primary vehicle simulation tool to support FreedomCAR and Fuels Partnership activities. PSAT has been used for numerous studies to assist DOE in identifying future research directions regarding HEVs as well as Plug-in HEVs. In addition, PSAT received an R&D 100 Award in 2004, ranking it among the 100 best newly available products and technologies from around the world. PSAT is currently used by more than 300 researchers worldwide in more than 60 companies and universities.

PSAT is a "forward-looking" model that simulates fuel economy and performance, especially emissions, in a realistic manner, taking into account transient behavior and control system characteristics. It can simulate an unrivaled number of predefined configurations (conventional, electric, fuel cell, series hybrid, parallel hybrid, and power split hybrid). Because of its forward architecture, PSAT component interactions are "real world."
This capability, when combined with the engineering, development, and testing resources at Argonne, substantially enhances USDOE's ability to assess the potential of advanced automotive technologies and streamline the development process for promising technologies. Moreover, PSAT has provided significant benefits to industry vehicle designers and university researchers as evidenced by their growing use of PSAT for both production-oriented and research design activities.

Within PSAT we can study, at least, the following:

- Fuel economy. See below for some results developed by PSAT for hybrid automobiles.
- Performance. In this regard all emissions are accounted for so that comparison to regulations can be undertaken and clear comparison of differences is afforded.
- Component sizing. Should the IMOT decide to modify the vehicles being offered, PSAT

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provides the tools to assess appropriate changes.

- Gradeability. Clearly, and especially within the Jerusalem environment, gradeability is a critical feature; PSAT permits looks at effects of grades and their impact on performance.
- Parametric studies. As we compare the various buses we will be able to make valid performance comparisons between them.
- Drivetrain configurations. For hybrids, PSAT permits a wide variety of configurations for simulation: standard diesel, series, single shaft parallel, double shaft parallel, power split parallel. In addition the PSAT library contains many of the typical bus components that will facilitate our use of the software.
- Drive and build drive cycles. There are, of course, standard drive cycles built into PSAT. Should these not prove acceptable, it is relatively easy to create our own that more meets the Israeli requirements.
- Design tools. While we will not need this capability, in the vehicles design process PSAT permits optimizing components, control strategies and so on.

While we do not wish to overburden this preliminary report with results from other studies, it is instructive to see some data from other hybrid simulations. These, provided by the PSAT developers, and shown in Exhibits 1 and 2, below, present fuel economy and state-of-charge for both the Toyota Prius and the Honda Insight under a variety of driving cycles.

Clearly these results are excellent. While there are no comparable results on emissions available, we should understand that when fuel consumption is predicted accurately, then given the relatively straightforward conversion to the combustion process, even with tailpipe captures, emissions are generally accurately modeled as well.

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Exhibit 1
Toyota Prius Results

Drive cycles	Fuel consumption Mpg		Percent difference	State of charge		Percent difference
	Test	Simulation		Test	Simulation	
Japan 10-15	44.9	45.1	0.4	0.580	0.583	0.5
EUDC	44.0	43.8	0.4	0.605	0.593	2.0
FHDS	48.2	46.7	3.2	0.571	0.573	0.3

Exhibit 2
Honda Insight Results

Drive cycles	Fuel consumption mpg		Percent difference	State of charge		Percent difference
	Test	Simulation		Test	Simulation	
Japan 10-15	57.9	58.8	1.5	0.610	0.611	0.4
NEDC	60.6	60.2	0.6	0.602	0.583	3.6
FHDS	74.2	75.3	1.4	0.588	0.589	0.2
FUDS	58.3	57.8	0.8	0.706	0.720	2.0

3. DUTY CYCLES THAT HAS BEEN USED

In many countries world-wide, there is a growing interest in the use of alternative fueled buses. This is especially true in those cities where environmental issues are coming to the fore and where there are older and historic buildings adversely affected by emissions. The purpose of our overarching project is to assess the status of alternative fuel technologies to see which are applicable, in general, to the Israeli market and, in particular, to the major cities in Israel.

Our goal is to look at the current status of the results from testing of existing fleets of alternative fueled vehicles now on-going in the United States to assess outcomes and see if the vehicles can effectively be employed in Israel. In particular we are studying the following issues:

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- # environmental benefits (emissions of particulates, NO_x, CO/CO_2, unburned hydrocarbons)
- # economic benefits
- # ability to integrate new systems into existing fleets
- # maintainability of the new systems
- # fuel availability, as applicable
- # safety issues - maintenance and personnel
- # passenger comfort and desirability (for example, low floor vs. high floor vehicles)
- # duty cycle consequences
- # vehicle cost factors
- # potential return on investment

Technologies we assess are those that have had rigorous evaluations so that a real data base can be developed for use in Israel. In addition we will need to evaluate these technologies in the Israeli environment and duty cycles so that adequate prediction of performance can be obtained. Clearly, the best way to do so, short of purchasing vehicles, is through simulation.

In this effort we take the point of view of the naive user. This is one who comes to ADVISOR and wishes to apply it directly without burrowing into the details of MatLab files or the simulation itself. That is, we wish to simply apply ADVISOR to current experimental results, evaluate the results and then see if they can be used to predict performance directly or just predict trends qualitatively.

The source of test data for this effort comes from a detailed experimental effort to measure bus performance and emissions. The Northeast Advanced Vehicle Consortium initiated the testing of hybrid-electric buses to demonstrate the energy efficiency and emission performance of "State of the Art" hybrid-electric heavy-duty vehicles with respect to late model conventional diesel heavy-duty vehicles and alternative fuel CNG buses. An independent team of engineers and scientists facilitated the evaluation consisting of personnel from M.J. Bradley & Associates and West Virginia University. Project participants included transit operators from Boston, Massachusetts and New York City who own and operate the buses. Several original equipment bus manufacturers, engine manufacturers and hybrid drive system manufacturers were on hand to assure that the testing was uniformly conducted and reviewed.

Emissions measured over a variety of driving cycles included: nitrogen oxides, carbon monoxide, carbon dioxide, organic compounds and particulate matter. Fuel economy for each vehicle was also determined.
For the study presented here, two buses were simulated to compare to the data from Ref 1.

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Exhibit 1 summarizes the basic characteristics of these buses:

Exhibit 1
Forty-foot buses tested

Bus OEM	Bus Chassis	Drive	Engine / Model year	After-treatment
Nova BUS	RTS	3 speed	DDC Series 50 / 1998	Oxidation catalyst
Orion	VI	LMCS hybrid	DDC Series 30 / 1997 & 1998	NETT particulate filter trap

The testing encompassed several different bus cycles. Those relevant to our study are shown in Exhibits 2 and 3 and discussed briefly below.

The central business district (CBD), which appeared as the Society of Automotive Engineers (SAE) recommended practice J1376, is commonly used to evaluate transit buses; it is included as one the many driving cycles available from within ADVISOR. The CBD cycle (see Exhibit 2) is typically used to evaluate transit buses and is made up of 14 identical sections containing an acceleration to 20 mph, a cruise at 20 mph, braking to a stop, then dwell. The total cycle covers 2.0 miles over 600 seconds. While the CBD cycle is repeatable from a driver in the loop standpoint, it has several drawbacks. The acceleration rate is fixed which tends to favor buses with five speed transmissions and larger engines. The cycle is dominated by the 20-mph cruise, which penalizes buses that are not geared for optimum efficiency at that particular speed. The deceleration from 20-mph is twice as fast as the acceleration to 20-mph, 4.5 seconds versus 9 seconds, which is not typical of actual in-use driving. The average speed for the CBD cycle is 12.6 mph, generally faster than that observed by most transit operations.

As a consequence and despite its adoption by the SAE, this test cycle often does not seem to accurately reflect actual service routes in many transit districts. Therefore, additional cycles (as following described) were used in this study for which experimental results are available.

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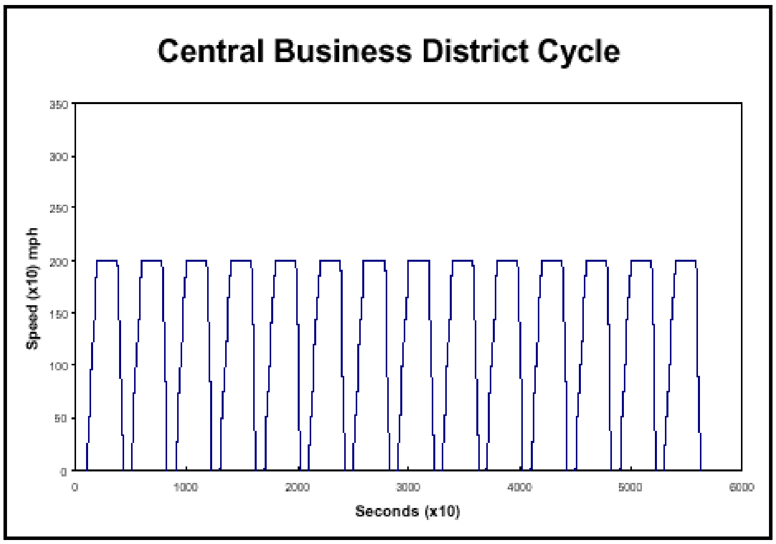
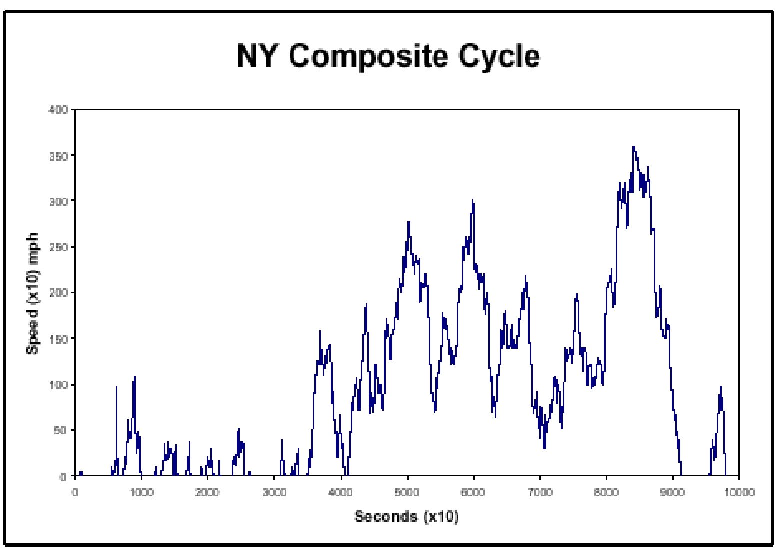
Exhibit 2: CBD Bus Cycle
Exhibit 3: NY Composite Bus Cycle





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The New York City Composite cycle, also available with ADVISOR, (see Exhibit 3) comprises acceleration and deceleration rates over a wider range of variation than the CBD. The NY Composite cycle represents a mix of inner city and urban transit bus use that allows for the bus to reach and sustain greater speeds. The average speed of the NY Composite cycle is 8.8 mph. It may be noted that it is an extremely difficult cycle for both the driver and the bus itself to follow accurately due to the large number of rapid speed changes (indeed we found that as well in the ADVISOR results). Buses that are powerful enough to follow the cycle are penalized by following a difficult cycle while less powerful buses effectively cheat the cycle, getting better fuel economy as a result. In any case most transit operators would suggest that actual operations (and thereby performance) likely lies between the Composite and the CBD. For design purposes, then, these are useful for our validation, and by extension, for our prediction study.

Following are described additional duty cycles used in this study to comply with experimental data provided by bus transit companies operating hybrid buses mainly in USA.

OCTA (Orange County Transit Authority) Test Cycle

The OCTA bus cycle is derived from real bus operating data and reflects a wide variety of accelerations, decelerations and cruise operations. In this way the cycle more closely imitates the variety of operation found during real bus use. Use of the OCTA cycle is in keeping with the trend of employing real world cycles that closely mimic real vehicle operation for emissions factor development. Figure 4 graphically represents one OCTA cycle.

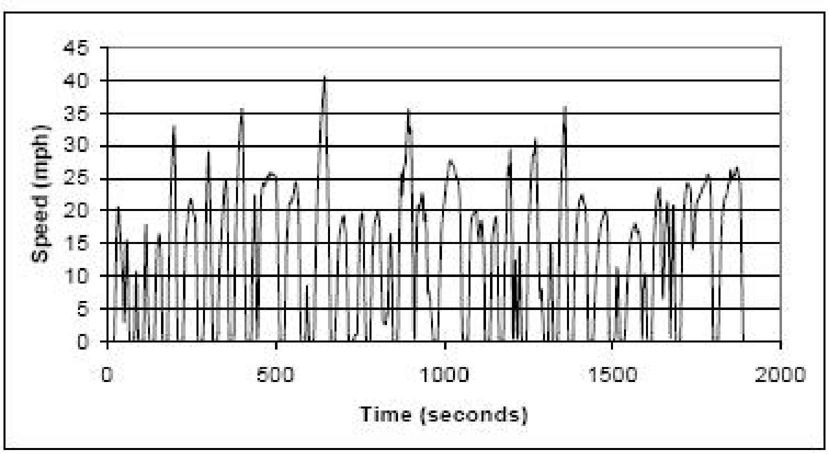

Figure 4. Orange County Transit Authority Cycle

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Manhattan Test Cycle

The recommended lower speed operation cycle is the Manhattan Cycle, which is representative of transit bus operation in city service. The Manhattan Cycle (Figure 5) was developed by West Virginia University from data logged from buses in operation in New York City.

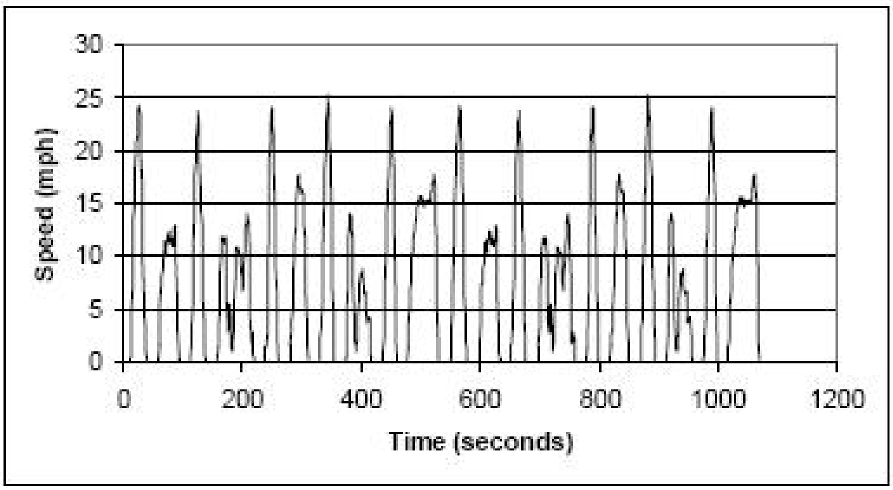

Figure 5. Manhattan Cycle

Two additional cycles were used in the test project; these were the Braunschweig and the ADME-RATP Parisian bus cycle which are illustrated in the Figures below.

According to the Dieselnet website the Braunschweig City Driving Cycle cycle was developed at the Technical University of Braunschweig. It is a transient driving schedule simulating urban bus driving with frequent stops. The ADME-RATP Paris cycle was developed by the Environment and Security Department of the Parisian Public Transport together with INRETS. The objective of the Paris effort was to develop a cycle representative of real world driving conditions in Paris.

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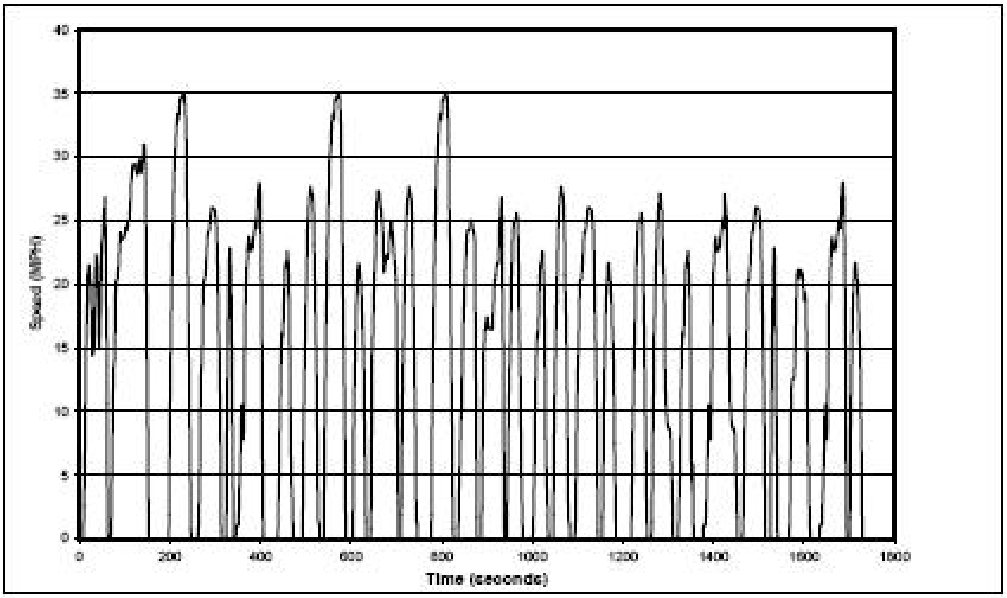

Figure 7 Braunschweig Cycle

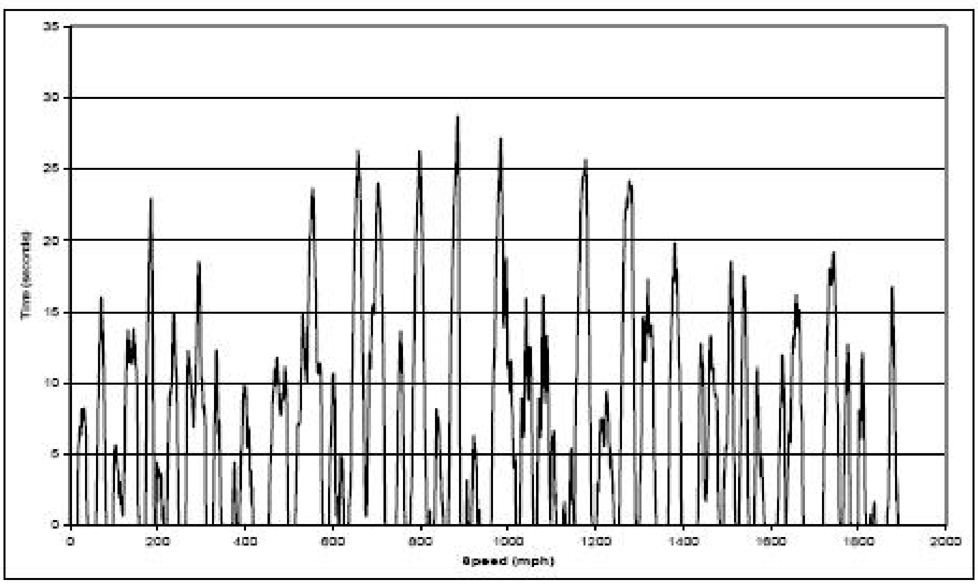

Figure 8 ADEME-RATP Paris Cycle

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Now we turn to the application of ADVISOR. Perhaps the easiest way to see our input data (again from the point of view of the naive user) is to look at ADVISOR displays directly. Note that we use three configurations for comparative purposes. The first (Exhibit 4) is used to predict fuel consumption for the standard diesel. Unfortunately the engine map from ADVISOR does not provide emissions data. We developed a second, with a scaled up engine, to use for the emissions validations (Exhibit 5). The last is a hybrid electric (Exhibit 6). All employed catalytic converters with appropriate power train controls. Note also that each case was run for four complete cycles.

Results are shown in Exhibits 7 and 8, for the standard diesel and the hybrid, respectively. Note that each exhibit displays the data separately for the CBD cycle and for the New York Composite cycle. For performance and emissions, inspection of these results suggests the following:

Fuel economy is well modeled. Comparative results indicate about a 10% difference between ADVISOR and the experiments.

For the standard diesel, CO results are poor; there is a significant understatement of these emissions. For the hybrid case, experimental emissions are about half those of ADVISOR. Note that errors between the vehicles are in different directions: the standard diesel underpredicts, the hybrid overpredicts.

Particulates are not modeled well for either vehicle on either cycle.

Unburned hydrocarbons (HC) are reasonably well modeled by ADVISOR. This is particularly true for the hybrid.

NOx is very well modeled. Results seem to follow measurements accurately.

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Exhibit 4Standard diesel — fuel use model

Exhibit 5
Standard diesel — emissions model

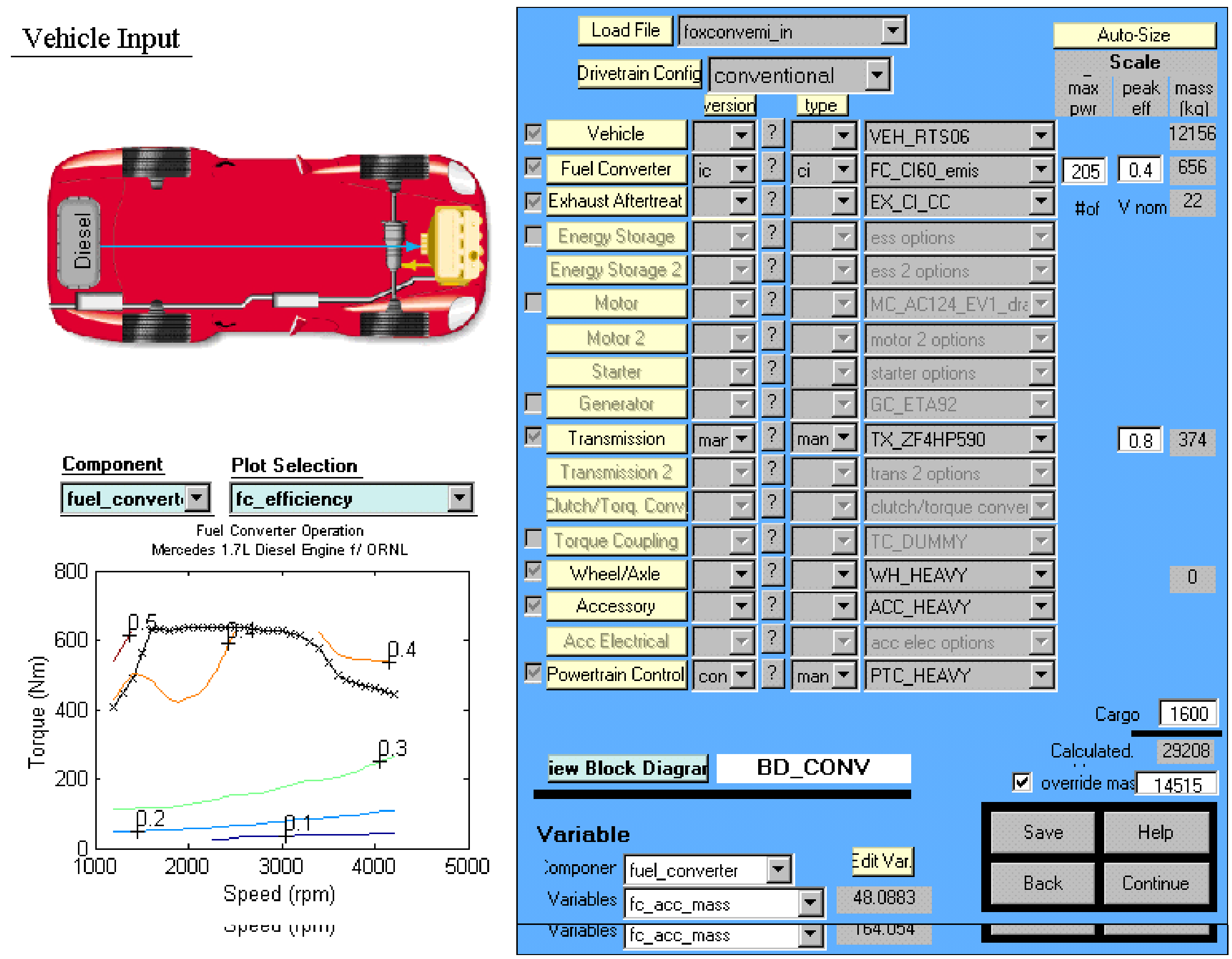

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Exhibit 6
Hybrid electric model

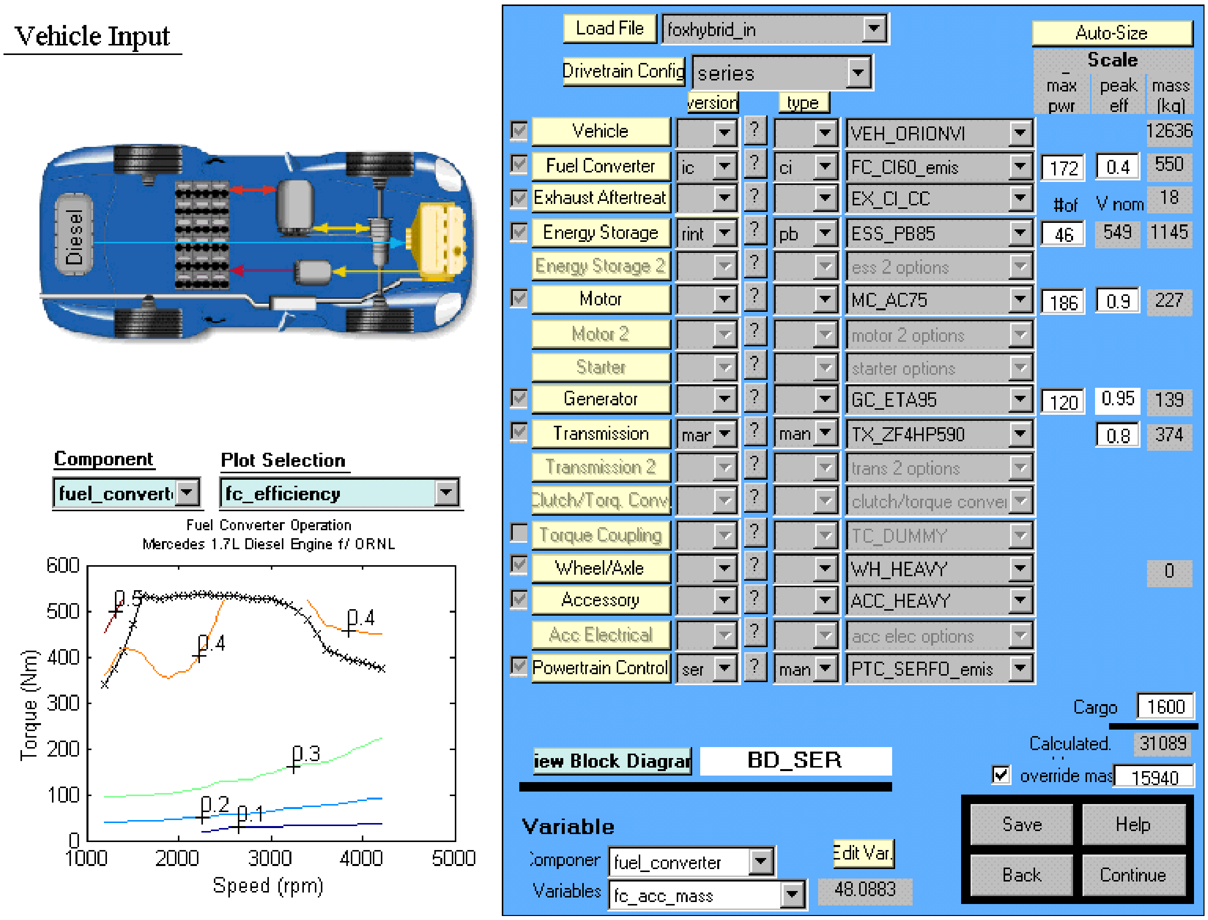

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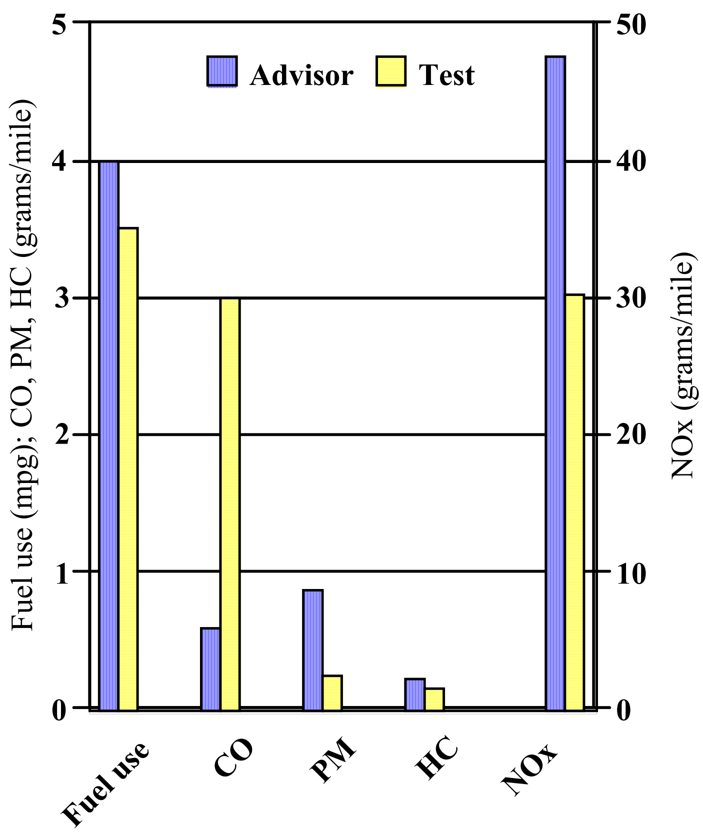
Exhibit 7
Validation Performance and Emissions Results
Standard Diesel

CBD Cycle



NYC Composite

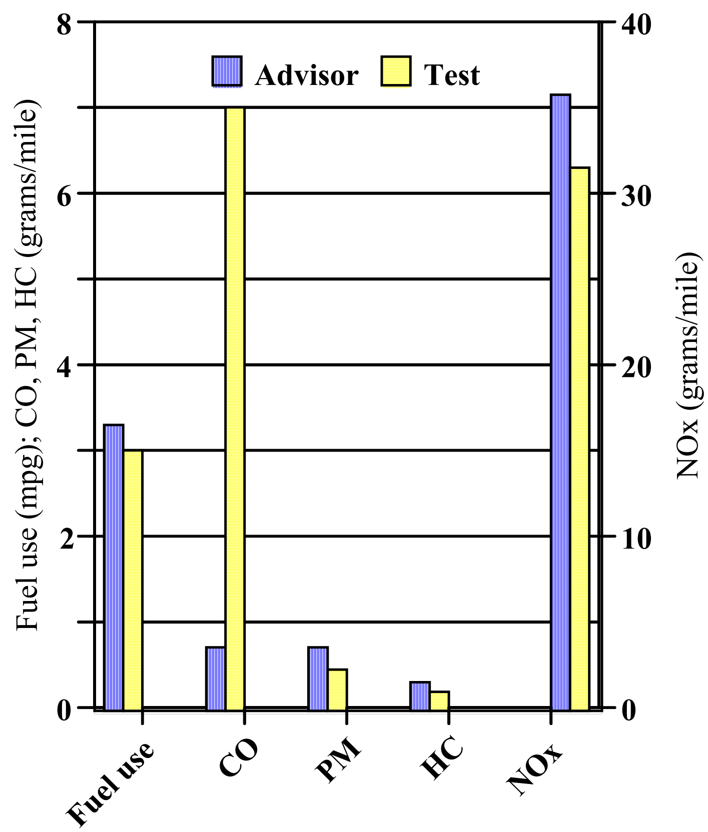
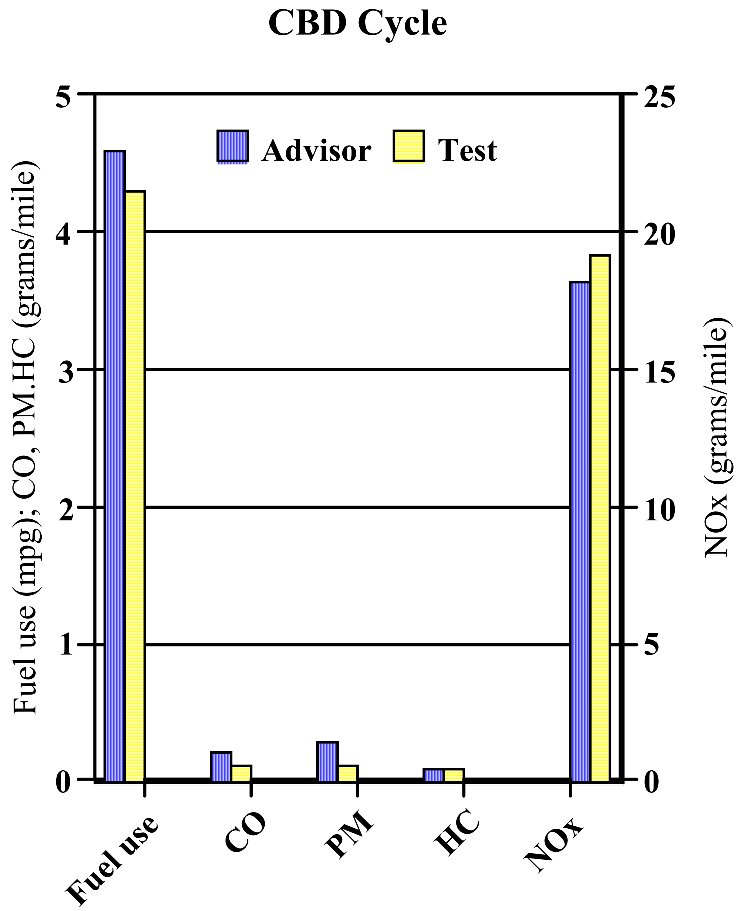
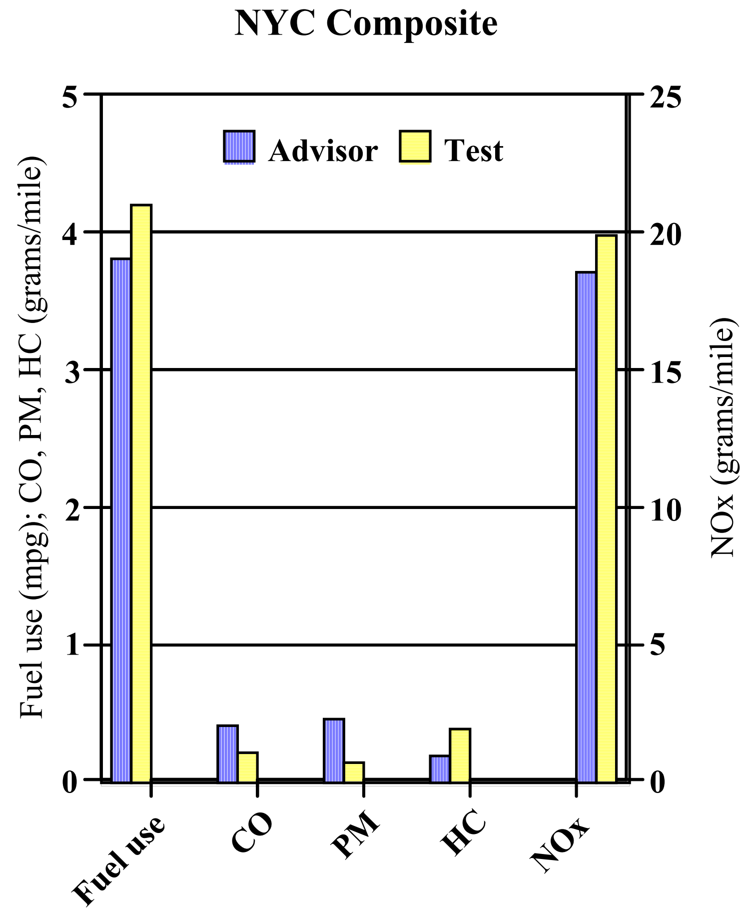


Exhibit 8
Validation Performance and Emissions Results
Hybrid Electric





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#

Finally we return to the original motivation for this effort and look at some results that may be considered typical of the major cities in Israel, Tel Aviv and Jerusalem. For the former, given its location on the Mediterranean, it would appear to be adequately modeled with the cycles shown earlier. And the trends developed there can be safely used for evaluating buses for them.

Jerusalem presents a different picture. Here grade is critical because of the nature of the topography and typical bus routes. For our purposes, in this preliminary assessment and to develop trend information, we present some data with the New York Composite cycle and the hybrid electric vehicle. We used two types of grade input. The first is a constant grade of 2% (available from within ADVISOR itself); the second is a variable grade shown in Exhibit 9 and developed by us. Comparative emissions and fuel use are shown in Exhibit 10, using the results from Exhibit 8 as the base. As might be expected, the effect of grade is considerable and bears heavily on choices for vehicles.

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Exhibit 9
Variable Grade Model

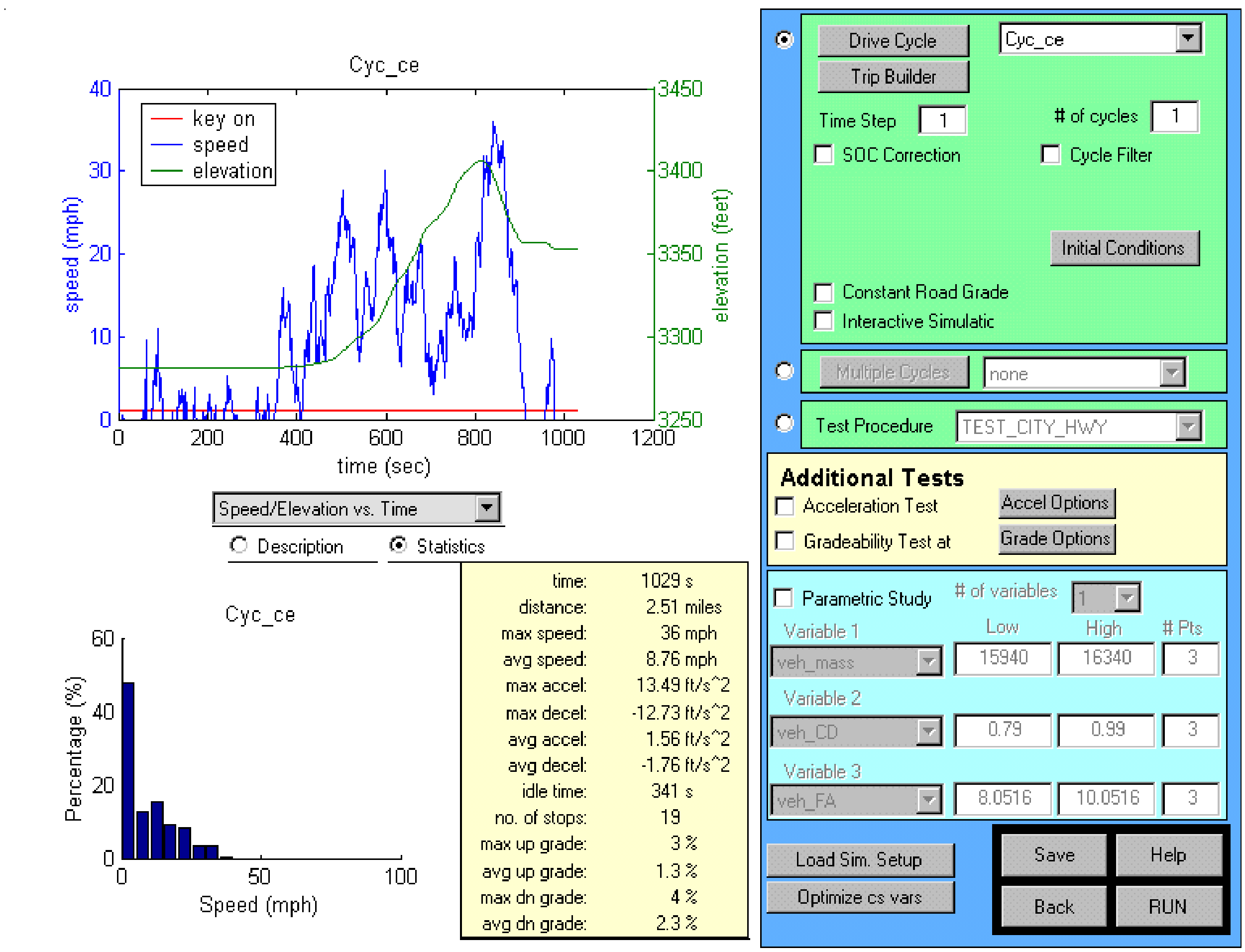

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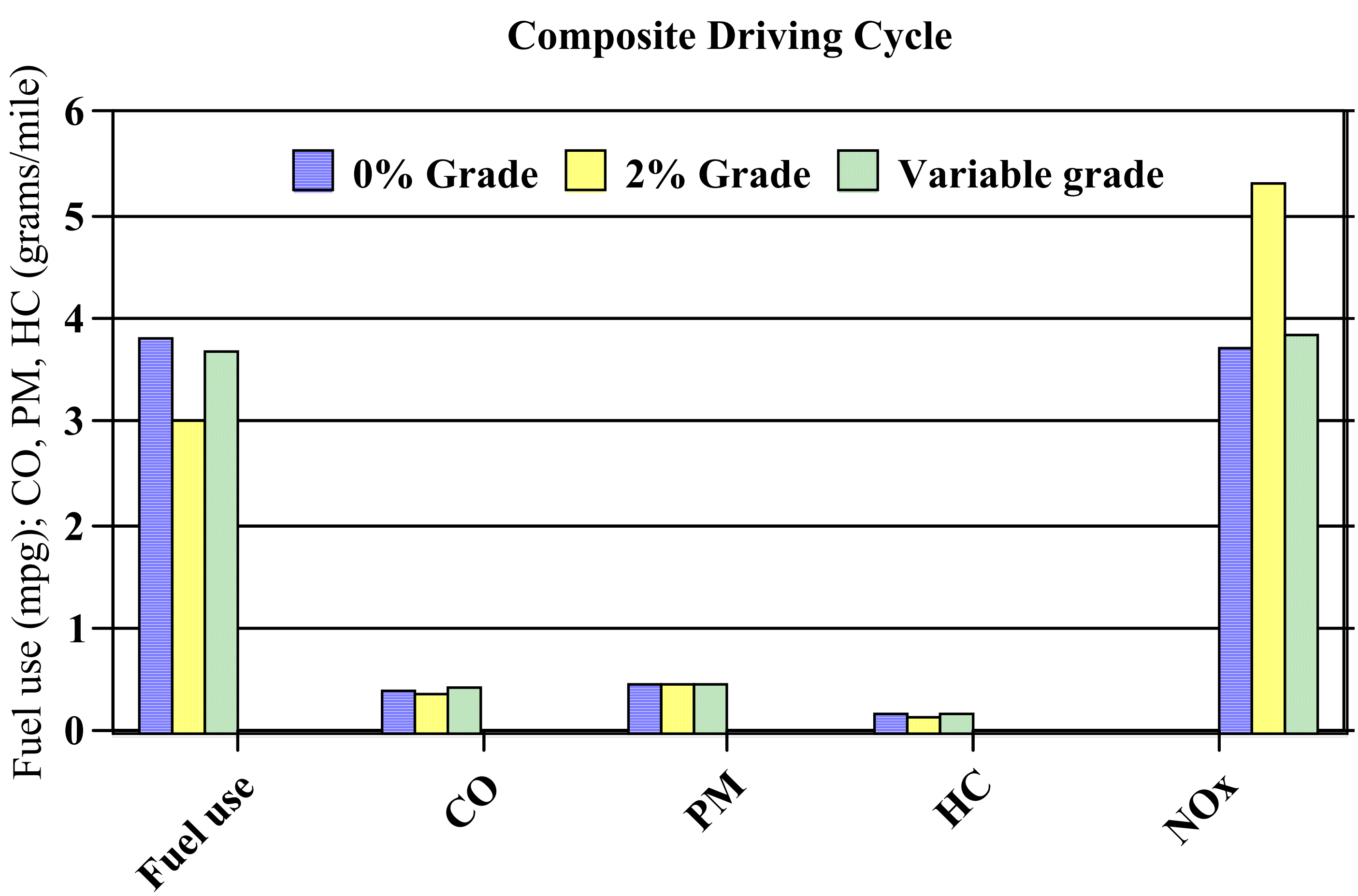
Exhibit 10
Effect of Grade - Hybrid Electric



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To further add a realistic look at what happens in a city like Jerusalem with its many hills, we further modified the grade component of both the cycles discussed earlier. Reference should be made to Exhibits 11 and 12 where grade versus distance is shown for the CBD cycle. Two basic cases were modeled: In the first (Exhibit 11), there is a single peak for the cycle; in the second (Exhibit 12), we have modeled a typical ride up and down hills in the two or so miles for the cycle. In addition we also doubled the maximum elevation driven. This gave us a set of four runs for comparison purposes. And although not shown here, the same four cases were introduced to the New York Composite Cycle.

Results for the hybrid electric bus are provided in Exhibits 13 and 14 for the CBD and Composite Cycles respectively. Fuel economy and emissions results are what might be expected and lead again to the suggestion that, at least qualitatively, ADVISOR provides appropriate trend information for evaluating bus performance and the advantages of selecting one type of vehicle over another.

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Exhibit 11

CBD Cycle
One peak in each cycle

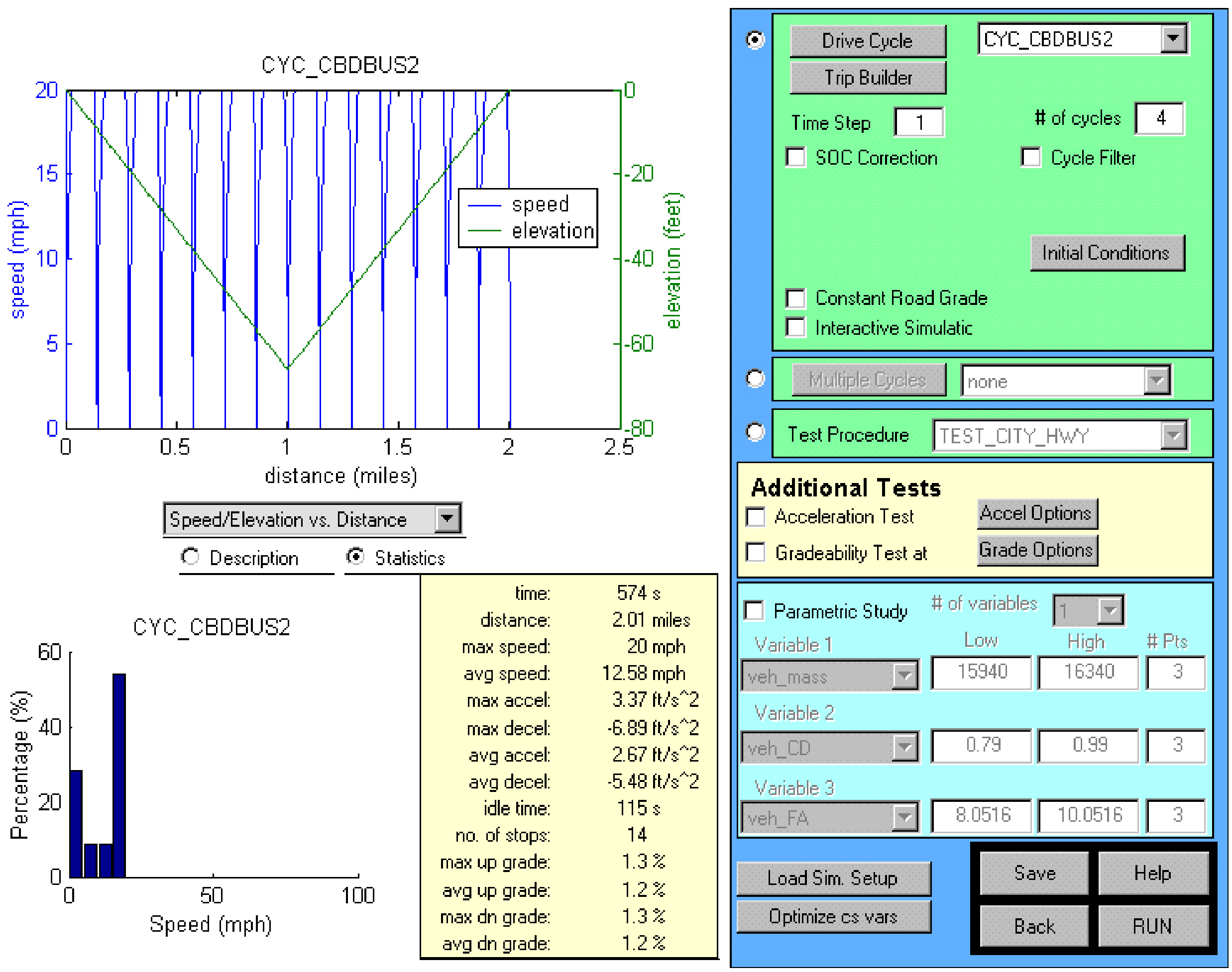

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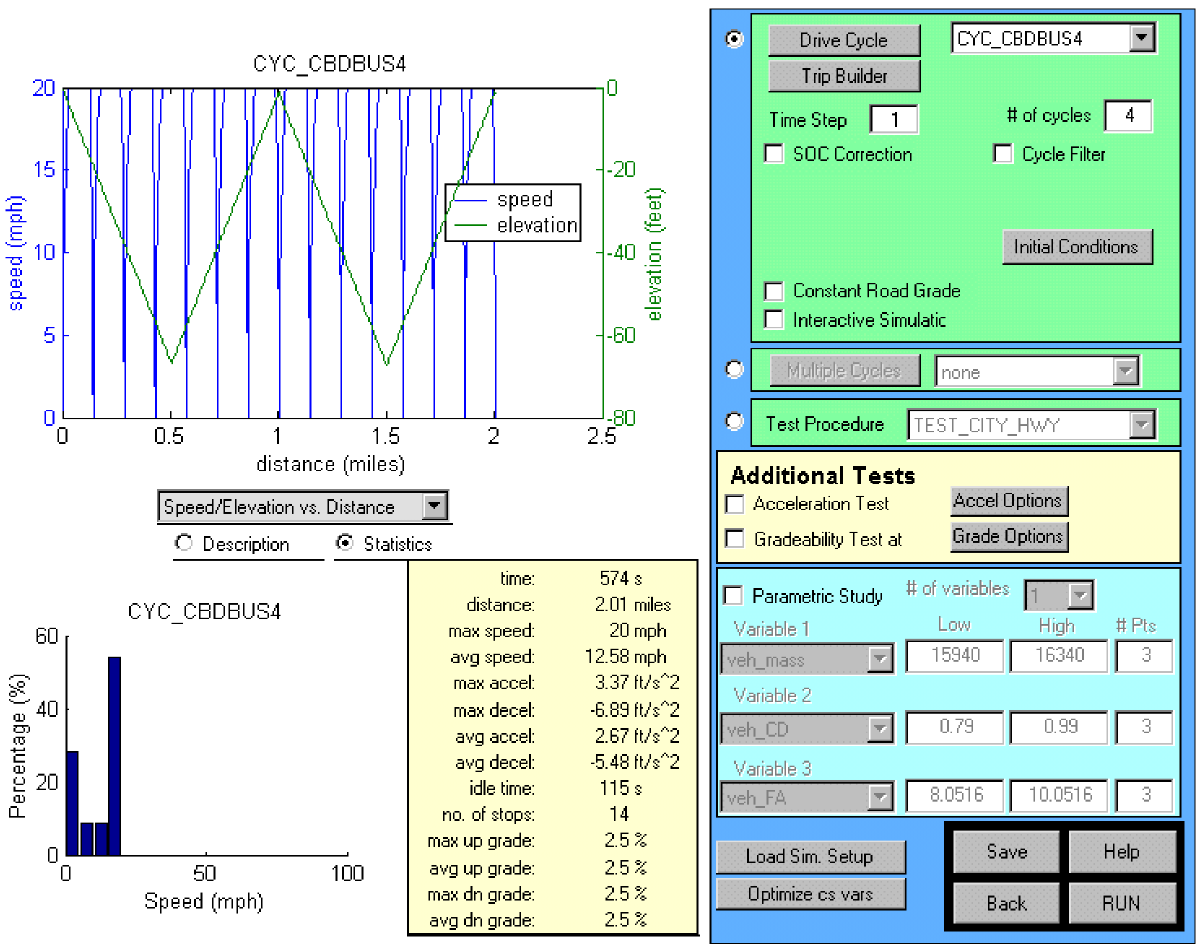
Exhibit 12
CBD Cycle
Two peaks in each cycle



THE NEW YORK COMPOSITE TWO PEAKS CYCLE IS CHOOSEN IN THIS REPORT TO BE THE JERUSALEM DUTY/ DRIVING CYCLE

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Exhibit 13
CBD Results

Approximate maximum elevation (feet)	Number of grades per cycle	Fuel use (mpg)	HC (grams/mile)	CO (grams/mile)	NOx (grams/mile)	PM (grams/mile)
0	0	4.6	0.083	0.205	18.179	0.287
65	1	4.3	0.087	0.212	19.133	0.295
65	2	3.8	0.085	0.216	22.704	0.299
130	1	3.9	0.088	0.220	22.142	0.302
130	2	3.7	0.090	0.226	23.324	0.305

Exhibit 14
New York Composite Cycle Results

Approximate maximum elevation (feet)	Number of grades per cycle	Fuel use (mpg)	HC (grams/mile)	CO (grams/mile)	NOx (grams/mile)	PM (grams/mile)
0	0	3.8	0.175	0.406	18.614	0.465
75	1	3.7	0.179	0.415	18.927	0.468
75	2	3.6	0.185	0.427	19.552	0.472
150	1	3.5	0.187	0.423	20.157	0.472
150	2	3.4	0.192	0.445	20.879	0.482

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4. STREETCAR SIMULATION

At Millbrook, UK, buses are tested on a dynamometer against a 159 London bus in normal service that has been captured in its entirety for simulation purposes. Test hybrid buses are "driven" to follow the actual bus journey. This typical London route starts at Brixton and travels through the heart of the city before traveling out the other side to a similar London suburb. At least 3 satisfactory runs are undertaken to arrive at an average performance. The buses are usually weighted to represent 50% average occupancy.

Buses are measured for NOx; CO; HC; particulates; fuel consumption/CO2. Since Millbrook undertakes most of the conventional diesel bus tests as well, they are able to provide comparative data of hybrid improvement against conventional equivalents.

Incidentally, the Las Vegas hybrid were at Millbrook from July 2007 for 3 months gone through a complete homologation testing routine, including the hybrid performance testing. Development work there is dynamic and therefore they made regular emission improvements. However the initial Millbrook test results were for the single and double deck hybrids:

	Single deck [12.5t]	**Double Deck [18t]**
NOX	1.43 Gms per K.	6.7 gms per K
HC	0.012 " "	0.006 " "
CO	0.051 " "	0.095 " "
Particulate	0.079 " "	0.02 " "
Fuel Cons.	10.65 Miles Per Gal.	8.65 Miles Per Gal

Actual performances will always be route specific dependent on topography, how drivers use/abuse the bus, the stop/go characteristics of the vehicle, national/local government political restrictions, etc. For example London originally insisted that the diesel engine always tick over rather than cut out when not needed.

Experience to date suggests that actual emissions performance are likely to be good but less compared to test conditions. For example they can achieve 9.0-9.5 mpg on a single deck against the conventional equivalent of c.7.0 mpg but less than the Millbrook results of 10.6. All the factors listed above play their part, particularly how well the driver is trained and adheres to hybrid bus driving conditions.

Following are the preliminary evaluated results regarding the STREETCAR hybrid BRT tests (emissions and fuel savings) in MILLBROOK. At the beginning is presented the bus chassis as considered in our program and picture of the bus.

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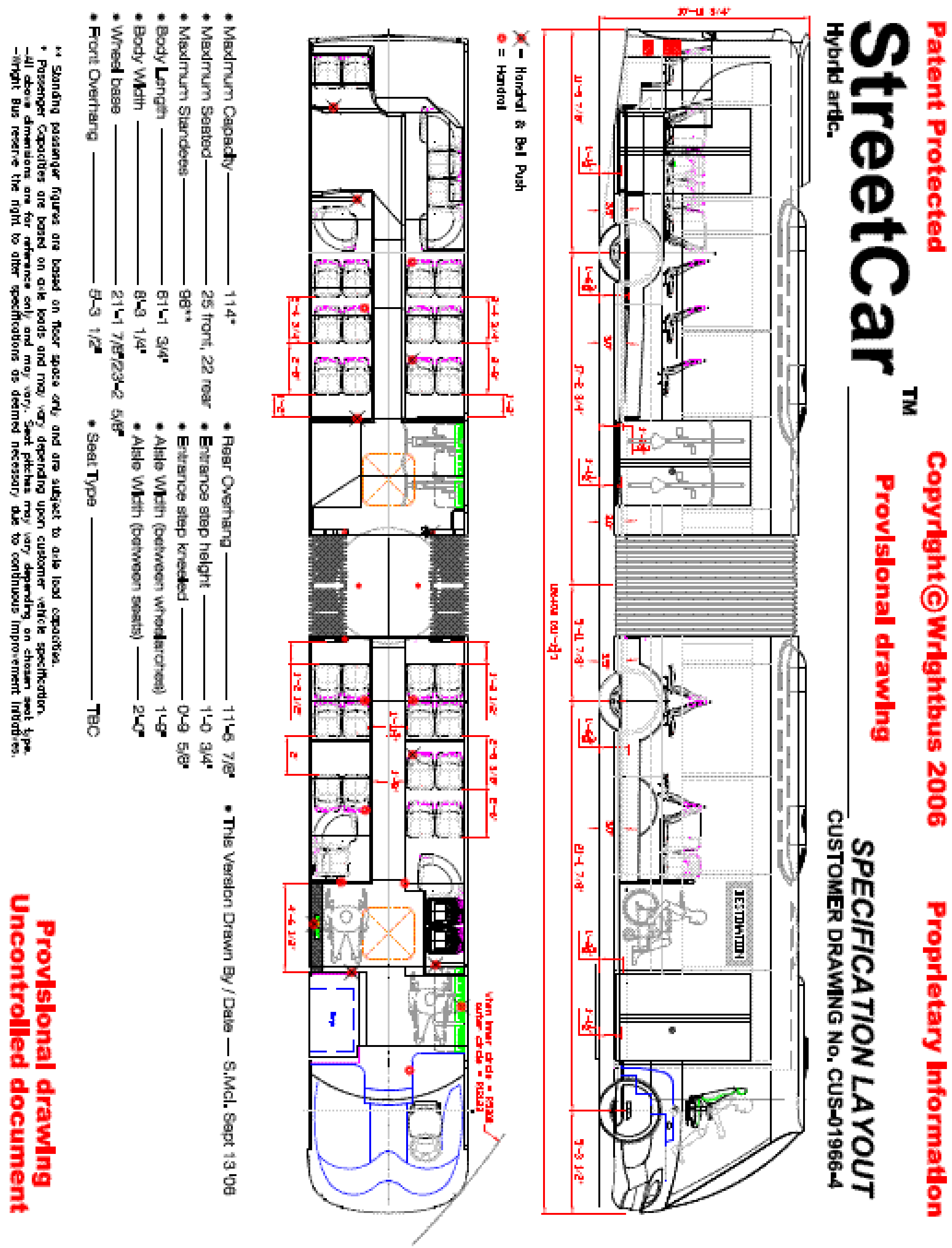

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62 Ft Stylized Articulated — Wrightbus StreetCar RTV

Hybrid diesel-electric, multiple door-loading vehicle that creates a "wow" feeling

Dimensions

Length 61.5 ft
Width 99 in
Height 129 in

Curb Weight

30,500 lbs

Price

$950,000 – 1,250,000

Capacity, Floor and Doors

- Seats - 45
- Flat floor
- 3 doors curb side, possible door locations on roadside
- 13 ½" floor height at doors

Electronics Options

- Traffic signal priority
- On-board fare machinery
- AVL & CCTV

Comfort Items and Amenities

- Ergonomic driver's interior
- Tinted, double-glazed windows
- LED lighting

Propulsion and Fuel

- Hybrid diesel-electric
- ISE
- Cummins ISL engine

Fuel **Storage**

- TBD

Construction	• Bolted aluminum system • Modular construction
Customers	• RTC Las Vegas

Website: www.the-wright-group.com Contact: info@wright-bus.com

Revised: June, 2006

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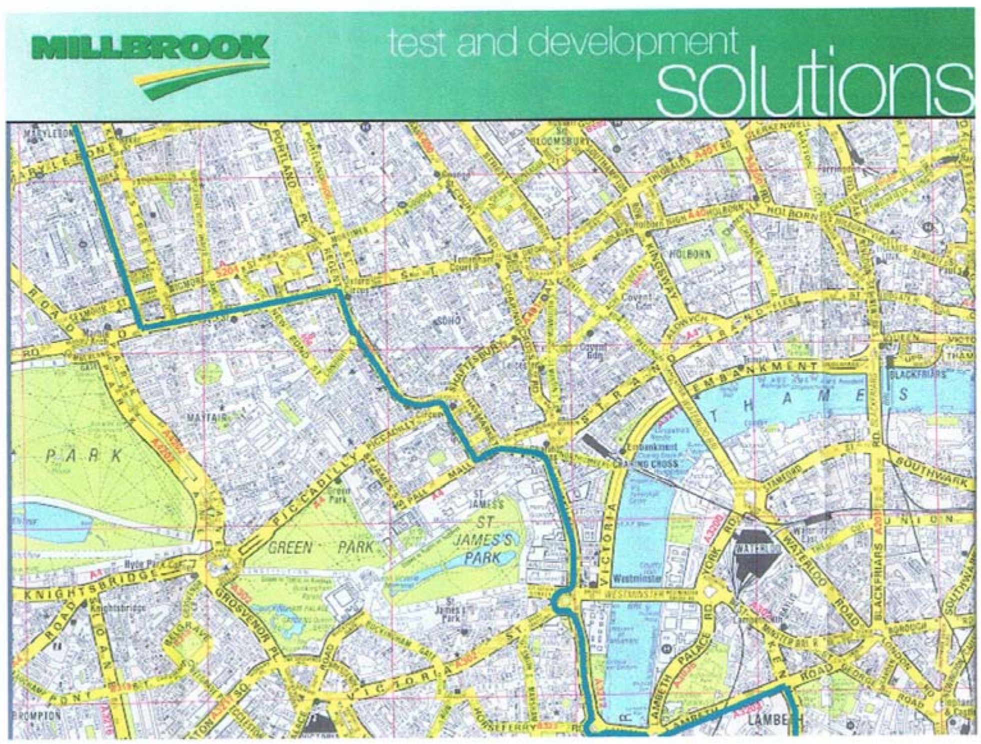

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MBK 297

MILLBROOK VEHICLE EMISSIONS LABORATORY MK45 2JQ

MLTB CYCLE DIESEL EMISSIONS TEST SUMMARY SHEET

Customer:	Wrightbus Limited
Customer Address:	Fenaghy Road, Ballymena, County Antrim, BT42 1PY
Test Purpose:	Development

Vehicle No:	*WRIGHTBUSDDHYBRID*	Site No.	2
Vehicle Type:			
Engine:	*Z19DTH (CDTI)*		
Transmission:	*Manual*		
Fuel Type:	*Pump Diesel*		
Millbrook Project No:	*9453*		

DYNAMOMETER SETTINGS	
INERTIA	15158 kg
F°	148.41 N
F^1	18.876 N/kmh
F^2	-0.23100 N/kmh ^{2}
F^3	0.003877 N/kmh ^{3}

Test No. *ML02007962*		*12-Oct-06*						Fuel Cons
Odo		UNITS	HC	CO	NOx	CO2	PM	(Carb Bal)
Phase 1	*Outer London*	grammes	0.050	1.919	47.202	5550.6	0.429	32.12
Phase 2	*Inner London*	grammes	0.011	0.066	23.605	2575.7	0.182	38.31
Combined result		g/km	0.007	0.218	7.779	892.8	0.067	litres/100km
								33.85

Test No. *ML02007963*		*12-Oct-06*						Fuel Cons
Odo		UNITS	HC	CO	NOx	CO2	PM	(Carb Bal)
Phase 1	*Outer London*	grammes	0.041	0.139	40.025	4788.5	0.368	27.86
Phase 2	*Inner London*	grammes	0.014	0.132	20.510	2220.2	0.156	33.33
Combined result		g/km	0.006	0.030	6.695	775.2	0.058	litres/100km
								29.39

Test No. *ML02007964*		*12-Oct-06*						Fuel Cons
Odo		UNITS	HC	CO	NOx	CO2	PM	(Carb Bal)
Phase 1	*Outer London*	grammes	0.049	0.266	53.442	5936.4	0.515	34.56
Phase 2	*Inner London*	grammes	0.018	0.070	22.942	2468.8	0.164	36.95
Combined result		g/km	0.007	0.037	8.446	929.4	0.075	litres/100km
								35.23

FULL LOADS

AVERAGE PERFORMANCE OVER 3 TESTS on 18T: 0.007 : 0.095 : 7.67 : 865.8 : 0.067 : 2.83K per L = 8.07M. per gallon

Simulation for a 26 ton Articulated: 0.010 0.137 : 11.0 1250 0.096 5.59M per gallon 1.96 K per L.

COMMENTS

Compiling Engineer:	DATE:	Approving Engineer:	DATE:

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5. EVALUATION AND SIMULATION RESULTS

For each bus selected for the simulation, we need the following typical data:

Complete specification of the drive train:

a) Parallel or series
b) Internal Combustion engine, size and manufacturer (for diesel and for bio-diesel)
c) Battery type, manufacturer, number and sizes
d) Special control strategies if any

Complete specification of the vehicle itself:

a) Weight
b) Height
c) Length
d) Drag coefficient

As pointed out earlier, many component manufacturers have offered their specifications to the PSAT development community so that vehicles can be modeled quite easily. On the other hand new data can be inserted into the component data base so that just about all hybrid buses would be available for simulating in the current project.

The final requirement is the establishment of the driving cycle. We will likely employ standard ones for these simulations as well as those perhaps more typical of the duty cycle in Israel.

With all these specified, results that can be expected include, but are not limited to:

- Fuel consumption
- State of charge
- Exhaust temperature range
- Cumulative heart rejected
- Oxygen flow rate
- Particulate matter emission mass flow rate
- Nitrogen oxide emission mass flow rate
- Carbon dioxide mass flow rate
- Unburned hydrocarbon emission flow rate

Such results will permit:

- Selection of a bus optimized for a particular driving cycle
- Selection of the optimal bus for all driving cycles
- Prediction of savings in fuel that might be realized with the introduction of a hybrid bus
- Prediction of savings in emissions that might accrue with the selection of a hybrid bus

All together these results will make an important step to the selection of appropriate hybrid electric buses for Israel and assist the Ministry of Transportation in its efforts.

Following are presented the specifications, evaluation and simulation results of the New Flyer DE60LF -BRT hybrid bus.

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60 Foot Stylized Articulated — New Flyer DE60LF-BRT

Step low-floor bus with advanced styling, diesel electric drive and amenities

Dimensions
Length 61 ft
Width 102 in
Height 136 in
(with roof mount battery pack)

Curb Weight
43,700 lbs

Price
Call for Quote

Capacity, Floor & Doors

- Seats – 47 to 53 (75% forward facing)
- Perimeter seating available
- Standees - 53
- Flip out wheelchair ramp
- Low floor at all doors, rear riser
- 3 to 5 Slide and Glide Doors

Comfort Items and Amenities

- 5.1 mpg fuel economy with Hybrid
- Up to 40% better mileage than diesel alone
- 50% reduction in NOx
- 90% reduction in PM, CO, HC
- Quiet, smooth take off
- Also available in 40 ft configuration

Electronics Options

- GPS, AVL
- Automatic Passenger Counting
- Luminator Destination Signs
- Onboard Routing/Travel Time/Stop
- Voice Messaging
- Video Surveillance
- Onboard Diagnostics
- Vehicle Monitoring
- Transit Signal Priority
- Automatic Guidance Ready

Propulsion and Fuel

- Diesel (Allison, ZF, Voith)
- Diesel Hybrid-Electric (Allison EP50 with 330 hp CAT C9)
- Gasoline Hybrid-Electric (ISE)

Fuel	Economy	Storage
ULSD	3.8 mpg	1 floor tank
ULSD H-E	5.1 mpg	1 floor tank

Construction

- Welded monocoque carbon steel using high tensile steel plate and tubing

Customers and Applications

- Lane Transit (Eugene, OR)
- Greater Cleveland RTA (Cleveland, OH)

Website: www.newflyer.com — Contact: buses@newflyer.com

Revised: June, 2006

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CBD	CO g/mile	CO_2 g/mile	NO_X g/mile	HC g/mile	PM g/mile
Conventional	1.77	4587.0	19.67	0.12	0.1010
E^P System	1.55	2991.0	14.44	0.03	0.0030
Improvement	14%	53%	36%	300%	3267%

OCTA	CO g/mile	CO_2 g/mile	NO_X g/mile	HC g/mile	PM g/mile
Conventional	2.29	4579.0	18.91	0.03	0.0500
E^P System	1.55	3001.0	13.51	0.03	0.0240
Improvement	48%	53%	40%	0%	108%

Manhatten	CO g/mile	CO_2 g/mile	NO_X g/mile	HC g/mile	PM g/mile
Conventional	3.13	6714.0	29.58	0.04	0.3800
E^P System	2.81	3771.0	18.12	0.05	0.0030
Improvement	11%	78%	63%	-20%	12567%

Jerusalem	CO g/mile	CO_2 g/mile	NO_X g/mile	HC g/mile	PM g/mile
Conventional	1.66	3446.0	14.74	0.13	0.1870
E^P System	1.07	2614.0	12.11	0.07	0.1080
Improvement	55%	32%	22%	186%	73%

ADEME-RATP	CO g/mile	CO_2 g/mile	NO_X g/mile	HC g/mile	PM g/mile
Conventional	1.77	6193.2	30.27	0.20	0.1511
E^P System	1.77	3999.1	21.00	0.08	0.0619
Improvement	0%	55%	44%	150%	144%

Braunschweig	CO g/mile	CO_2 g/mile	NO_X g/mile	HC g/mile	PM g/mile
Conventional	0.76	4576.4	21.85	0.12	0.0959
E^P System	0.77	2956.3	15.11	0.03	0.0335
Improvement	-2%	55%	45%	300%	186%

The results presented above are valid for the Allison hybrid transmission installed in this bus.

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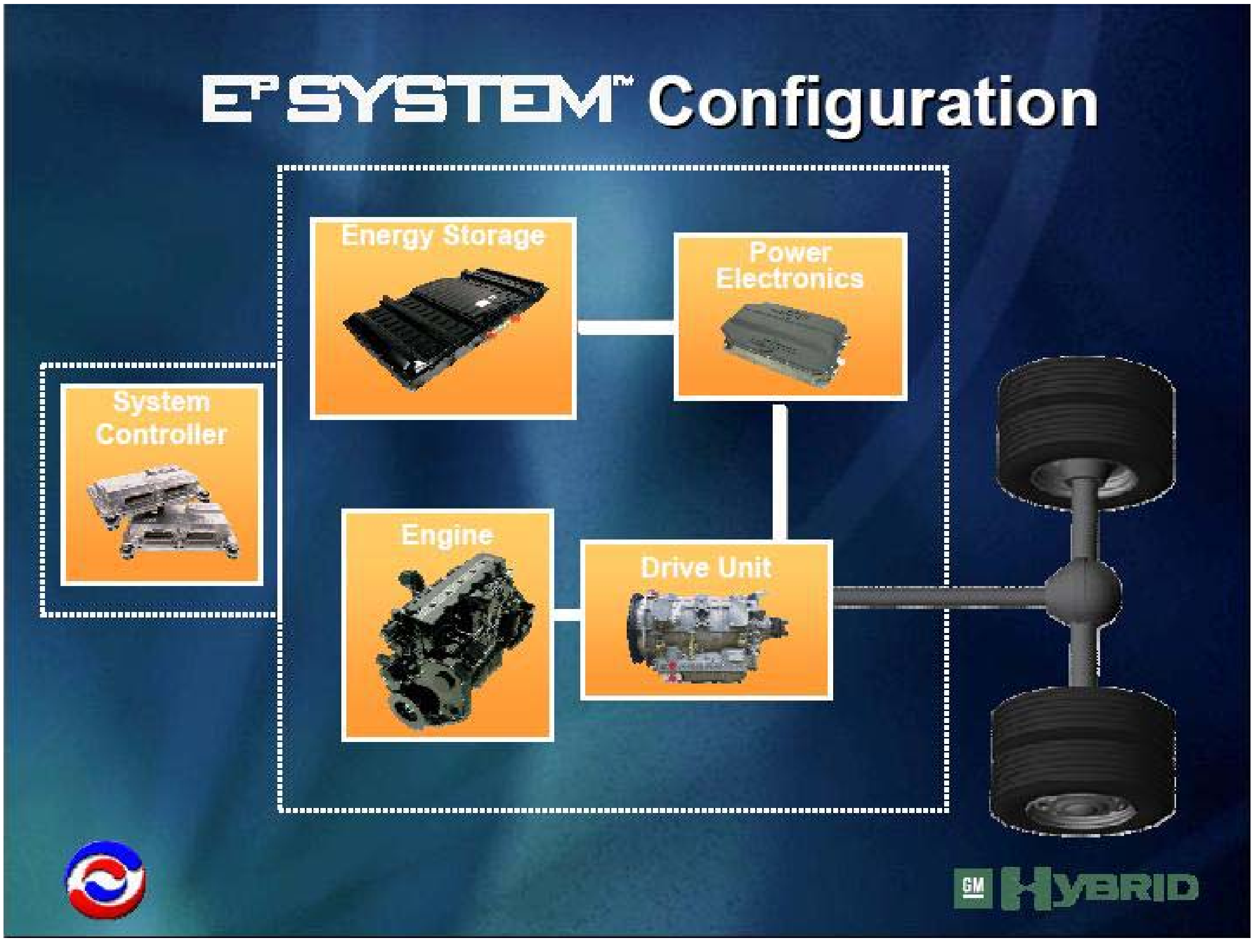
Following is a short description of the Allison hybrid system.



The evaluated and simulated results obtained for the New Flyer DE60LF-BRT bus could be relevant also for other hybrid buses like the New Flyer DE60LF and the APTS Phileas 60 BRT bus as described following. In the final report we will summarize also the final evaluation and simulation results to be obtained for the STREETCAR, the APTS Phileas 60 and the NABI 60 LFW articulated bus.

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60 Foot Specialized BRT — APTS Phileas 60

Full low-floor bus with European exterior/interior styling and magnetic guidance system

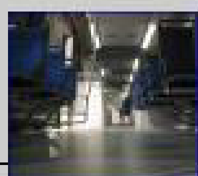
Dimensions
Length 60.5 ft
Width 100 in
Height 123 in

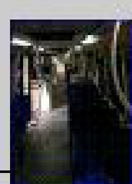
Curb Weight
35,300 lbs

Price
Call for Quote

Capacity, Floor & Doors

- Seats - 29 (forward facing)
- Standees - 111 (6 passengers/m2)
- Full low-floor (100%)
- 3 doors, on one side, or 6 doors on both sides





Comfort Items and Amenities

- Futuristic and innovative styling
- Fully guided as tram or manually driven as bus
- Spacious and flexible interior (seats, doors)
- High quality passenger information, audible and visual systems
- Flexibility, large doors both sides
- Fully independent suspension
- Low interior and exterior noise levels
- All-wheel steering

Electronics Options

- GPS, AVL, APC, TSP, Surveillance
- Electronic fare payment
- Electronic automatic guidance until 50 mph with magnetic markers
- Automatic precision docking
- All-wheel steering

Fuel and Propulsion

- ULSD
- GM-Allison Parallel Hybrid–Electric Drive System
- Fuel economy is at least 25% greater than conventional European buses due to its hybrid element and light weight construction

Construction	• Lightweight corrosion-resistant monocoque body • Lightweight modular sandwich composite
Customers and Applications	• Region of Eindhoven, Netherlands – BRT • Region of Douai, France • License agreement with South Korea

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