Executive Summary and Policy Recommendations
Toledo Area Regional Transit Authority (TARTA)
And the City of Toledo
Biodiesel Study

June 1, 2006 through December 31, 2009

Sponsor: Congresswoman Marcy Kaptur –
Her vision and support are vital to this project.

Partners: TARTA, the City of Toledo, the Intermodal Transportation Institute at
The University of Toledo, H2 Engine Systems, Shrader Tire and Oil, Chevron,
and Biodiesel Partnership for Renewable Energy
OVERVIEW AND BACKGROUND

With the vision and leadership of Congresswoman Marcy Kaptur, the Toledo Area Regional Transit Authority (TARTA) and the Intermodal Transportation Institute (ITI) at The University of Toledo developed a long-term, large-scale comprehensive research project to understand and assess the impacts of using a mixture of renewable bio-fuel and diesel fuel (B20: 20% bio-fuel and 80% diesel) compared to currently available diesel fuel. Efforts to initiate the study began in the late summer of 2005. The City of Toledo had three vehicles operating on B20. TARTA selected thirty-eight Thomas buses with 2003 Detroit Diesel MBE 900 engines and ten Bluebird buses with 2006 Cummins ISB engines. Half of each type used ULS diesel and the other half used B20 made with ULS diesel. There were no significant problems in switching from diesel to biodiesel, or problems with operations. The mechanics who worked on the vehicles did not see a significant difference between working on vehicles using standard diesel versus biodiesel, and a survey of drivers showed a slight preference for vehicles burning biodiesel.

SUMMARY OF PERFORMANCE AND COSTS

Fuel Costs (B20 became cheaper than standard diesel): The cost of standard diesel (ULS diesel) varied significantly over the study period from $1.859/gallon in October 2006 to a high of $4.19 in June 2008 back to a $1.88 at the close of data collection in May 2009. The lowest cost was $1.64/gallon. The cost of B20 varied significantly over the study period from $2.039 in October 2006 to a high of $4.049 in July 2008 back to a $1.781 at the close of data collection in May 2009. This fluctuation masked a change in the relationship between the price of standard diesel and B20. In the first year, the average cost of standard diesel was $1.975/gallon and B20 was $2.088 making B20 more expensive by $0.113/gallon. In the second year, the comparison was $2.864 versus 3.007 making B20 more expensive by $0.143/gallon. However, in the third year, it was $2.613 versus 2.507 making B20 less expensive by $0.106/gallon.

Miles per Gallon (MPG) and Fuel Cost per Mile (FCM): For the Thomas buses, the MPG was lower and the FCM was higher for the buses run on B20 than the buses run of standard diesel. There was no such pattern for the Blue Bird buses. Over the life of the study, the FCM was approximately the same if one considers the large fluctuations in price during the study period. For the City of Toledo’s F-250 truck, FCM was actually lower for B20 than for standard diesel. One of the primary differences between this vehicle and all of the other vehicles in the study is that the F-250 was taken on longer trips, while the buses and other trucks operated by the City of Toledo were operating in stop-and-go mode traveling short distances between stops. To lend some support to this, a test was done with both Thomas and Blue Bird buses to see if there was a difference between “stop-and-go” use and “over the road use.” For the Thomas buses in over-the-road use, the advantage enjoyed by standard diesel over B20 in MPG and FCM was reduced. For the Blue Bird buses in over-the-road use, the vehicles using B20 had an advantage in MPG and FCM over the vehicles using standard diesel.

Maintenance and Repair Costs: For the Blue Bird buses, engine-related repair cost per mile was higher for the buses using standard diesel than for the buses using B20. However, for the Thomas buses, the results were not conclusive.
SUMMARY OF EXHAUST EMISSIONS AND INDOOR AIR QUALITY

The real-world on-road exhaust emission concentrations from transit buses equipped with MBE and Cummins engines, fuelled with B0, B5, B10, and B20 were measured. The emission variation of the monitored pollutants with biodiesel blends is shown in Figure 1. CO emissions decreased with an increase in percentage of biodiesel in the base fuel. The reduction was found to be 38% with MBE engines, from B0 to B20; and 22% for Cummins engines from B5 to B10. The emissions of NOX increased proportionally with the biodiesel concentration in the base fuel. The percentage of increase was about 15% from B0 to B20 for MBE engines; and 10% for Cummins engines from B0 to B10. CO2 exhaust emissions reduced by 11% from B0 to B20 for MBE engines and increased up to 23% from B5 to B10 for Cummins engines. SO2 emissions are a result of combustion of fuels containing sulfur and the concentrations decreased by 5% from B0 to B20 for MBE engines. Exhaust emission analysis of 300 series (Bluebird, Cummins engines) fleet and 500 series (Thomas, Mercedes Benz engines) fleet revealed CO and CO2 emission levels to be higher for 300 series fleet under all conditions. The 500 series fleet buses fueled with biodiesel burn cleaner as compared to 300 series buses.

Indoor air quality in buses operating on B20 grade biodiesel and ULSD has been studied for more than two years on 500 series fleet. Two different statistical analyses namely regression analysis and regression tree analysis have been used in determining the factors affecting indoor air quality levels. It was observed that the factors affecting in-vehicle pollutant levels varied for each month, season, and year from these analyses. Vehicular pollutant trends have been plotted and the possible reasons for variations have been discussed in detail in different papers. The average indoor air concentrations of measured pollutants were found higher indoors as compared to outdoor levels as can be observed from Figure 2(a). Also, higher concentrations were observed during the winter months compared to the other seasons due to lower air exchange in winter. It was also observed that particulate matter concentrations were higher both indoors and outdoors when the bus is placed in the garage surrounded with other idling buses as compared to the time when it is on the route for the run or when it is in the garage with no other idling buses as can be seen from Figure 2(b).

Exposure study revealed that the mean 8-hour exposure to carbon dioxide and sulfur dioxide were significantly higher inside ULSD buses as compared to B20 fueled buses, while the carbon
monoxide and nitric oxide concentrations were higher inside B20 buses. Exposure to nitrogen
dioxide and particulate matter were statistically similar for both the buses. None of the in-vehicle
pollutants monitored exceeded the TWA limits with the exception of CO.

![Figure 2(a). CO2 Concentration: I Vs O.](image)

![Figure 2(b). PM1.0 Concentration: I Vs O.](image)

The physical and chemical characterization of particulate matter was carried out with non-
destructive techniques such as X-ray Diffraction, Fourier Transform Infrared Spectroscopy,
Magnetic Susceptibility, Raman Spectroscopy, X-ray photoelectron spectroscopy and Scanning
Electron Microscope with Energy Dispersive Spectroscopy in order to understand the particle
characteristics. The surface of most particles was coarse with a fractal edge that could provide a
suitable chemical reaction bed in the polluted atmospheric environment. The three sorts of
surface patterns of squares were smooth, semi-smooth, and coarse. The three sorts of square
surface patterns represented the single inhalable particle’s morphology characteristics in the air
inside the bus in the Toledo, Ohio. The size distribution was generally multi-modal for the
ULSD but uni-modal for the B20-fueled bus. The aspect ratio found for different filters collected
inside the bus fueled by both the B20 blend and ULSD were in the average value range 2.4-3.6
and 2.3-2.9 with standard deviation range 0.9-7.4 and 1-7.3 respectively. The square and oblong-
shaped particles represented the single inhalable particle’s morphology characteristics in the air
of a Toledo transit bus. Chemical characterization of fine particulates was carried out in order to
understand the sources of the particles. Polycyclic aromatic hydrocarbons were absent in the
indoor environment of the bus.

**POLICY RECOMMENDATIONS AND FUTURE STUDIES**

It is clear from this study, that the environmental advantages of B20 over standard diesel are
substantial and that the economic advantages of standard diesel over B20 on a unit cost basis
have reversed recently. Biodiesel offers significant greenhouse gas emissions reductions
compared to its petroleum counterpart and has one of the best energy balances of any fuel
available. However, in this study, B20 suffers a fuel cost per mile disadvantage because B20
delivers a lower mile per gallon in stop and go driving, which offsets B20’s lower purchase
price. Supporting the use of B20, is the fact that B20 is made with energy grown/produced in the
U.S., so the use of B20 reduces the United States’ negative trade balance and increase economic
activity. Biodiesel creates meaningful jobs, strengthens the economy, and increases energy and
homeland security. Depending upon the assumptions, the precise advantages are difficult to
measure precisely. Each year in the United States, the use of biodiesel replaces tens of millions
of barrels of petroleum, adds about $4 billion to the economy, reduces carbon monoxide,
hydrocarbons, and other harmful emissions. Following are some recommendations that should be considered:

1. Requiring all public transit fleets to use at least B10 provided sufficient supply of biodiesel. As a result of this study TARTA will use B20 in all of its large bus fleet. This can be phased in over a few years so there is not an unexpected surge in demand.

2. Require all diesel sold in the US to be at least B5 provided sufficient capacity of bio-fuel is available. John Hausladen, President of the Minnesota Trucking Association (MTA), spoke in favor of Minnesota’s move to a B5 blend. “Due to the diligent work of the states biodiesel manufacturers and distributors, the MTA is confident that we will have no operational problems as we move to the B5 blend. In the long run, we believe the best solution for the state and the national economy is to adopt a single, nationwide diesel fuel standard. We believe that biodiesel can be an important component in making this a reality. Before following through with this recommendation these items should be considered:
   a. Making this recommendation for the nation, clearly requires a careful examination of the supply and demand balance.
   b. It requires additional research and development for engine design to determine how (?) MPG and emissions can be optimized for biodiesel. There are engine parameters that can be adjusted, and one question is can these be set to get better performance from biodiesel. Support joint research with engine manufacturers to understand how engines can be redesigned/recalibrated to use B05 and other blends of biodiesel more effectively.
   c. Before full-scale rollout, it would be useful to develop a research partnership with a university or group of universities and a large truck fleets like UPS or FedEx Ground to test the use of different biodiesel blends in over the road trucks. Is the fuel economy as measure in MPG or fuel cost per mile different in over-the-road trucks versus stop-and-go buses? What is the impact on truck maintenance and other life cycle cost issues.

3. It is recommended that windows be kept in closed position during heavy traffic to reduce penetration of exhaust emission pollutants from surrounding vehicles and also self exhaust. Because this part of the study involves testing of only two buses, it is recommended that more buses be used for testing before making a final conclusion on the public transport microenvironments using biodiesel and ultra low sulfur diesel.

4. It is recommended that fine particulate analysis of exhaust gases and indoor air in the bus is expanded to study risk to human.

5. It is recommended that fine particulate chemical analysis should be carried out to identify the sources of the pollution and in particular the fine particles.

6. Polycyclic aromatic hydrocarbons should be monitored on a regular basis to understand the concentration of most carcinogenic substance in the bus.

7. Laboratory and field studies should be conducted to understand the environmental impact of using biodiesel made from different raw material. This study focused only on soy based biodiesel.