



Development and Deployment of Generation 3 Plug-In Hybrid Electric School Buses

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Agenda

- ***Program Overview***
- ***Relevance***
- ***Approach/Strategy for Deployment***
- ***Technical Accomplishments and Progress***
- ***Collaborations and Coordination with Other Institutions.***
- ***Proposed Future Work/Activities***

Program Overview

Timeline

- October 2009 to September 2014

Budget

- \$20,030,696
 - \$7,153,644 Navistar
 - \$2,999,550 School Corps.
 - \$9,877,413 DOE
- Spend thru 2010: \$1,377,419

Vehicle Technical Barriers

- Cost
- Battery life.
- Availability of Components

Partners

- National Renewable Energy Laboratory.
- Oak Ridge National Laboratory.
- Arvin Meritor.

Objective

- *Develop* a plug-in hybrid school bus that
 - achieves at least *20 miles electric range*,
 - meets FMVSS requirements,
 - and is commercially acceptable,
- *Demonstrate* the performance and advantage of Plug-In hybrid technology through
 - Prototype evaluation of 2 system types, followed by a
 - 1-year field evaluation of *30 school buses*,in order to gain customer acceptance and reduce U.S. dependence on petroleum.

Relevance



- School Buses represent a fleet of over 200,000 vehicles operated within the United States.
- School Bus provides a platform to build public awareness and acceptance of electric propulsion.
 - Each School Bus serves up to 77 passengers.
- School Buses have daily drive cycles that match with plug-in hybrid .
 - Limited distance, repeatable routes.
 - high idle times.
 - Breaks between morning and afternoon routes, allowing plug-in charging twice per day.
- PHEV technology for school buses can easily be deployed to other class 6 and class 7 applications.

Approach/Strategy for Deployment

- Use simulation to predict system performance and to down-select from 12 to 2 candidate systems and to size motor and battery components. (complete)
- Competitively Bid Components from demonstrated heavy vehicle suppliers. (in progress)
- Build demonstration hardware. (4 school buses, consisting of 2 buses of 2 types).
- Evaluate performance of 2 system types.
- Based on test performance of 4 school buses, pilot build a 30-bus fleet, and Monitor the fleet for 1 year.

Approach/Strategy for Deployment

- Goal established to minimize battery size.
 - Battery Storage dominates PHEV system cost.
 - Power Requirements for less expensive “Energy Cells” rather than “Power Cells.”
- In order to improve cost, performance targets were challenged and revised with marketing and DOE input.
 - Reductions of electric speed and electric range provided for lower power and lower energy, and hence lower cost
 - 30 mile range reduced to 20 miles,
 - 45mph all-electric operation reduced to 25mph.
 - NREL school bus fleet monitoring under Advanced Vehicle Test Activity provided statistical data to confirm that these changes still satisfy customer needs.
- Using simulation to down-select to two alternatives now allows Navistar to focus resources rather than dividing resources among four concepts.
 - Dual Mode and Parallel Transmission systems available and demonstrated in market.
 - Status vs. cost targets is being evaluated in 2011 through competitive quotations.

Technical Accomplishments and Progress

- Simulation was completed for 12 system types utilizing 4 hybrid architectures and 4 combustion power plants.
 - Series 6.4L V8 engine
 - Pre-Parallel 4.8L I4 engine
 - Post-Parallel Generator Set
 - Dual Mode Microturbine
- Dual Mode and Parallel architectures prioritized.
 - Series and Gen-Set did not perform as well due to conversion efficiencies.
- Simulation and optimization support provided by Oak Ridge National Laboratory.

Technical Accomplishments and Progress

Powerplant selection

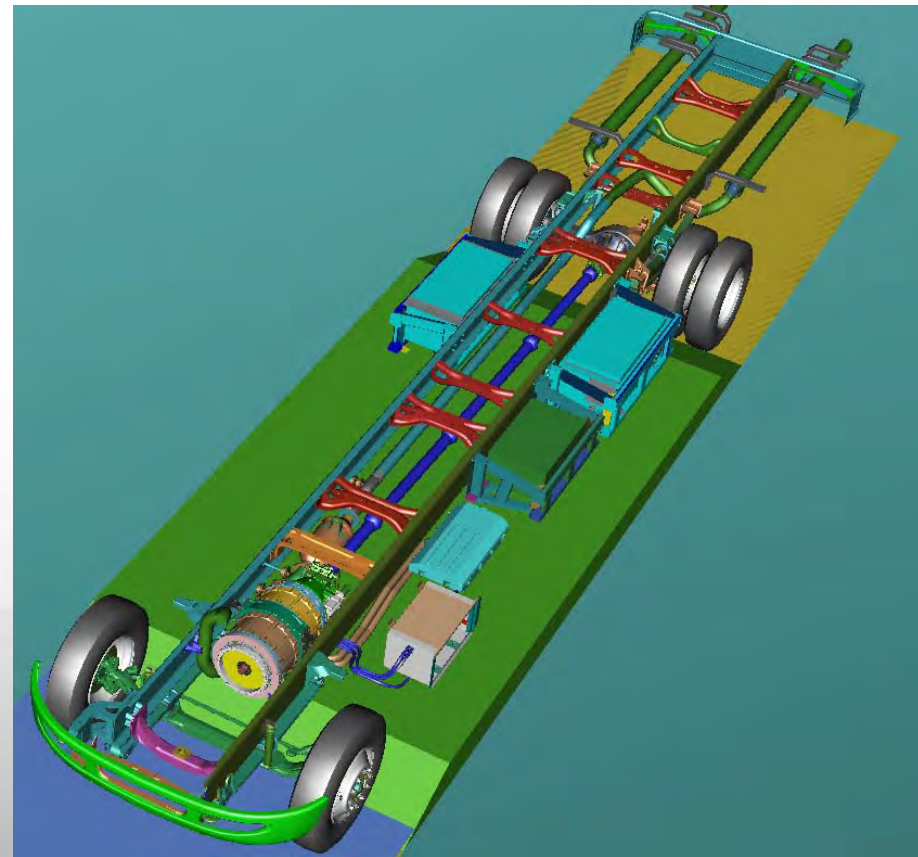
- Maxxforce7 V8 6.4L diesel engine
 - Engineering effort focused on developing present engine for idle start/stop and after-treatment operation at reduced duty cycle.
- MWM 4.8L I4 diesel engine
 - Smaller engine provided superior fuel economy results vs. options.
 - EPA-certified version not available in time for program.
- Diesel Generator Set
 - Did not identify gen set supplier with a product meeting EPA emissions.
 - Simulation showed gen-set fuel economy lower than alternatives.
- Microturbine
 - Simulation showed poor fuel economy due to thermal efficiency vs. internal combustion engines, and higher battery throughput.

Battery Technical Accomplishments

- Requirements for Battery Size compared through simulation.
 - Parallel architectures allow for reduced battery.
 - Blended control strategies offer battery advantages, but customers strongly desire “all electric” functionality.
- Lessons learned from Navistar E-Star vehicle being applied to Plug-In Hybrid bus.
 - Cold temperature effects on battery performance.
 - J1772 connection and Battery Charger integration.
 - High voltage distribution to accessories.
- Packaging Study of Drive and Battery completed.
- Requirements studied for commonality of battery modules for PHEV and EV applications.

PHEV School Bus Design Progress

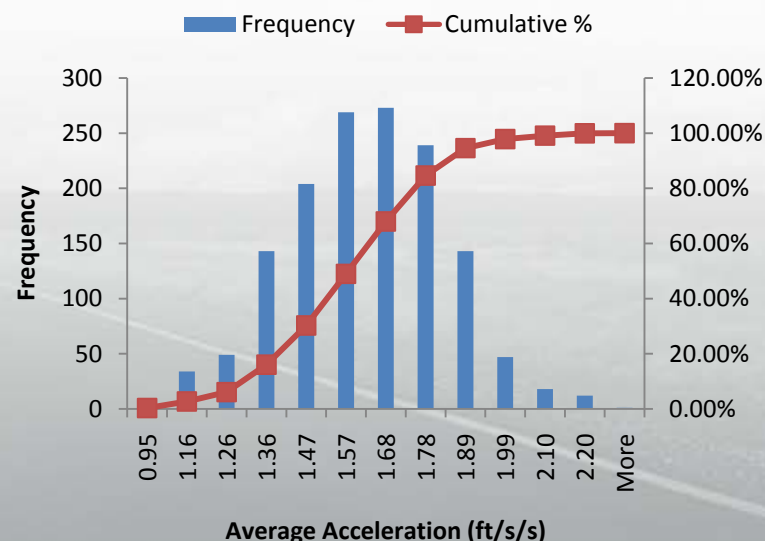
- PHEV Batteries placed on both sides of chassis.
- Dual Mode transmission model fitted.
- Weight distributed to front axle a concern.



Collaborations and Coordination with Other Institutions

- National Renewable Energies Laboratory collected data from 212 school buses operated in Washington state, Colorado, and California.
- NREL performed statistical analysis of the fleet data to determine key parameters.
 - Route Distance.
 - Idle Time.
 - Drive Cycle.
- Based on this data, the team was able to select drive cycle and to reduce battery size consistent with route length.

Route Average Acceleration Histogram



Collaborations and Coordination with Other Institutions

- The Oak Ridge National Laboratory completed Autonomie simulation of pre-transmission, post-transmission, and dual mode hybrid architectures
- Simulation data was based upon real-world battery and motor data received from SAFT and Remy.
- Based on this data, the team was able to rank fuel economy performance of the hybrid architectures.
 1. Dual Mode
 2. Parallel
 3. Series
 1. 4.8L I4 (Euro 4)
 2. 6.4L V8 (EPA 2010)
 3. 2.4L Genset (EPA Tier 4)

Proposed Future Work/Activities

Milestones	Start	Finish
PSDM Requirements	Feb 4, 2011	March 11, 2011
PT Simulation		March 29, 2011
Design Requirements Documents	Feb 25, 2011	April 7, 2011
Concept sheets	April 25, 2011	June 1, 2011
Detailed Design	June 20, 2011	July 29, 2011
Sourcing	June 2, 2011	July 1, 2011
Component Delivery	July 1, 2011	Sept 22, 2011
Simulate/Test/Verify	Sept 23, 2011	Feb 16 ,2012
Build	Feb 17, 2012	Feb 23, 2012

Summary

- Navistar originally proposed a program to develop and demonstrate up to 4 types of systems in hardware.
- Navistar and the Department of Energy's national labs have used fleet field test data and Autonomie simulation to compare several architectures and select hybrid directions based on their fuel economy and performance.
- Navistar's challenge in 2011 will be to design, procure, and integrate a dual mode hybrid drive system and a pre-transmission parallel hybrid drive system into 4 evaluation vehicles.

Technical Back-Up Slides



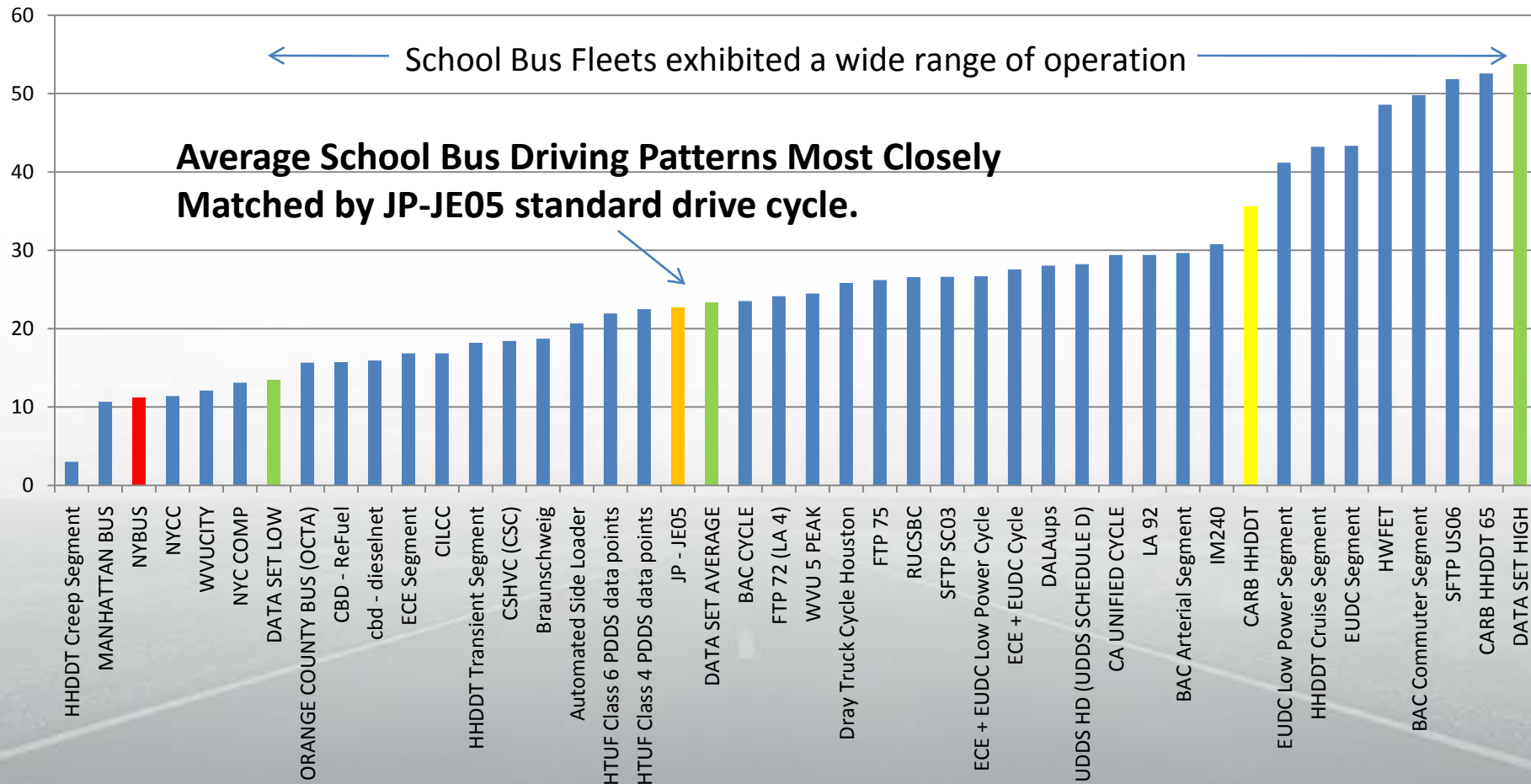
Recommended Test Cycles

- Cycle Selection for average cycle based on the average absolute percent difference between standard cycle and aggregate data set average.
- High/Low cycle selection focused on absolute percent difference between standard cycle and maximum/minimum driving metrics from data set. (i.e. for high aggressiveness cycle, we would want a cycle with higher stops/mile, higher Characteristic Acceleration, low Aerodynamic Speed, and Low Average Driving Speed, and low Maximum Driving Speed)
- Metrics selected based on a minimization of the average of % differences in select operating metrics
- List of selection metrics:
 - Average Speed (speed >0)
 - Maximum Driving Speed
 - Standard Deviation of Speed
 - Characteristic Acceleration
 - Aerodynamic Speed
 - # of Stops Per Mile
- Recommended test cycles:
 - JP-JE 05
 - RUSCBC
 - CSHVC (CSC)

Metric	DATA SET AVERAGE	JP - JE05	RUSCBC	CSHVC (CSC)
maximum driving speed (mph)	54.48	54.43	49.70	43.80
average driving speed (speed > 0, mph)	23.32	22.70	26.59	18.44
standard deviation of speed (mph)	14.12	15.94	16.05	13.06
number of stops per mile	1.73	1.62	1.44	1.95
characteristic acceleration (ft/s/s)	0.63	0.40	0.86	0.56
aerodynamic speed (ft/s)	47.63	51.31	51.88	40.66
kinetic intensity (1/mile)	1.63	0.80	1.68	1.79

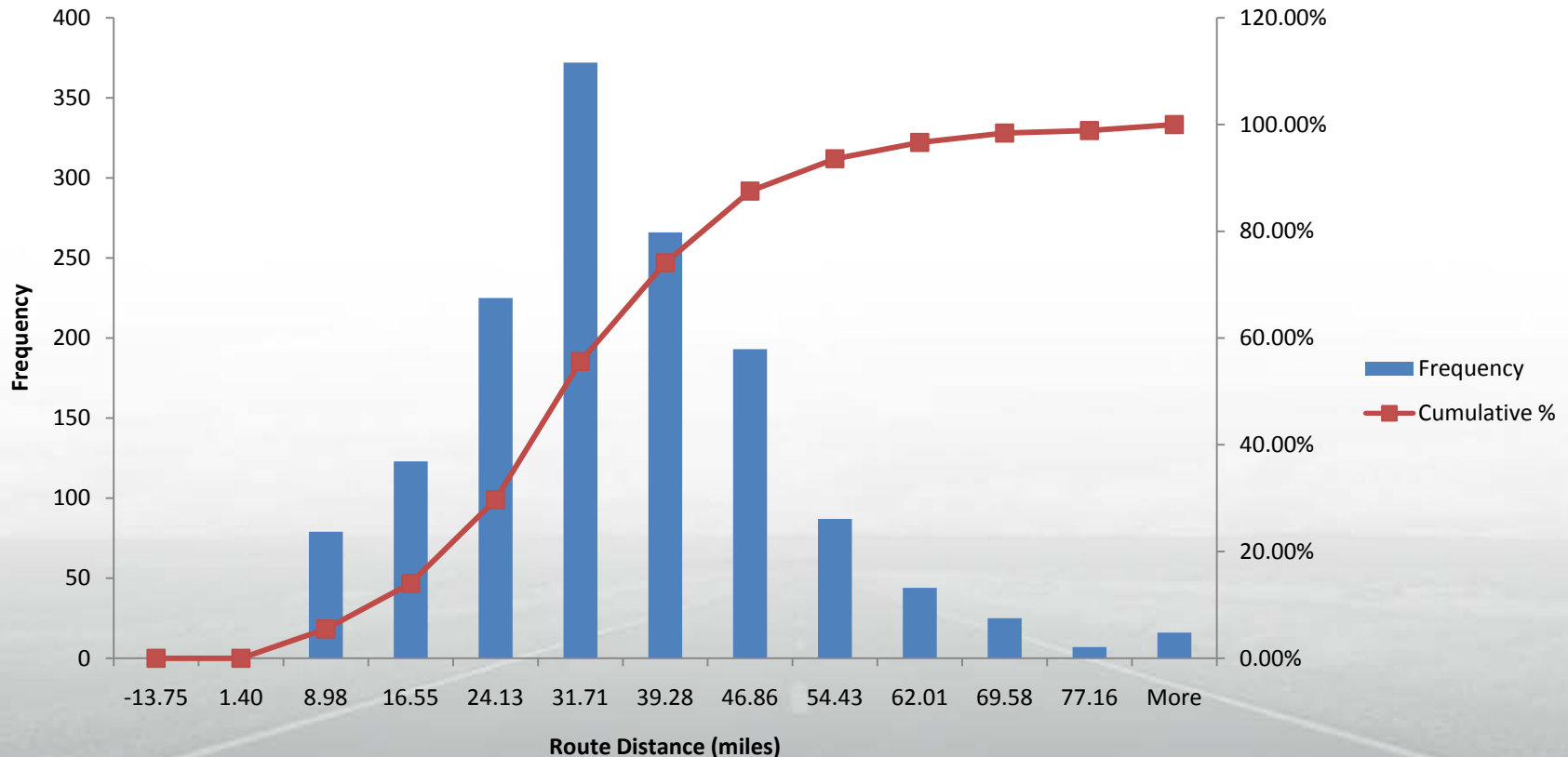
School Bus Statistics vs. Standard Drive Cycles

average driving speed (speed > 0, mph)



School Bus Route Distances

Total School Bus Route Driving Distance Distribution

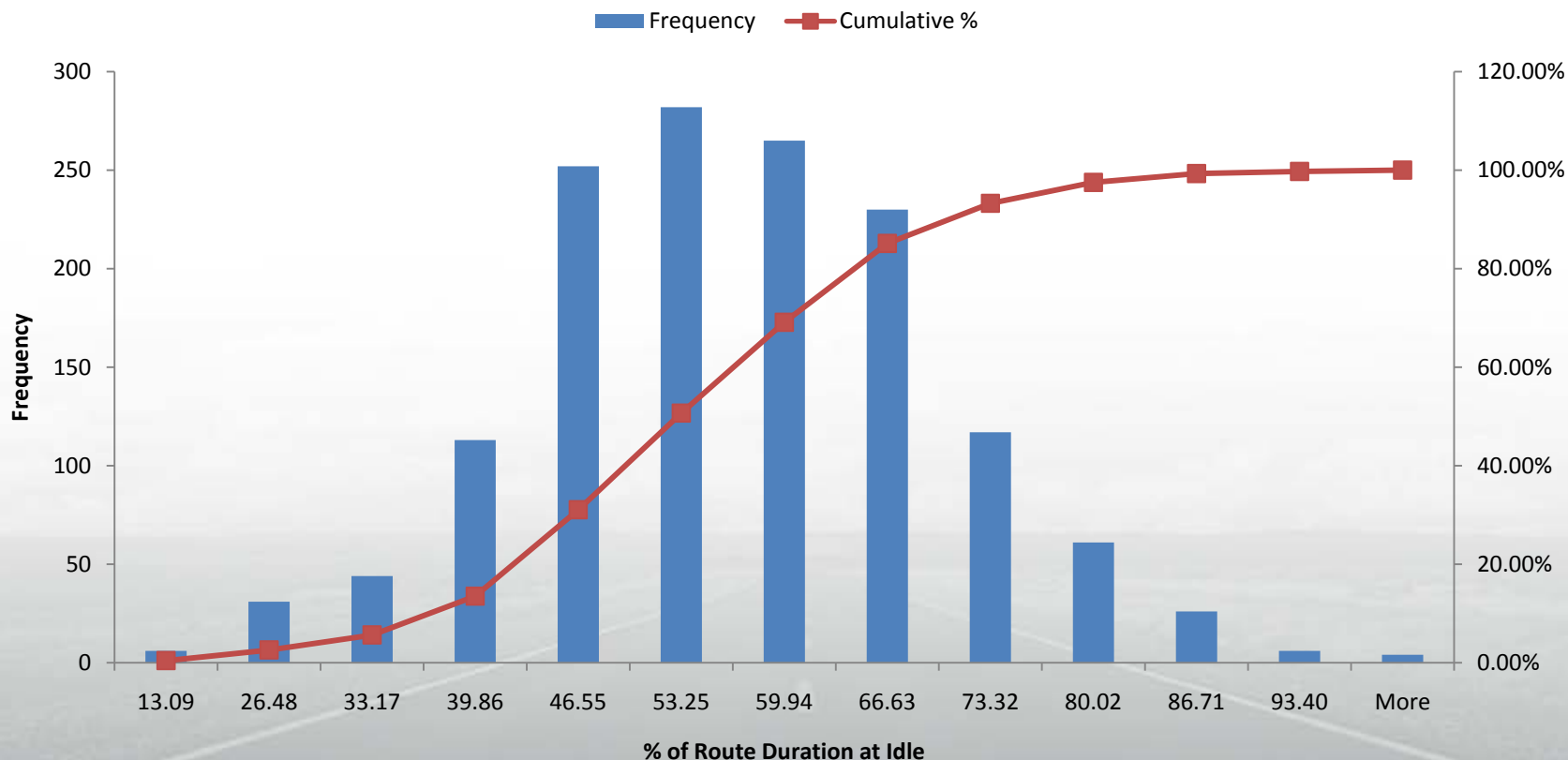


80% drive at least 40 miles. Average Route is 32 miles.

Based on 212 bus samples

School Bus Idle Statistics

Aggregate % Idle Histogram



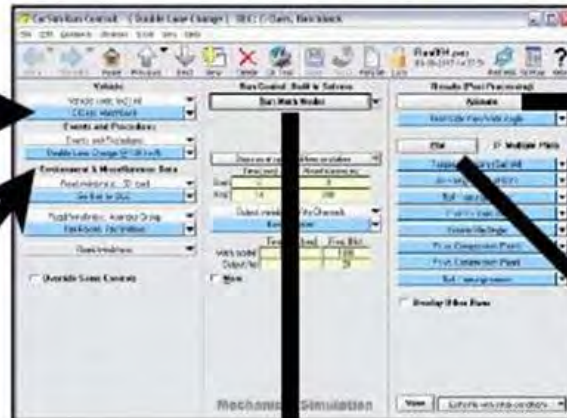
School buses spend over 50% of their run time at engine idle.

Navistar Truck Simulation Overview

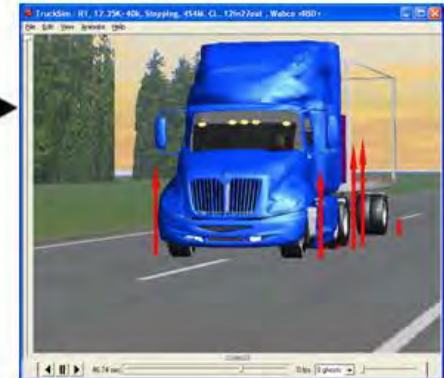
Vehicle properties



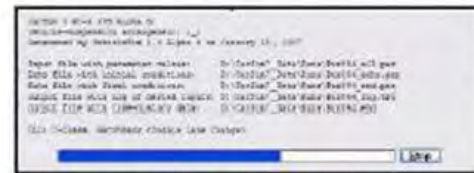
Home screen: Run Control



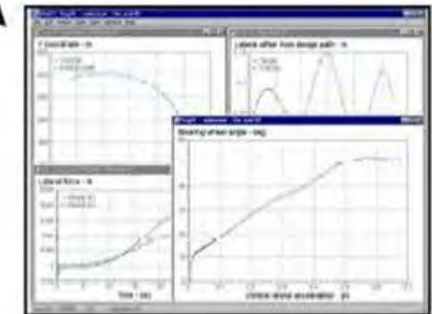
3D animator



Test conditions



VehicleSim solver



Engineering plotter

Navistar PHEV Concepts Investigated

Twelve configurations (2 Post Parallel, 4 Series, 2 Dual Mode, and 4 Pre-Transmission Parallel)

1a: Parallel Post Transmission with a MaxxForce7 Engine and Allison 2500 Transmission

1b: Parallel Post Transmission with a MWM I4 Engine and Allison 2500 Transmission

2a: Series with a MaxxForce7 Engine

2b: Series with a MWM I4 Engine

2c: Series with Tier 4 John Deere generator set.

2d: Series with Micro Turbine generator

3a: Dual Mode with a MaxxForce7 Engine

3b: Dual Mode with a MWM I4 Engine

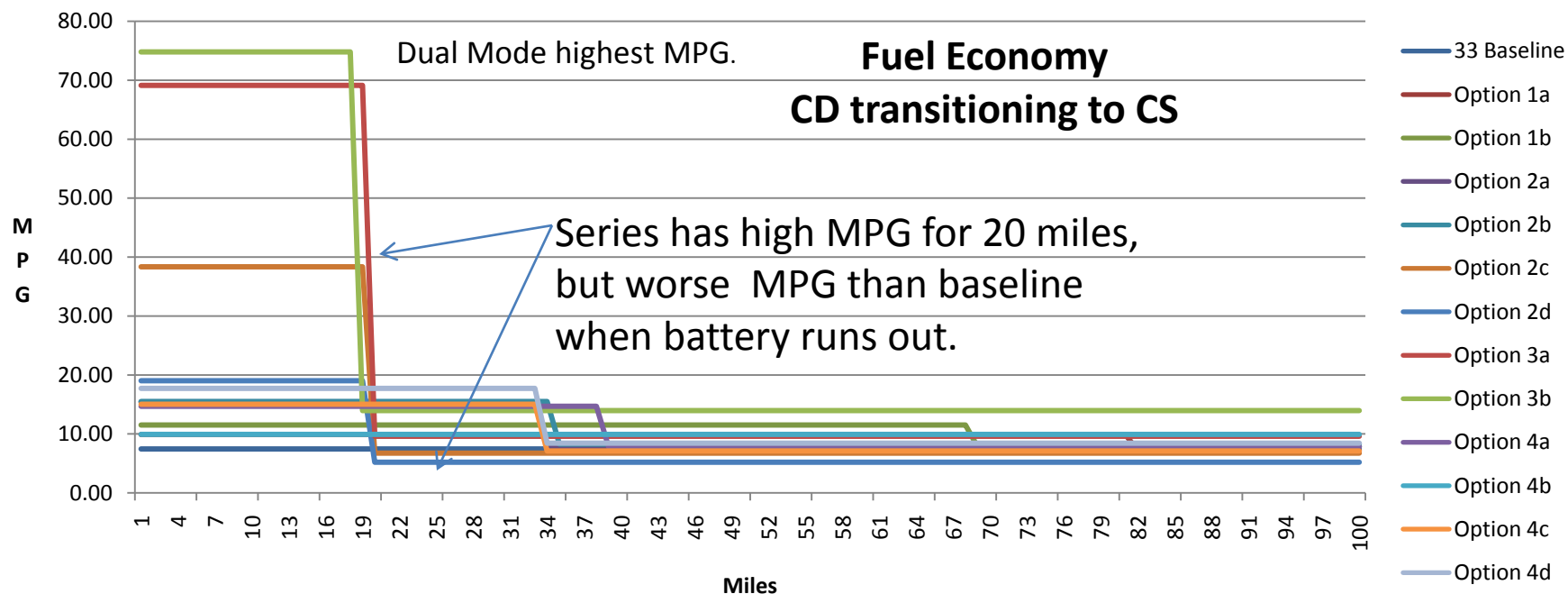
4a: Pre-Transmission Parallel with a MaxxForce7 Engine and Allison 2500 Transmission

4b: Pre-Transmission Parallel with a MWM I4 Engine and Allison 2500 Transmission

4c: Pre-Transmission Parallel with a MaxxForce7 Engine and Eaton Ultra Shift Transmission

4d: Pre-Transmission Parallel with a MWM I4 Engine and Eaton Ultra Shift Transmission

Navistar MPG Simulation Results



		Parallel - Post Transmission		Series				Dual Mode		Parallel - Pre Transmission			
33 Baseline		Option 1a	Option 1b	Option 2a	Option 2b	Option 2c	Option 2d	Option 3a	Option 3b	Option 4a	Option 4b	Option 4c	Option 4d
UDDS CD MPG	7.45	9.90	11.52	15.43	15.51	38.36	19.02	69.12	74.81	14.69	9.92	15.04	17.73
UDDS CS MPG	7.45	7.12	7.78	7.81	8.29	6.74	5.19	9.61	13.96	7.80	8.71	7.10	8.43
CD miles		81.4	68.7	34.0	34.4	19.3	19.7	19.8	18.8	38.6	242.0	33.7	33.8

ORNL Simulation

