

TRESP II Testing of AFS Dual Fuel System

Prepared by

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16. Abstract A dual fuel CNG and diesel system was retrofitted to a 13 L Volvo semi tractor for testing to verify the fuel economy and CNG substitution rate. The semi tractor was tested on interstate and mountainous highway routes with a loaded trailer. Fuel economy, CNG substitution percentage, and cost of fuel per mile were calculated.			
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Describe in detail the milestones listed in the application that were met or any other achievements made during the course of the project.

Project Statement of Work Tasks as Proposed

Task 2: Dedicated Test Truck Retrofit

A Penn State owned test truck will be retrofitted with a second dual fuel system to allow investigators to perform off line calibration work on this dedicated truck at our test track facility while the partner's on road truck is kept in continuous service gathering data at the sponsor.

Task 2.1: Source and install dual fuel system

A second dual fuel system and accessories will be sourced and installed on a 2000 Volvo tractor with a 13 liter Diesel engine. Also a second control system will be sourced, programmed, and installed in the dedicated test truck.

A 2000 Volvo semi-tractor with a 13 liter Diesel engine and automatic transmission was delivered from Penn State to AFS for retrofit of their FIT system in late September 2012. The retro-fitted Penn State truck was picked up in late October 2012 to begin testing. The final revised budget supported installation of only FIT system and it determined to test this on the dedicated Penn State truck, not the Hawbaker Granite truck in service which had been previously tested in the original TRESP project. Figure 1 shows the FIT natural gas mixer and the FIT dash controls. Notice that the FIT mixer is installed in the air intake upstream of the turbocharger and intercooler. The original black rubber elbow just upstream of the turbocharger was found to collapse from the heat and vacuum of the turbocharger at high engine loads. It was later replaced by a stronger version.



Figure 1: Left - FIT CNG mixer unit near turbocharger, Right – FIT dash controls

Task 2.2: Install compressed natural gas (CNG) fuel system

CNG tanks, valves, fuel filters, and lines will be installed on the dedicated Volvo tractor to support testing of the dual fuel system.

In September 2012, the Larson Institute team at Penn State installed a single CNG tank of about 8 gasoline gallon equivalent (gge) capacity in a vertical orientation behind the cab of the Volvo semi-tractor. This included supporting structure and external covers as shown in Figure 2. A valve body and pressure gauge were installed on the tank. High pressure rated stainless steel tubing was installed to deliver CNG at tank pressure to the AFS installed fuel system regulator. Wiring of

the valve and the remainder of the fuel system was completed by AFS as part of their final system installation and debug.

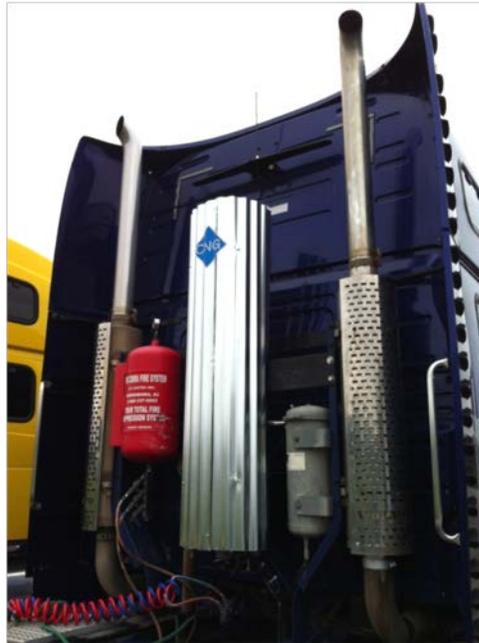


Figure 2: CNG tank installed on the Volvo 770

Task 2.3: Integrate control system and sensors

The dual fuel system and controller will be integrated with additional sensors as required to support off line testing.

The Larson Institute team sourced and installed sensors and a Controller Area Network (CAN) hub to integrate data acquisition on the Volvo tractor. This system gathered and stored relevant information broadcast on the vehicle CAN bus combined with dual fuel specific signals such as CNG tank pressure for later analysis.

AFS completed installation of the FIT control and fuel systems on the Penn State Volvo during October 2012. This was followed by a short period of road testing before delivery on October 31. AFS did not have access to a loaded trailer so debug testing was carried out with the truck in “bob-tail” configuration. The tractor was delivered to Penn State for further testing and debug. Several electrical issues were initially encountered during testing and the issue was eventually traced to a loose electrical system ground point on the Volvo engine block. Repairs/replacement of some AFS control system components was necessary. One electrical issue unresolved by the ground repair was frequent failure of the engine exhaust gas temperature (EGT). Testing was delayed by EGT sensor failure because the engine control module (ECM) uses EGT as a critical parameter and de-rates engine power when EGT is out of normal range. Testing continued through November and December 2012 to resolve this issue. Half a dozen exhaust gas temperature sensors failed and were replaced. W.W. Engine, the local Volvo dealer, was consulted and they suspected the cause was electrical. Finally, during testing in December, the engine lost almost all power under load and it was discovered that a modified air intake tube was collapsing under vacuum pressure during high engine load conditions. This restricted air flow to the engine and caused high exhaust temperature spikes which would damage the EGT sensor. A

significant portion of the budget for road testing was consumed during this period of extended debug which later limited the amount of road test data collected. AFS replaced this tube with a heavier version and the first successful road test was accomplished in January 2013 on a mountainous course with good results approaching 30% CNG substitution on an energy basis. Subsequent testing on a highway course yielded less favorable CNG substitution results in the 11% region. Penn State returned the Volvo truck to AFS which completed a second series of upgrades and testing on the FIT system in June 2013 to improve the highway substitution CNG rate. These version II upgrades to the FIT system were tested in September 2013 with more favorable highway CNG substitution results approaching 20% substitution. One factor to note is that the Volvo engine ECM and automatic transmission controller (TCM) both use the accelerator pedal signal to determine diesel fuel flow and transmission downshift points respectively. The AFS FIT system electronically modifies the pedal signal received by the ECM/TCM downward in proportion to CNG substitution rate. This creates a tradeoff on grades limiting possible CNG substitution rates in order to maintain proper downshift points to maintain performance. One conclusion can be drawn from this tradeoff for automatic transmissions. It is likely that the AFS FIT system could be tuned to deliver higher CNG substitution rates on grade and under heavy load for a truck equipped with a manual transmission since its downshift points are under driver control not the TCM computer. Even higher CNG substitution rates could likely be achieved with active OEM engineering support to retune the stock ECM and TCM for dual fuel operation. Both of these scenarios would be excellent candidates for follow-on projects.

Task 3: Management and Reporting

Project management will be performed to maintain the project on schedule and keep the sponsor and partners informed of progress.

Project management included frequent updates and meetings with Ben Franklin and Hawbaker representatives.

Task 3.1: Weekly Updates

A brief technical update e-mail will be prepared and shared each week for sponsors and partners, and a bi-monthly conference call or face-to-face meeting will be held to address any changes necessary in the SOW, and to ensure all sponsors and partners are up to date on the project .

Task 3.2: Management

Project management will insure the investigators are properly tasked, informed, and equipped to perform their duties.

List the milestones or intended accomplishments enumerated in the original application that were not met during the course of the project. What prevented their being met?

Task 1: Validation of On-Road Fuel Economy

On road fuel economy testing of the existing heavy truck will be continued for approximately three months under continuous improvement of dual fuel system algorithm and calibration.

The original project scope intended to test AFS FIT systems in parallel on both the Hawbaker Granite tractor and a Volvo tractor owned by Penn State. A reduced project scope was negotiated which did not provide funds for the purchase and installation of a second AFS FIT system onto the Hawbaker Granite tractor. This effectively postponed Task 1 and Subtasks 1.1-3. It was jointly agreed to first fully develop and test the AFS FIT system on the dedicated Volvo test truck before implementing it on the Hawbaker Granite tractor to avoid adverse effects on their daily operations. With the current project completed, retrofit of the Hawbaker Granite with an AFS FIT system can now be considered as a follow on project with confidence that Hawbaker operations will not be affected by significant down time and that economically favorable results can be achieved.

Task 1.1: Collect and Analyze Data

The project will collect, compile, and analyze on road data from the partners truck each day of operation from the onboard network, fueling records, and routes. A brief data form will be developed for the driver to complete each day regarding issues encountered. Investigators will set up a system for retrieving storage devices and downloading data.

Task 1.1: Updates of control system calibration

Analysis of the collected on road data and off line testing of a dedicated test truck will be used to develop a control system calibration update on a weekly basis. Support will be provided to install updates to the dual fuel control system.

Task 1.3: Support of on road fuel economy testing

Engineering support will be provided to the sponsor on a daily basis to resolve issues, answer questions, perform maintenance, and install upgrades.

How will the results of the project change the nature of the underlying technology or its use?

This project involved testing of emerging dual fuel CNG/diesel technology which adds CNG fumigation upstream of a conventional diesel engine. This technology allows retro-fit of existing diesel truck fleets, without OEM engineering support, to use some portion of CNG as fuel. The specific purpose of this project was to validate that the resulting CNG substitution rate and corresponding fuel economy and performance achieved by the AFS FIT system under various road and load conditions could be economical. In the course of this project, AFS gained access

to a dedicated test vehicle, loaded trailer, sophisticated data acquisition and analysis, and engineering assistance to further develop their product. Several upgrades to the technology were implemented and tested in the process resulting in testing of version II of the FIT system. The subsequent availability of third party test data and recommendations for best practices will allow interested trucking firms to better plan field trials of the AFS FIT dual fuel CNG/diesel system with greater confidence that their cost and performance goals will be met.

How did the results of the project improve the commercial viability of the research or technology (If the findings indicate that the technology is not commercially viable, please also state this)?

This project validated the AFS FIT system as delivering 20-30% CNG substitution for Diesel on an energy basis with approximately 10% loss in overall fuel economy for a MY2000 truck with automatic transmission. Higher rates should be achievable in a truck with a manual transmission. The fuel \$/mile breakeven point appeared to occur at around 20% substitution assuming \$4 per gallon diesel fuel and \$2 per gasoline gallon equivalent for CNG fuel. This result from a credible testing organization will allow informed decisions by potential users in the trucking industry.

What financial or other impacts will the results of this project have on the research institution, the commercial partners, or the Commonwealth of Pennsylvania immediately and over the next three years?

Commercial partners likely to immediately benefit financially from the results of this project include Alternative Fuel Solutions PA through the sale and support of additional FIT systems. Because of its previous involvement with this technology, Glenn O. Hawbaker Inc. is in a good position to rapidly deploy this system and benefit from fuel cost savings in their truck fleet. Further development and validation of this dual fuel system technology will promote greater market penetration into the trucking industry resulting in energy and financial benefits nationwide over the next several years. Pennsylvania would benefit from increased demand for natural gas from the Marcellus Shale as a transportation fuel over the next several years since these dual fuel systems can be implemented rapidly and use existing natural gas fueling technology.

What additional work must be done to commercialize the technology? What resources would be required?

This technology is fully commercialized but larger volumes would result in system cost savings. Lower system cost would promote faster ROI for trucking firms. Additional testing to validate dual fuel economics and performance across the various truck power train configurations and truck applications would promote more rapid market penetration. Most important would be to complete additional mountainous route testing. Lastly, a demonstration with OEM engineering support to retune ECM and TCM controllers for dual fuel operation would reveal the ultimate technical boundaries of dual fuel system economy and performance.

Is there interest among the researchers, research institution, and/or commercial partners to continue research in this area? If so, what is the basis for that interest?

Now that this dual fuel system has demonstrated potential to deliver economic benefits in a mixed route semi-trailer application, a fuller matrix of road and load tests should be completed to give a fuller picture of potential benefits over a wider range of trucking applications. This would likely include collection and analysis of the data from a combination of field testing and controlled testing over a range of vehicle configurations and sizes. This effort could begin quickly with retro-fit of the Hawbaker Granite tractor used haul heavy construction equipment with an AFS Fit system. This truck is already equipped with a natural gas fueling system from previous testing of another dual fuel system. Data and experience from the current project indicates that higher CNG substitution rates will be achieved under heaviest loads in a truck equipped with a standard transmission that allows the driver to manually control downshifting.

Please attach a listing of all of the expenditures during the project.

Funding for this project consisted of a grant from Ben Franklin TRESP with matching federal funding from the Mid-Atlantic Universities Transportation Center (MAUTC) at the Larson Pennsylvania Transportation Institute. AFS of Pennsylvania also provided the FIT kit and installation at a discounted cost. TRESP and MAUTC funding was completely expended before the final testing was completed due to an extended debug period for the vehicle. Some additional costs were covered to complete the final testing with research incentive funds of the principle investigator, Dr. Joel Anstrom. A general listing of expenditures during the project by category includes:

- \$30799.16 Ben Franklin salaries and fringe for faculty, staff, and technicians
- \$ Federal match salaries for faculty, staff, and technical services (drivers)
- \$ 553.24 Ben Franklin laboratory supplies
- \$ 12,381.61 Ben Franklin automotive hardware
- \$ 260.00 Ben Franklin steel components for CNG tank mounting
- \$ 583.25 Ben Franklin in-state travel
- \$3764.79 Ben Franklin consulting fees
- \$1556.25 Ben Franklin software
- \$149.00 Ben Franklin printing

Total TRESP expenditures: \$50,047.30

- \$21919.24 MAUTC salaries and fringe for faculty, staff, technicians
- \$789.33 - travel
- \$10900.13 - overhead

Total federal expenditures: \$33608.70

- \$800.06 Anstrom RIF salaries and fringe for technicians
- \$461.05 Anstrom RIF automotive parts
- \$140 Anstrom RIF estimated diesel and CNG fuel
- \$300 Anstrom RIF trailer rental

Total Anstrom RIF expenditures: \$1701.11

Appendix: Please attach summaries of all of the relevant and important data, results, or findings from the research that supports the answers to the questions above.

Appendix A: Test Procedure

Debug and testing of the installed AFS FIT system began in October of 2012 with a series of road tests on a mountainous highway route between the Penn State Bus Test Track and Philipsburg via I99 and PA Route 322. A fuel efficiency test procedure was developed to allow measurement of diesel and CNG fuel versus miles traveled. The most accurate method used to measure fuel is to weight diesel and CNG tanks before and after fueling and convert to gallons using density values. However, within the budget for this project, the practical and cost effective alternative was to rely on the accuracy of the diesel pumps at the Penn State Bus Test Track and CNG filling station at Penn State Office of Physical Plant (OPP). This required the Volvo 770 to be parked on the level near the test track diesel pump where tire locations would be marked on the pavement. Diesel fuel would then be topped off to the bottom of both fuel cap spouts and fuel quantity in diesel gallon equivalent (dge) would be recorded. Odometer miles would also be recorded. The truck would then be driven to the OPP fueling area on diesel only and filled with CNG to the maximum available pressure at that time. Maximum CNG pressure available at OPP varies depending on recent fueling activity. The CNG pressure and gasoline gallon equivalent (gge) of CNG would be recorded and corrected later for maximum fill pressure differences. The dual fuel system would then be switched on if required for that test. The route would then be completed from the OPP fueling station and CNG pressure was recorded in route on the CAN logger and manually at stops. Upon return to the OPP CNG station, the CNG tank was refilled to maximum available pressure and the dual fuel system would be switched off. CNG gge was recorded along with final pressure. Upon return to the test track, the truck tires were realigned to pavement marks and both diesel tanks were topped off to the fill cap spout reference marks. Diesel gallons (dge) were recorded along with final odometer miles. Using this method, the diesel fuel used was corrected for diesel only miles between the test track and OPP CNG fueling. Alternatively, the CNG tanks could be filled prior to and after diesel fueling. Both methods were used to collect data for this project.

Initially, a dump trailer loaded with 2B stone was leased from Valley Towing. The truck and trailer were weighed on scales at the Hawbaker quarry in Pleasant Gap. When this trailer became unavailable, subsequent tests were run with a low boy trailer borrowed from Penn State OPP and loaded with concrete Jersey barriers. The truck and trailer were weighed on scales at the Penn State recycling facility.

The test routes were run at posted speed whenever possible.

The truck, as currently configured, demonstrated perceivably better performance in dual fuel operation than diesel only. It simply had more power and torque for hills in dual fuel operation. This may indicate a possibility for increased CNG substitution through further tuning.

Appendix B: Data Assumptions and Analysis

CNG gasoline gallon equivalent (gge) energy was converted to diesel gallon equivalent (dge) using a ratio of gasoline and diesel fuel gravimetric and energy densities. (Bosch Automotive Handbook 4th Edition pp 238) Fuel costs of \$4 per diesel gallon and \$2 per CNG gge were assumed. All fuel efficiency calculations were completed in miles per dge. Fuel efficiency and fuel costs were used to calculate fuel \$/mile. Finally, CNG percent substitution rate was calculated on an energy basis using the ratio of CNG dge to diesel gallons.

Results:

Table 1 summarizes the test results for a mountainous highway route and a series of interstate highway routes in units of fuel efficiency (mi/dge), % CNG substitution, and fuel cost per mile (\$/mile).

From Table 1 it can be noted that the AFS system in its initial version I achieved a good result of 30% CNG substitution on the mountainous route. Under heavy load the AFS system can operate over a large proportion of the engine map allowing for greater CNG substitution without tradeoffs in performance. This route was run at a gross vehicle weight of 40220 lbs with the dump trailer which had unfortunately been emptied of its initial load of 2B stone at this point in time. This route was a mixture of 55 and 65 mph posted speed. Fuel economy for this route was the highest achieved at 7.03 mi/dge, most likely due to the lower weight. It is highly recommended that additional testing include more mountainous runs to capture the effect of AFS version II upgrades and at full gross vehicle weight which should yield CNG substitution values over 30%.

Subsequent highway tests achieved only 11.7% CNG substitution with a 10% drop in fuel economy. These tests were performed fully loaded at 73,400 lbs. The fuel \$/mi were actually higher for the dual fuel case by 4.2%.

The highway tests were repeated after AFS completed Version II upgrades to the dual fuel system and additional tuning. Highway testing this time achieved 19.68% CNG substitution with a 7.8% drop in fuel economy and nearly equivalent fuel costs of \$0.77/mi for both diesel and dual fuel operation.

These results indicate that break even fuel costs can already be achieved on the highway for a dual fuel system at \$4 per diesel gallon and \$2 per CNG gge. Better CNG substitution approaching 30% or higher can be achieved as routes become more mountainous and as loads increase. Results should be further improved for manual transmission trucks (allowing more aggressive CNG substitution tuning) and with OEM engineering support for tuning ECM and TCM computers. The average CNG substitution rate will be determined by the combination of truck or bus powertrain, load, and route. Depending on these factors, favorable ROI may be possible depending on the price of fuel and cost of CNG fueling infrastructure

Table 1: Summary of AFS FIT system testing by on a MY 2000 Volvo 770 tractor

Category	Mountainous highway dual fuel	I99 Diesel Only	I99 Dual Fuel	I99 Diesel only	I99 Dual Fuel
Route	Test track - Philipsburg	Test Track to Altoona	Test Track – I99 Exit 23	Test track – I99 Exit 23	Test track – I99 Exit 23
Date	January 13, 2013	February 11, 2013	February 11, 2013	September 5, 2013	September 5, 2013
FIT version	I	I	I	II	II
Test Weight lb	40220	73400	73400	73830	73830
Trailer	dump	dump	low boy	low boy	low boy
Efficiency mi/dge	7.03*	5.74	5.18	5.14	4.74
Posted mi/hr	55 and 65	Mostly 65	Mostly 65	Mostly 65	Mostly 65
Basis miles	92.7*	118	129	118.1	118
Diesel dge	9.26*	20.55	25.5	22.95	20
CNG dge	3.92	0	3.40	0	4.90
% CNG energy	29.73*	0	11.757	0	19.68
Fuel \$/mile	0.484*	0.697	0.726	0.777	0.771

*Corrected for one leg from track to OPP on diesel only

Appendix C: Conclusions and Recommendations

The following conclusions and recommendations can be made regarding the AFS dual fuel system as tested on the Larson Institute MY 2000 Volvo 770 truck:

1. AFS FIT dual fuel system has demonstrated 20-30% CNG substitution rates
2. Fuel cost \$/mi break even occurred around 20% CNG substitution assuming \$4 gallon diesel and \$2 gge CNG
3. Highest CNG substitution was achieved under high load as on mountainous route
4. Lowest CNG substitution was achieved on level interstate routes
5. Fuel efficiency of dual fuel is about 8-10% less than diesel only as tested
6. The truck as tested had perceivably better performance in dual fuel operation than diesel
7. A manual transmission truck has potentially higher CNG substitution rates
8. All truck configurations have potentially higher CNG substitution with OEM tuning support
9. Additional mountainous and heavily loaded tests would be a first priority for new testing
10. Transit buses on urban stop and start routes may also achieve high CNG substitution rates
11. Recommend replacing the current Technocarb dual fuel system with an AFS FIT system in the Hawbaker Mack Granite for further testing

Appendix D: Acknowledgements

This project was conducted by the Hybrid and Hydrogen Vehicle Research Laboratory (HHVRL) within the Larson Pennsylvania Transportation Institute (LTI) for the Ben Franklin Technology Center of Central & Northern Pennsylvania in coordination with the Shale Gas Innovation and Commercialization Center (SGICC). Volvo Trucks donated their MY 2000 770 Tech Truck to Penn State which was modified with a FIT Dual Fuel system provided at cost by Alternative Fuel Systems of Pennsylvania. WW Engine & Supply Inc. of Altoona provided some technical support and documentation to help resolve the issue with failing exhaust temperature sensors. Track space and driver coordination was provided by David Klinikowski and Dennis Kovalick at the Penn State Bus Research Center. HHVRL contributors included Dr. Joel Anstrom, Timothy Cleary, and Mike Anderson. Dr. Kirk Collier provided consulting services regarding the theory of dual fuel systems as detailed in the appendix.

Appendix E: Consultation on the limitations of dual fuel technology

Summary: Kirk Collier Ph.D. was contracted to provide an expert opinion on the limitations of dual fuel technology as implemented in the AFS FIT system. His analysis supports the result of high CNG substitution ratios only being achievable under heavy engine loads. At light engine load, there is simply too much oxygen present in the cylinder to reach a combustible air-fuel mixture for effective methane combustion. Also, methane air-fuel ratios in the intake must be held below combustible mixtures to avoid the danger of pre-ignition. Dr. Collier also points out that accurate analysis of dual fuel combustion would require sophisticated levels of laboratory testing and computer based combustion modeling.

Analysis: Kirk Collier, Ph.D. Consultation Report on AFS Dual Fuel System as installed on Volvo 770

Pre-Trip Analysis

The problems associated with natural gas (NG) supplementation of a diesel engine can be separated into two areas.

1. NG behavior before diesel injection
2. NG behavior after diesel injection

Before Diesel Injection

The major consideration here is to avoid compression ignition of the NG. This is further complicated when NG introduction occurs upstream of the turbocharger inlet. The large amount of combustible mixture that is contained in the intake system, including the intercooler, makes this a very significant issue.

The resistance to compression ignition is directly proportional to the amount of methane in the NG. Unfortunately, the user will have no control over this parameter. Therefore, systems must be engineered for the worst case NG chemical composition. A conservative approach would be to limit the introduction of NG to be below the lean limit of combustion. A reasonable first assumption would be to limit the initial introduction of NG to be an equivalence ratio of about 0.6. This value should eliminate any combustion within the intake system. There may be some question as to its ability to resist compression ignition, but this value should be very close to optimum.

After Diesel Injection

Maximizing the amount of NG in the fuel mixture should result in an exhaust containing about 0.5% oxygen. Maximum engine efficiency would be attained at about 4% exhaust oxygen. A factor to be considered should be minimizing fuel cost rather than maximizing engine efficiency. In this case, producing engine output power with slightly less overall thermal efficiency with a less expensive fuel might be the best approach.

For this part of the exercise, I am assuming that the diesel and NG combustion can be viewed as two separate processes. That is, the diesel combustion results in a given amount of available free oxygen.

This free oxygen is than available to NG combustion as if it were not influenced by diesel combustion byproducts (internal EGR). This is really a shaky assumption. However, given the incredible complexity of the process and having no laboratory testing results it is a reasonable place to start. This assumption achieves some support by the fact that a good portion of the NG combustion will occur in volumes where no diesel fuel exists and hence no diesel combustion.

This assumption then allows us to perform some calculations regarding possible NG supplementation strategies. The strategy is to supplement a quantity of NG that results in a NG equivalence ratio of at least 0.7 with the oxygen that remains after diesel combustion and results in 0.5 to 4% oxygen after NG combustion.

Ramifications of the Above Strategy

The boundaries created by adopting the above strategy are as follows:

Low power outputs will not be able to be supplemented with NG. If the equivalence ratio of NG must be at least 0.7 in the cylinder for proper combustion, there will be way too much NG for low power output. The control strategy would then have to be: Idle will be 100% diesel. Initial responses to foot throttle input will also be 100% diesel. As the exhaust gas oxygen decreases with increased amount of diesel combusted, the amount of NG that will result in an equivalence ratio of 0.7 will not be excessive for the power output desired. This condition is being approached from two directions. One is that as power output increases, the fraction of available oxygen is being reduced. The other is that the additional power provided by the NG is more commensurate with the output power requested.

Final Thoughts

The previous discussion represents the simplest first approach to the problem. In reality, the NG and diesel are co-combusting in part of the cylinder volume and the NG combusting alone in other parts of the cylinder. This is a very complex situation and would require significant laboratory or sophisticated computer simulation (KIVA, etc) to properly analyze. However, assuming that the diesel and NG share the available oxygen within the combustibility limits of NG, this is a good place to start. Given that, we can estimate engine power output comparing each fuel's heating value per mole of oxygen consumed.

We know that NG generator sets are in operation where the NG is introduced upstream of the turbocharger. Obviously, equivalence ratios above 0.6 exist in the engine intake system. However, I don't think that it is worth the risk of intake explosions for the minimal increase in NG usage.

Trip Report

The day of January 25, 2013 was spent with the Penn State team discussing the implementation and control options for the fueling system being tested. The test procedures, data acquisition hardware and methodologies were also discussed and critiqued.

We performed level highway performance of the vehicle loaded to maximum GVW. The testing was to compare fuel economy and amount of natural gas supplementation to previous severe gradient highway data as well as to level highway operation without natural gas supplementation.

Unfortunately, the weather did not allow us to complete the level highway without natural gas supplementation. Also, the weather conditions for testing with natural gas supplementation were such that a direct comparison to the severe gradient highway data would be suspect.

It is the opinion of this consultant that fuel economy data collection, the test methods and data analysis strategies are very well conceived and implemented. Although no substantive conclusions can be made at this time, those conclusions will be presented in our final report after considering further test data.