BROOKHAVEN NATIONAL LABORATORY

Brookhaven Science Associates, LLC

Program Status Report

BNL Contract No. 723418

DOE Contract No. DE-AC02-99CH10980
(Amendment 1)

November 20, 1999

Improvement In LNG Storage Tanks

Full Scale Demonstration Testing

Phase I Level 3

Prepared for:

BORG-WARNER

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Sept 25, 2002
Date

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Table of Contents

Program Summary	5
General Comments.....	5
Testing	5
Tank Deliveries.....	5
Technology Overview.....	6
Current Technology.....	7
BW/CFI Advanced Technology.....	11
Design Features	12
Suspension System.....	12
Thermal Performance.....	14
Fuel Delivery Strategy	14
Pressure Management.....	16
Engineering	
Production Engineering Drawings.....	18
Tank Structural Analysis	18
Thermal Performance Analysis	18
Vacuum Acquisition System	19
Manufacturing	
Tank Fabrication.....	21
Testing	
End Item Acceptance Testing (EIAT).....	22
Instrumentation and Data Acquisition	25
Engine Test Stand	25
Depletion and Pressure Management	27

List of Figures

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	In-tank Pump System	7
2	Preconditioned Tank System	8
3	Vapor Flow vs Pressure Drop	9
4	Fuel Density Comparison.	10
5	Beam Suspension System	11
6	Mack Truck Structural Testing.	13
7	Thermal Performance Comparison.	14
8	Pressure Decay vs Fuel Flow	16
9	Vacuum Acquisition System	20
10	Test Report and Procedure	23
11	Test Setup Schematic	24
12	Engine Test Stand	25
13	Test Data Format	26
14	Cantest-E-F	28
15	Cantest-E-E	29
16	Cantest-E-E-F	30
17	Cantest-L-W	31
18	Cantest-L-W-A	33
19	Cantest-L-W-B & C	34

List of Exhibits

Exhibit

Title

A	Drawing List & Specifications, One hundred (100) Gallon Tank
B	Drawing List & Specifications, Sixty Gallon (60) Gallon Tank
C	Mack Truck Test Report
D	Nova Bus, Test Data
E	Roadway Test Summary
G	Thermal Analysis
H	Structural Analysis

Program Summary

This status report covers the work performed by BorgWarner, Air/Fluid Systems, formerly Snyder Tank Corporation, under Brookhaven National Laboratory (BNL) Contract No. 723418, as amended, October 21, 1998.

The design and engineering phase is essentially 95% complete. Final engineering work activities will include the completion of reports, thermal analysis, structural analysis, test documentation, and any drawing maintenance or configuration control changes that may be required on the two (2) production engineering drawing packages.

Extensive bench flow testing and engine test runs , with LNG, were completed on two (2) fuel system modules, for Gary Indiana Transit. Each system module consists of three (3) tanks, a dual function heat exchanger and the associated components that control pressure management and fuel delivery to the engine. Fuel flow rates, pressure build and tank depletion test results were within design specifications.

These fuel system modules were delivered to Nova Bus, in Roswell NM in September and installed by BorgWarner personnel. Acceptance test runs were performed by Nova and Detroit Diesel in October and the buses have now been accepted by Gary Transit for revenue service.

In addition to the Gary Transit tanks, two (2) sixty gallon tanks were also fabricated, one for "projectile penetration" testing and, one for drop test certification of the sixty gallon tank to verify structural and leakage rates for code compliance with DOT 4-L. This testing is scheduled to be accomplished as part of the Phase II follow-on program. A complete listing of the tank serial numbers and their end-use designations is shown in Exhibit C of this report.

Technology Overview

In the early 1990's several major engine manufacturer's initiated research programs to develop and produce dedicated natural gas engines for medium duty truck and transit bus end-use. The initial thrust of this development work was focused on compressed natural gas (CNG) fuel systems, operating at pressures of up to 3600 psi.

During this same period several major trucking and transit bus fleets, driven by State and Federal clean air legislation, conducted their own independent test and evaluation of LNG as their alternative fuel of choice. Their objective was to overcome the weight and range problems inherent in CNG fuel systems.

In responding to this emerging LNG market requirement, engine manufacturer's attempted to use the same pressure regulators and fuel mixers as were currently being used with CNG. This equipment required inlet pressures of 80 to 110 psi, to the first stage of the primary regulator. The "industrial gas" cryogenic tank suppliers had no problem meeting this operating pressure requirement, since their tanks were already designed to be operated at pressures of up to 350 psi.

However, serious problems were encountered early on in these test and demonstration programs, primarily with the pressure management system and the ability of the tank system to deliver consistent fuel flow/quality to the engine. The end result, in many cases, was excessive venting of the LNG and/or damage to the engine. These same performance issues, pressure management and fuel quality, continue to present major operational problems. Several transit operations, have reportedly experienced excessive venting and lack of reliability in fuel delivery as reasons for delaying or postponing planned expansion of their LNG bus fleets. Dallas Area Rapid Transit is the most recent example. These performance issues, if unresolved, will undoubtedly influence fleet operators planning to implement programs to use LNG as a substitute for diesel in many of the fourteen (14) non-attainment regions in the United States.

Current LNG Tank Technology

In order to meet the high operating pressures, being specified by the various engine manufacturers, two totally different design concepts were promoted by the industrial gas sector, in an attempt to solve the pressure management problem, and to provide reliable, consistent, fuel delivery to the engine.

In-Tank Pump System: The “in-tank pump” approach was selected by Houston Metro in 1992 with a contract award to CVI, of Columbus Ohio, for an LNG fuel system that used a hydraulically driven cryogenic pump, that was mounted in one of the three (3) onboard fuel tanks.

Figure No. 1 In-Tank Pump System

An engine mounted hydraulic pump is then used to supply hydraulic fluid to drive a cryogenic pump capable of delivering 0.5 GPM at up to 400 psi to the fuel vaporizer. Four pressure regulators were required for pressure management. After the liquid fuel is converted to a gaseous state the fuel pressure is reduced to 100 psi at the first stage regulators. The second stage regulator, located on the engine, is then used to reduce the fuel pressure to 2 inches of water above the intake manifold pressure. The major problems encountered with this design were fuel delivery reliability, resulting in major engine damage, poor thermal performance, excessive weight and high cost.

Preconditioned LNG Fuel System: One of the major barriers to the successful end-use of LNG as an alternative fuel is that very specialized equipment is required to liquefy, store, transport and distribute the fuel. Unlike passive fuels such as gasoline, diesel, propane or compressed natural gas, LNG is continually changing state as heat enters the liquid through the tank suspension system and the insulating material. This "heat leak" has a dramatic effect on the pressure, temperature and density relationships of the LNG and results in phase-change behavior that is very different from conventional fuels.

Figure No. 2 Preconditioned LNG Tank

However, because of the high "heat leak" of industrial type cryogenic tanks, pressure management can only be achieved by withdrawing both vapor, (100% methane) and liquid from the tank at the same time. Since there is a high expansion ratio between the liquid to gas phase of methane, removing even a small amount of methane vapor will cause the tank pressure to drop rapidly. (Ref. Fig 3)

Figure No. 3 Vapor Flow vs Pressure Drop

An additional problem is encountered when the LNG is stored in a vehicle fuel tank that is continually in motion. The resultant sloshing and mixing (equilibration) of the LNG can induce a drop in tank pressure and variations in the quality of the fuel entering the

regulator/mixer, which in turn can compromise driveability, or result in damage to the engine. The "industrial gas approach" to preventing pressure decay, due to vapor withdrawal and liquid equilibration, was to precondition the LNG, by adding low watt density heat to the fuel, prior to transfer into the vehicle tank. This raises the saturated pressure of the LNG to the required operating pressure of the engine and the tank operating pressure will not decay any lower than the saturated pressure of the liquid. However, adding heat to the LNG, to raise the saturation pressure, also reduces the density of the fuel, resulting in a loss of operating range, increased operating cost and a negative effect on the viability of LNG as an alternative fuel. (Ref. Fig. 4)

Figure No. 4 Fuel Density Comparison

It should also be pointed out that if pure methane gas is being withdrawn, during normal operation of the vehicle, the methane content of the LNG can be reduced to below the engine manufacturer's minimum requirement of approximately 90% methane. This "weathering" of the LNG, due to the continuous withdrawal of pure methane vapor, has created a requirement for LNG with a minimum, 98.0% methane content, at an additional cost of about \$0.10 per gallon. This high purity requirement is

currently being specified in several fuel supply contracts. High purity LNG also has a lower BTU content. The average methane content of conventional LNG, as produced by U. S. gas utility "peaking plants", is about 95% with an energy content of over 1050 Btu's/scf as compared to about 900 Btu's/scf for LNG with a 98% methane content.

BW/CFI Advanced Technology

A recent report, prepared by the Maryland Transit Administration in 1996, pointed out the need for improved thermal performance of the LNG fuel storage tank as a prerequisite for the future use of LNG as a fuel for transit buses. The report also cited excessive venting and weathering of the LNG, in the fuel tank, as primary reasons for terminating their demonstration and test program in 1996. In addition, the report stressed the need for improved reliability and simplification of the fuel control and conditioning system in order to assure that consistent fuel quality is delivered to the engine.

These performance requirements were given top priority during the initial design phase of the BorgWarner LNG tank system. Prior to finalizing the tank design, an in-depth study was made of several major truck and transit fleet operations, in order to establish sizing parameters and to assure compatibility of the tank design with vehicle duty-cycle, range requirements, fueling procedures and vehicle operating environment. The final tank design included many operating and structural capabilities specifically engineered for truck and transit bus end-use. It was from this data base that the baseline design criteria was evolved.

These advanced technology tanks are currently being produced, by BorgWarner, under a long term, "Technology Licensing Agreement" with Cryogenic Fuels Inc. , a Virginia Corporation, with over 20 years experience in the design, production and operation of LNG vehicular fuel systems and fueling facilities.

Design Features

Systems Approach: The most critical performance requirement is the reliable delivery of the fuel to the first stage regulator, on the engine, at the required flow, pressure, density and quality. In order to meet this requirement it was necessary to develop a total "systems approach" that would include the fuel tank, or tanks, the plumbing manifold, the fuel delivery and pressure management subsystems and the appropriate heat exchanger to vaporize and condition the fuel. The following features of the tank design represent positive advancements in cryogenic container technology that will improve the market viability of LNG as a substitute for petroleum based fuels.

Suspension System: The major difference between the CFI tank design and the conventional industrial cryogenic tank, is in the method of suspending the inner pressure vessel within the outer tank. The CFI suspension system features an all composite, central support beam, with discreet internal load bearing points, as opposed to conventional, load bearing supports at each end of the tank. This design effectively reduces the conductive heat transfer into the stored LNG to less than 13% of the total system heat leak. (Ref. Fig. 5)

Figure No. 5 Beam Suspension System

This central support beam is designed for reacting high static and dynamic, vehicular induced loading, while at the same time providing a very low conductive heat path into the inner tank. The support beam assembly consists of a composite tubular structure installed within a stainless steel pipe. The beam design incorporates discreet radial pads, that react the applied loading and provide the only contact points with the steel pipe assembly. The distance between these inner thermal contact points to the outer tank shell is the primary reason that the conductive heat leak of the BW/CFI tank system can be reduced by a factor of 4 to 1 over conventional industrial cryogenic tanks.

The central beam suspension system is a very rugged design that is capable of surviving in the severe operating environment of transit buses and heavy duty trucks. As part of the design verification process the "tank system" was subjected to dynamic structural testing by Mack Truck at their Allentown truck test facility. Shock loads of 3.5 G's were induced for a total of 308,000 cycles to simulate 500,000 miles of operational service. The testing was performed at cryogenic temperatures without loss of vacuum and all system components functioned normally during and after testing. (Ref. Fig. 6)

Figure No. 6 Mack Truck Structural Testing

Thermal Performance: In the final analysis there are three modes, or mechanisms, of heat transfer that affect the thermal performance of any cryogenic container, radiation, convection and conduction,. As a result of the reduction in conductive heat transfer, with the beam suspension system, it was determined that thermal performance could be further enhanced by reducing the "heat leak" via the convection and radiation modes. This was achieved, by BW/CFI, with innovations in vacuum acquisition and multi-layer insulation materials. The end result is a 4 to 1 improvement in thermal performance of the "advanced technology" LNG fuel system compared to the conventional industrial type cryogenic tank. (Ref Fig. 7)

Figure No. 7 Thermal Performance Comparison

By achieving this level of thermal performance it was then possible to incorporate a fuel conditioning and control strategy for the system that would assure reliable fuel delivery to the engine, at the required flow, pressure, density and quality.

Fuel Delivery Strategy: Since it is not necessary to withdraw vapor from the BW/CFI tank, in order to maintain the system operating pressure, liquid only may be withdrawn from the bottom of the tank and maintained as a single phase, "Zero Quality" liquid from the tank, through the fuel flow manifold and into the heat exchanger where it is vaporized. Having this capability, to withdraw liquid only from the tank, eliminates any pressure decay, due to vapor withdrawal. Using this strategy the operating pressure of the tank is totally independent of the LNG saturation pressure, and can be maintained in thermal balance from tank full to tank empty conditions.

Fuel flow from the tank is pressure driven and is initiated by activation of the engine vacuum manifold switch, which in turn, provides 12 vdc electrical power to the fuel delivery solenoid valve and the pressure management solenoid valve. There are no manual valves required to operate or fuel the BW/CFI tank system. However, a manual valve is installed directly on the vapor line of each tank, in order to comply with Section 2.3.4. of NFPA-57. This valve is required, as an emergency or as a service valve, to isolate an individual tank from the rest of the fuel system.

In accordance with the existing codes and regulations, NFPA-57, California, Title 13 and the Texas Railroad Commission, manual or remotely operated valves are required on both the vapor and the liquid lines of each individual tank. The codes do not address the issue of multiple tanks, installed as a modular unit, that may be controlled and/or served by common plumbing with one pair of control valves.

Fuel delivery from multiple BW/CFI tank installations may be, depending on user requirements, in parallel with individual fuel lines to a common fuel manifold, or in series with fuel delivery cascaded from tank to tank to the manifold. If equal depletion is specified, parallel flow paths to the fuel manifold (reservoir), are recommended. For most other applications the series (cascade) depletion method is recommended. This design approach has fewer control components, costs less and is not as susceptible to tank pressure differential or liquid level "head" differential between individual tanks.

Pressure Management: Historically, the “industrial gas” business sector and the engine manufacturers have specified that the saturation pressure of the LNG must be at or slightly above the minimum operating pressure of the engine. With a “liquid only” fuel flow capability, the BW/CFI fuel tank pressure management design incorporates a more conventional pressurization concept where the tank pressure may be maintained, totally independent of the saturated pressure of the LNG. The design parameters for the CFI pressure management subsystem, including pressure build rate, fluid flow rate vs. tank volume were thoroughly analyzed and verified in actual depletion runs in early 1990. LNG flow testing was performed using both 20 gallon and 50 gallon tank sizes. Flow rates of up to 160 lb/hr were maintained from tank full to tank empty conditions to establish the decay rate for LNG at saturated pressures of under 20 psi. The magnitude of the average pressure decay rates observed during these tests were also later confirmed by computer modeling of simulated depletion tests runs at different pressures and flow rates. The results, of a typical computer run on a 110 gallon tank, flowing liquid only, at four (4) different operating pressures, are shown below in Figure 8.

Figure No. 8 Pressure Decay at 200 lb/hr Flow

It was also determined that variations in the pressure decay rate, as a function of tank size or flow rate, were very slight. This was attributed to the very low heat leak of the tank. Even at extreme difference's in flow rates of 20 lbs/hr vs 160 lbs/hr the variations in tank pressure decay were less than 1 psi at the completion of the test runs. Based on this information it was possible to determine the amount of liquid flow and pressure differential that would be required to drive the fluid into the pressurization coil of the dual function heat exchanger for expansion and return to the vapor space of the tank. The CFI external pressurization circuit may be controlled by either a conventional pressure regulator or a pressure switch/solenoid valve combination. The desired tank pressure can be pre-set in either case. For multi-tank installations the pressurization circuit is plumbed to provide equal tank pressure and thermal balance to all tanks.

The rate of tank pressurization is influenced by a number of variables including, engine coolant flow rate, heat exchanger coil size, sizing of the control components and most importantly, LNG fuel quality. The flow must be single-phase, liquid only, into the heat exchanger in order to produce the liquid to gas expansion ratio that is required for tank pressurization, from tank full to tank empty conditions.

One of the primary objectives of the Brookhaven contract was to test and demonstrate advanced cryogenic tank technology that would improve the market viability of LNG as a vehicular fuel for trucks and buses. This objective has been achieved. Specific benefits to be derived from the BW/CFI technology may be summarized as follows:

- **Weathering:** With "liquid only" fuel withdrawal, the weathering of LNG in the vehicle tank has been eliminated; therefore, the need for 98% methane content is no longer valid and the per gallon cost of LNG can be reduced by at least ten cents.
- **Fueling Facility Cost Reduction:** With an on-board system pressurization capability it is not necessary to precondition the LNG to maintain tank pressure. This feature alone simplifies fueling operations and reduces the cost of LNG fueling facilities.

Engineering

The engineering services performed, in support of the Phase I Brookhaven program, were provided by Cryogenic Fuels under a subcontract from Snyder Tank Corporation. CFI engineering personnel also designed and prepared the procurement specifications for the vacuum acquisition system that was used to pump the ultra-high vacuums that are unique to the BW/CFI tank technology. On-site technical support and overall program coordination was also provided by CFI personnel during the fabrication and testing of the tanks

Engineering Drawings and Tank Specifications:

- A summary of the engineering production drawings and design specifications for the SC-60-22-1 fuel tank is provided in Exhibit A of this report.
- A summary of the engineering production drawings and design specification for the SC-100-26-1 fuel tank is provided in Exhibit B of this report.

Tank Structural Analysis:

A formal structural analysis was prepared on the 60 gallon tank pressure vessel. The analysis includes the cylinder and head shells under pressure loading and conforms to applicable paragraphs of DOT 178. 57 specification 4L. The analysis uses the allowable tensile and yield stress for the ASTM-A 240 type 304 stainless steel used to fabricate the pressure vessel and defines the maximum service pressure for the tank. (Ref. Exhibit H)

Thermal Performance Analysis:

This analysis is required to certify compliance with the applicable sections of NFPA-57, California Title 13 and the Texas Railroad Commission, pertaining to allowable pressure build-up and no-vent standby time in LNG vehicle fuel systems. (Ref.Exhibit G)

Vacuum Acquisition System:

The average service vacuum in industrial cryogenic tanks is typically in the 10^{-4} Torr range. These vacuum levels are usually obtained with diffusion type vacuum roughing pumps in combination with a turbo molecular pump for final pumping. This service vacuum was considered adequate since the conductive heat leak of the industrial tank is quite high and can account for as much as 70% of the total heat leak into the tank. For this reason an improvement in vacuum was not considered to be cost effective compared to the minimal increase that could be gained in the thermal performance of the tank.

However, with the development of the CFI beam suspension system and the reduction in conductive heat leak it became both feasible and fairly simple to improve the thermal performance of the tank even further by increasing the vacuum levels into the 10^{-6} Torr range. This was accomplished, with the CFI designed vacuum acquisition system, by utilizing a CTI Corporation, On-Board Cryopump as a third stage vacuum pump-out process, in combination with the conventional diffusion roughing pump in stage one and a turbo pump process in stage two. (Ref. Figure 9, Page 20)

The cryopump has the highest water vapor pumping speed of any vacuum pump technology available today. Since water vapor comprises over 97% of the residual gas load in the tank at 10^{-3} Torr and below it is essential to maximize water vapor pumping speed in order to reduce pumpdown time.

During the course of this program the CTI On-Board Cryopump has been demonstrated to be an effective and economical method of adding cryogenic speed to turbo pumped and diffusion pumped vacuums without the cost and labor involved with liquid nitrogen based cryopumps. The vacuum acquisition system demonstrated under Phase I of the Brookhaven program is capable of pumping twenty (20) 100 gallon size tanks to a hard vacuum level of 10^{-6} Torr in approximately 96 hours.

Figure No. 9 Vacuum Acquisition System

Manufacturing

A total of eight (8) tanks were manufactured and tested during Phase I of this contract.

The tank serial numbers and end -use designation are as follows :

End- Use: Gary Transit Bus No. 1 Serial No. 69902-001

69902-002

66902-003

Gary Transit Bus No. 2 Serial No. 69902-004

66902-005

66902-006

Drop Test, DOT Certification Serial No. 69907-009

Projectile Penetration, Serial No. 69907-006

Testing

The product test program established for the BW/CFI tank assures code compliance with the following codes and regulations, as they pertain to the design and test of the relief system and the thermal performance of the tank.

NFPA-57, 1999 Edition, Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems, Section 2-4.1 Pressure Relief Devices in accordance with *CGA Standards S-1-1, Pressure Relief Device Standards-Part 1 - Cylinders for Compressed Gasses* and *S-1-3 Pressure Relief Standards- Part -3 - Compressed Gas Storage Containers*.

Section 2-3.5 Heat Leak (Thermal Performance)

Title 13 California Highway Patrol, Section 935 Para. (a) 1 (Thermal Performance) & Para (b) 1 Safety Relief Valves

Texas Railroad Commission, LIQUEFIED NATURAL GAS REGULATIONS

DOT CFR-49 Part 178.57-13 Pressure Relief Devices

End Item Acceptance Testing (EIAT) : This test is performed on each individual tank to verify thermal performance (no-vent standby time), pressurization and activation of both the primary and the secondary relief devices. The quantity gauging system is also tested and calibrated during this test sequence. Acceptance testing is also required on multi-tank fuel systems to confirm satisfactory operation of the pressure management system while monitoring fuel deliver and tank depletion performance. Several examples of typical test documentation have been selected from the more than 200 hours of EIAT recorded data and are presented on the following pages. (Ref. Fig. 10 & 11)

**SNYDER TANK CORP.
END ITEM ACCEPTANCE TEST
PROCEDURE**

TEST:	PROCEDURE NO.	TEST ENGINEER:	DATE:
TEST ARTICLE:	PART NO.:	S/N:	W.O.

TEST OBJECTIVES:

1. Quantity gauge calibration and operation.
2. Test primary and secondary relief devices.
3. Verify thermal performance

PROCEDURE:

1. Refer to EIAT "test setup".
2. Place tank in fixture LG-1, record dry weight and calibrate quantity gauge per Essex procedure.
3. Set LN₂ tank regulator @ 65 psi, open MV-1 and fill "test tank" with 23 gallons of LN₂ (approximately 155 lbs.), record tank weight. Close MV-1 and allow tank temperature to stabilize for six (6) hours.
4. Record tank weight and pressure. Open MV-1 and fill tank until liquid flow is achieved thru MV-3.
5. Close MV-3, allow tank pressure to stabilize @ 65 psi. Close MV-1. Record weight and pressure at lock-up.
6. Verify quantity gauge operation and calibrate per Essex procedure.
7. With MV-2 open, record pressure and time up to RV-1 crack (84 to 92 psi). Record vent flow rate.
8. Close MV-2 and increase tank pressure until RV-2 is activated. Record crack pressure (109 to 122 psi).

**SNYDER TANK CORP.
END ITEM ACCEPTANCE TEST
DOCUMENTATION**

TEST: <u>EIAT</u>	PROCEDURE NO.	TEST ENGINEER:	DATE: <u>4-1-99</u>
TEST ARTICLE: <u>60 GAL TANK</u>	PART NO.:	S/N: <u>002</u>	W.O.

QUANTITY GAUGE CALIBRATION		NOMINAL	ACTUAL	TANK WEIGHT (GROSS)
	% Full			
• Empty	-0-	240-360 pf	<u>286</u>	
	25			
	50			
	75			
• Full	100	300-420 pf	<u>324</u>	<u>389</u>
• Tank full light		300-420 pf		
THERMAL PERFORMANCE				
• Tank wt. 30% full (23 gallons) ...		155 lbs. LN ₂		
• Tank wt. 90% full (60 gallons) ...		403 lbs. LN ₂	<u>389</u>	
• Lock up time		120 hours		
RELIEF SYSTEM TEST				
• Lock-up pressure		65 psi	<u>44 PSI</u>	
• RV-1 crack		84 to 92 psi	<u>93.5</u>	
• Vent rate		.084 lbs/ (GN ₂)	<u>Full</u>	
• RV-2 crack		109 to 121 psi	<u>121.6</u>	<u>387.6</u>

Comments: AFTER RV-2 RESET PRESSURE IS @ 2.0 PSI

Figure No. 10 Test Report and Procedure

Figure No. 11 Test Setup Schematic

Instrumentation and Data Acquisition: As can be seen from the test setup schematic, the computer controlled data acquisition system was designed to provide a continuous record of the critical test parameters, including pressure, temperature, fuel flow and tank depletion. Thermocouples and pressure transducers were installed at critical locations throughout the plumbing manifold to monitor the temperature/pressure changes that occur in the LNG as flow is initiated from the tank, into the dual function heat exchanger/vaporizer and on to the first stage regulator on the engine test stand. Load cells under each tank provide real time data regarding fuel depletion rates and residual fuel levels during the test run. In addition to being recorded the test data is also presented in real-time for visual observation by engineering test personnel during the course of the test run. (Ref. Figure No. 13)

Engine Test Stand: A modified, 6.0 Liter, dedicated natural gas engine, coupled to a portable dynamometer is used to impose load and power requirements on the LNG fuel system to simulate a range of operating conditions to which it could be subjected to in truck and bus fleet operations. (Ref. Figure No. 12)

Figure No. 12 Natural Gas Engine Test Stand

Figure No. 13 Test Data Format

Depletion and Pressure Management: The nominal operating pressure of the LNG fuel tanks produced and tested during Phase I of the Brookhaven contract is 50 to 65 psi. The primary relief is rated at 92 psi and the secondary relief is set at 115 psi. Both the Cummins and Detroit Diesel dedicated natural gas engines operate within this pressure range. The test plan for the pressure management system on the BW/CFI fuel tank was designed specifically to verify the response time and the pressure build capability for single tank and multi-tank LNG fuel systems. The following test reports were selected as examples of the test results obtained during this phase of the test program.

- Cantest-E-F, Single Tank; Test objective was to establish response time and pressure build rate with solenoid valve/pressure switch control configuration. Residual fuel level at 50 %. Result: Fast response, pressure build @ + 10 seconds. (Ref. Fig. 14)
 - Cantest-E-E, Single Tank; Test objective was to establish response time and pressure tolerance of the A-36 regulator with a 8241 spring. Residual fuel level was under 50%. Result; Tank pressure stabilized within 1 psi of regulator setting. (Ref. Fig. 15)
 - Cantest-E-E-F, Single Tank; Test objective was to compare the pressure build rate and response time of the 8240 spring with Cantest-E-E. Result; Slower response time but well within the desired pressure build rate. (Ref. Fig. 16)
 - Cantest-L-W, Three Tank Module; Test objective, determine maximum pressure build capability from 30 psi (dispenser discharge pressure) to 75 psi, upper operating pressure limit. Result 160 psi/hr pressure build rate. (Ref. Fig. 17)
 - Cantest-L-W (Rerun) Same as above with start pressure set at 60 psi. Result, pressure build rate 77 psi/hr. (Ref. Fig. 18)
 - Cantest-L-W-A, Three Tank Module; Test objective, build and maintain system operating pressure during extended depletion run. Result, pressure build and fuel flow to engine were within specified limits. (Ref. Fig. 19)
 - Cantest-L-W-B/C, Three Tank Module; Continuation of Cantest-L-W-A above. Test results were within specified limits. (Ref. Fig. 20)
-

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)						Date: 8/31/99			
Test Procedure: Depletion and Pressure Management						Test Article: 60 Gallon LNG Tank						Part No. 60-1000-1			
Test		Cantest- E-F Single (1) Tank — (Ref. Fuel System Test Schematic Drawing 60-5003 (Rev. A)										Test Eng: Werkmeister			
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		*Engine Flow Rate	
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour	
8/31	18:50	30.8	60.1	19.1	91.0	6.5	92.6	+12°	+74°	+72°	+84°	57			
	18:59	30.0	67.1	18.9	91.3	6.2	92.7	-236°	+22°	-57°	+150°	67			
	19:08	29.2	79.4	19.0	91.6	6.5	92.7	-240°	+12°	-172°	+147°	79			
28															
Totals	18 min.	-1.6	+19.3	—	—	—	—	—	—	—	—			5.6	

Test Setup:

Regulator position: Replaced by solenoid valve SV-4	Solenoid valve mode:
Regulator spring No: --	SV-1: Energized (open)
Regulator Pressure Setting: --	SV-2: De-energized (closed)
Manual valve mode:	SV-3: De-energized (closed)
MV-1: Closed	Type heat exchanger: Dual Hex
MV-2: Closed	
MV-3: Closed	Check valve location: Between fuel flow manifold and SV-4
*Fuel flow control: By engine only	Check valve crack pressure: 1 psi

Test Summary:

- Fuel flow controlled by engine @ 5.6 GPH
- Positive gas flow in pressure build circuit during test
- Fast response, positive pressure build @ +10 seconds

Comments:

Figure No. 14 Cantest E-F

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)				Date: 9/1/99				
Test Procedure: Depletion and Pressure Management						Test Article: 60 Gallon LNG Tank				Part No. 60-1000-1				
Test		Cantest- E-E Single (I) Tank — (Ref. Fuel System Test Schematic Drawing 60-5003 (Rev. A) (Rerun with 8241 spring)										Test Eng: Werkmeister		
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		*Engine Flow Rate
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour
9/1	16:55	23.6	70.0	57.3	47.3	56.0	44.0	+32°	+79°	+51°	+126°	68		
	17:08	22.1	74.1	57.5	45.5	55.9	43.1	-239°	-81°	-156°	+148°	74		
	17:20	21.1	76.3	57.3	45.0	56.1	42.4	-242°	+75°	-174°	+144°	76		
29														
Totals	25 min.	-2.5	+6.3	—	—	—	—	—	—	—	—			5.6

Test Setup: Regulator position: 4 in. from dual hex
 Regulator spring No: 8241 (75-150 psi range)
 Regulator Pressure Setting: 75 psi
 Manual valve mode:
 MV-1: closed
 MV-2: closed
 MV-3: closed
 *Fuel flow control: By engine only

Solenoid valve mode:
 SV-1: Energized (open)
 SV-2: De-energized (closed)
 SV-3: De-energized (closed)
 Type heat exchanger: Dual Hex
 Check valve location: Under fuel flow manifold
 Check valve crack pressure: 1 psi

Test Summary:

- Fuel flow controlled by engine @ 5.6 GPH
- Positive gas flow in pressure build circuit during test
- This test is a re-run of cantest E-E with 8241 spring

Comments:

Figure No. 15 Cantest E-E

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)						Date: 9/1/99			
Test Procedure: Depletion and Pressure Management						Test Article: 60 Gallon-3 Tank System						Part No. 60-1000-1			
Test		Cantest- E-E-F Single (1) Tank — (Ref. Fuel System Test Schematic Drawing 60-5003 (Rev. A) (8240 Spring Repeat)										Test Eng: Werkmeister			
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		*Engine Flow Rate	
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour	
9/1	15:28	30.4	61.5	57.1	55.1	55.7	56.0	+105	+78	+79°	+76°	61			
	15:46	28.3	65.9	57.2	49.5	56.1	51.6	-243	+98	+141°	+149°	66			
30	16:04	26.5	70.6	57.2	46.5	57.2	49.2	-246	+70	-180°	+145°	70			
	16:22	24.5	73.1	57.2	44.1	56.1	46.8	-245	+78	-130°	+145°	73			
Totals	54 min.	-5.9	+11.4	—	—	—	—	—	—	—	—			6.0	

Test Setup: Regulator position: 4 in. from hex
 Regulator spring No: 8240 (40-80 psi range)
 Regulator Pressure Setting: 75 psi
 Manual valve mode:
 MV-1: Closed
 MV-2: Closed
 MV-3: Closed
 *Fuel flow control: By engine only

Solenoid valve mode:
 SV-1: Energized (open)
 SV-2: De-energized (closed)
 SV-3: De-energized (closed)
 Type heat exchanger: Dual purpose
 Check valve location: Under fuel flow manifold
 Check valve crack pressure: 1 psi

Test Summary:

- Fuel flow controlled by engine @ 6.0 GPH
- Positive gas flow in pressure build circuit during test
- This test was repeated to confirm performance of 8240 spring on 8/31 cantest-E-E

Comments:

Figure No. 16 Cantest E-E-F

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)						Date 9/3/99		
Test Procedure: Depletion and Pressure Management						Test Article: 60 Gallon (3) Tank						Part No. 60-1001-1		
Test		Can Test - L-W, Three (3) Tanks (Ref. Fuel System Test Schematic Drawing: 60-5003 (Rev. A))										Test Eng: Werkmeister		
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		*Engine Flow Rate
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour
9/3	17:04	47.3	36.3	53.3	36.7	51.1	36.6	+97°	+85°	+84°	+82°	35		
	17:12	46.2	40.9	53.2	41.2	51.3	40.8	-249°	-28°	-162°	+159°	39		
31	17:20	44.6	76.7	55.7	77.3	48.7	77.3	-237°	-20°	-172°	+167°	76		
Totals	16 min.	-2.7	+40.4	+2.4	+40.6	-2.4	+40.7							10.8

Test Setup: Regulator position: 4 in. from dual hex
 Regulator spring No: 8241 (75-150 psi range)
 Regulator Pressure setting: 75 psig
 Manual valve mode:
 MV-1 open
 MV-2 open
 MV-3 closed

*Fuel flow control: By engine only

Solenoid valve mode:
 SV-1 Energized (open)
 SV-2 Disconnected (closed) @ +2 min.
 SV-3 Disconnected (closed) @ + 1 min.

Type heat exchanger:

Check valve location: At bottom of fuel flow manifold

Check valve crack pressure: 1 psi
 Pressure build return line to tank No. 3

Test Summary:

- Fuel flow controlled by engine @ 10.8 GPH
- Positive flow at pressure build circuit
- Regulator approx. 3 psi above set pressure
- Pressure build rate projected at 160 psi/hr+

Comments:

Figure No. 17 Cantest L-W

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)						Date 9/9/99		
Test Procedure: Depletion and Pressure Management						Test Article: 60 Gallon (3) Tank						Part No. 60-1001-1		
Test		Can Test - L-W, Three (3) Tanks (Ref. Fuel System Test Schematic Drawing: 60-5003 (Rev. A) (Rerun)										Test Eng: Werkmeister		
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		*Engine Flow Rate
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour
9/9	11:17	37.9	57.9	44.5	58.3	38.3	58.2	+2°	+72°	+9°	+89°	57		
	11:28	35.1	81.2	44.7	81.8	38.1	81.7	-228°	-13°	-165°	+129°	77		
32	11:38	32.7	84.7	44.7	85.1	38.3	85.1	-228°	+71°	-164°	+162°	87		
Totals	21 min.	-5.2	+26.8	+0.2	+26.8	-0.0	+26.9							16.2

Test Setup: Regulator position: 4 in. from dual hex
 Regulator spring No: 8241 (75-150 psi range)
 Regulator Pressure setting: 75 psig
 Manual valve mode:
 MV-1 open
 MV-2 open
 MV-3 closed

*Fuel flow control: By engine only
 Cascade series fuel delivery

Solenoid valve mode:
 SV-1 Energized (open)
 SV-2 Disconnected (closed)
 SV-3 Disconnected (closed)

Type heat exchanger: Dual hex

Check valve location: Under fuel flow manifold

Check valve crack pressure: 1 psi
 Pressure build return line to tank no. 3

Test Summary:

- Fuel flow controlled by engine @ 16.2 GPH
- Positive flow in pressure build circuit
- Regulator was not set at 75 psig
- Pressure build rate projected at 77 psi/hr

Comments:

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)				Date: 9/9/99				
Test Procedure: Depletion and Pressure Management						Test Article: 60 Gallon Three (3) Tank System				Part No. 60-1000-1				
Test		Cantest- L-W-A Three (3) Tanks, (depletion run) — (Ref. Fuel System Test Schematic Drawing 60-5003 (Rev. A))								Test Eng: Werkmeister				
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		*Engine Flow Rate
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour
9/9	13:57	13.8	50.5	59.9	50.6	59.9	50.3	+93°	+73°	+68°	+73°	50		
	14:42	32.6	83.2	44.7	83.8	45.7	83.7	-233°	-13°	-168°	+142°	82		
33	15:27	21.5	79.6	43.9	80.4	45.5	80.4	-287°	+72°	-146°	+129°	79		
	16:01	13.4	78.6	43.4	79.4	45.4	79.1	-290°	+71°	-38°	+126°	77		
Totals	124 min.	-0.4	+28.1	-16.5	+28.8	-14.5	+28.8							15.7

Test Setup:
 Regulator position: 4 in. from dual hex
 Regulator spring No: 8241 (75-150 psi range)
 Regulator Pressure Setting: 75 psig
 Manual valve mode:
 MV-1: open
 MV-2: open
 MV-3: closed
 *Fuel flow control: By engine only

Solenoid valve mode:
 SV-1: Energized (open)
 SV-2: De-energized (closed)
 SV-3: De-energized (closed)
 Type heat exchanger: Dual hex
 Check valve location: Under fuel flow manifold
 Check valve crack pressure: 1 psi
 Cascade, series fuel delivery

Test Summary:

- Fuel flow controlled by engine @ 15.7 GPH
- Positive flow in pressure build circuit
- Pressure build response @ +4 minutes
- Pressure build up to 8 psi above regulator set point

Borg Warner Air/Fluid Systems						End Item Acceptance Test (EIAT)						Date 9/10/99			
Test Procedure: Depletion and Pressure Management						Test Article:						Part No. 60-1000-1			
Test		CANTEST-LW-B&C (Ref. Fuel System Test Schematic Drawing: 60-5003 (Rev. A) Three (3) Tank (Depletion Run)										Test Eng: Werkmeister			
Parameters		Tank No. 1		Tank No. 2		Tank No. 3		Temperature (°0 F)				Pressure (psig)		•Engine Flow Rate	
Date	Time	W-1 Fuel (gallons)	P-1 Pressure (psig)	W-2 Fuel (gallons)	P-2 Pressure (psig)	W-3 Fuel (gallons)	P-3 Pressure (psig)	T-1	T-2	T-3	T-4	P-4		Gallons per hour	
9/10	7:32	18.4	70.2	36.3	70.3	39.2	70.0	+94°	+73°	+70°	+69°	69			
	8:14	7.1	78.9	35.3	79.7	39.2	79.6	-271°	+77°	-64°	+129°	78			
34	8:54	3.7	75.1	29.2	76.1	39.1	76.2	-290°	+66°	+49°	+133°	73			
	9:39	3.6	75.0	21.7	76.0	39.1	76.0	-278°	+69°	+61°	+126°	73			
Totals	127 min.	-14.8	+4.8	-14.6	+5.7	-0.1	+6.0							15	

Test Setup: Regulator position: 4 in. from dual hex
 Regulator spring No: 8241 (75-150 psi range)
 Regulator Pressure setting: 75 psig
 Manual valve mode: Open
 MV-1: Open
 MV-2: Open
 MV-3 Closed
 *Fuel flow control: By engine only

Solenoid valve mode:
 SV-1: Energized (open)
 SV-2: De-energized (closed)
 SV-3: De-energized (closed)
 Type heat exchanger: dual hex
 Check valve location: Under fuel flow manifold
 Check valve crack pressure: 1 psi
 cascade series, fuel delivery

Test Summary:

- Fuel flow controlled by engine @ 15.0 GPH
- Positive flow in pressure build
- Pressure controlled by regulator
- Pressure build max. = 8 psi

Comments:

Regulator opened briefly at start of test.

Figure No. 19 Cantest L-W-B&C

EXHIBIT A

60 GALLON LNG FUEL TANK

DRAWING LIST

60 Gallon LNG Fuel Tank Drawing List

Model 60-22-1

Drawing No.	Title	Revision
60-0000-1	Sheet 1 Gary General Arrangement	
60-0000-2	Sheet 2 Gary General Arrangement	
60-0000-3	Sheet 3 Dallas General Arrangement	
60-1000	Tank assembly	
60-1000	Tank assembly sheet 2	
60-1000	Tank assembly sheet 2	A
60-1004	Quantity gauge system	
60-2000	Beam assembly	
60-2001	Entrant tube assy	
60-2002	PV assembly	B
60-2003	Head assy O.S. component end	B
60-2004	Head assy O.S. plain	
60-2005	Insulation installation	
60-3000	Center tube	
60-3001	PV head plain end	
60-3002	PV head component end	
60-3003	Head O.S. component end	A
60-3006	Elbow vent	
60-3007	Pin cap beam	
60-3008	Pin support tube	
60-3009	Weld stand-off tube	
60-3010	weld stand-off cap	
60-3011	Support beam	
60-3012	Adapter entrant tube	
60-3013	Adapter, pumpout valve	
60-3014	Rod antirotation	
60-3015	Bracket ent tube sup	
60-3016	Support probe	
60-3017	Manifold block	A
60-3018	Bracket	B
60-3019	Bracket solenoid valve	B
60-3020	"T" assy	

60 Gallon LNG Fuel Tank Drawing List (Continued)

Drawing No.	Title	Revision
60-3021	Entrant tube	
60-3022	Spacer	
60-4000	Beam	C
60-4001	Head pressure vessel	A
60-4002	Heat outer shell	A
60-4003	Signal Conditioner	
60-4004	Probe Assy	
60-4005	Cable Assy	
60-5000	Fluid Schematic	
60-5001	Electrical Schematic	
60-5002	Cascade Sys/Eng. Test	
60-1001	Plumbing assy Gary	
60-1003	Plumbing assy Dallas	
60-2006	Plumbing Assy Vent	
60-2007	Sol Valve Assy	
60-2007	Sol Valve Assy	A
60-2008	Tube Assy Supply	
60-2009	Tube Assy Pressure Build	
60-2010	Tube Assy Fill/Vent	
60-2011	Tube Assy Fill	
60-2012	Tube Cascade Fill	
60-2013	Manifold, "Y" Block Assy	
60-2014	Tube Assy Bus Vent	
60-2015	Tube Assy Pressure Build Return	
60-2016	Tube Assy Hx	
60-2017	Tube Assy Backup Pressure Relief Hose	
60-2018	Tube Assy Eng Gas Supply	
60-2019	Tube Assy, Solenoid Valve Input	
60-3023	Tube, Supply Tnk 1	
60-3024	Tube, Supply Tnk 3	
60-3025	Manifold, "Y" Block	
60-3026	Tube, Solenoid Input	

60 Gallon LNG Fuel Tank Drawing List (Continued)

Drawing No.	Title	Revision
60-3027	Tube, Solenoid	
60-1002	Dual Hx	
60-3028	Tube Dual Hx	
60-3029	Plate, End Hx	
60-3030	Tube Coil Hx	
60-3031	Tube Pressure Build Hx	
60-1002	Dual Hx	
60-3028	Tube Dual Hx	
60-3029	Plate, End Hx	
60-3030	Tube Coil Hx	
60-3031	Tube Pressure Build Hx	
60-4006-1	Relief Valve, SCD	
60-4006-2	Relief Valves, SCD	
60-4007-1	Pressure Switch Gary #1, #2	
60-4007-2	Pressure Switch Dallas	

EXHIBIT B

100 GALLON LNG FUEL TANK

DRAWING LIST

100 Gallon LNG Fuel Tank Drawing List

Drawing No.	Title	Revision
P90034	Head Pressure Vessel	C
P90035	Heat Outer Shell	E
90036	Tank Assembly	F
9003602	Pressure Vessel Insulation	C
9003603	Rear Outer Shell Assembly	H
9003604	Front Outer Shell Assembly	E
90037	Pressure Vessel Assembly	F
BA90042	Beam Assembly	D
P90042	Pressure Vessel Support Beam	E
100-2001	Entrant Tube Assy	D
P-ST90046	Serpentine Tube	E
90046	Serpentine Tube	
100-4004	Probe Assy	
100-1004	Qty Guage System	
100-4003	Signal Conditioner	
100-4005	Cable Assy	
P-90047	Shroud Assy	
P-MB90047	Mounting Bracket Assy	
90050	General Arrangement 100-26-1	A
90089	Bracket Entrant Tube	
90090	Bracket Probe	
90092	General Arrangement 100-26-2	
90093	Vacion Pump	
90094	Vacion Pump Adapter	
90095	Shroud	
90096	Vacion Assy	
T99000	Plumbing Schematic	
T98000-1	Electrical Schematic	A
T-101000	SCD Pressure Switch	
T-100000	SCD Solenoid Valve	
T-104000	SCD Disconnect Plug	
T-102000	SCD Relief Valve	

100 Gallon LNG Fuel Tank Drawing List (Continued)

Drawing No.	Title	Revision
T-105000	SCD Vacuum Seal Off Valve	
90091	Tank Assy	
T-9000	LNG tank pressure vessel support beam assembly layout - 100 gallon (useable) quantity; 26 in. OD. tank	B
T-11000	Pressure vessel support beam 100 gallon (useable quantity); 26 in. O.D. LNG fuel tank	A
T-13000	Component/plumbing mounting panel - 100 gallon (useable) quantity; 26 in. O.D. LNG fuel tank	B
T-15000	Component flow control module - 100 gallon (useable) quantity; 16 in. O.D. LNG fuel tank	E
T-17000	LNG fuel tank fluids control and conditioning plumbing assembly 26 in. O.D. Tank (sheets 1 and 2)	A
T-37000	Flow transition fitting - 100 gal. LNG tank	A
T-41000	Heat exchanger - optional tank pressurization - 26 in. O.D.; LNG fuel tank assembly	A
T-45000	Supply line tube assy, 100 gal. useable LNG fuel tank	C
T-47000	Vent tube assembly 26 in. O.D. LNG fuel tank	
T-49000	Fill tube assembly - 26 in. O.D. LNG fuel tank	
T-51000	Relief valve tube assembly - 26 in. O.D. LNG fuel tank	
T-59000	Fill/vent quick disconnect scupper assembly	
T-61000	Pressure build/pressure control tube assembly 100 gallon (useable) LNG fuel tank	D
T-63000	Pressure build/pressure control tee assembly 100 gallon (useable) LNG fuel tank	C
T-65000	Tank vent tube assembly 100 gallon (useable) LNG Fuel Tank	
T-67000	Tank fill tube assembly 100 gallon (useable) LNG fuel tank	A
T-69000	Relief valve tube assembly 100 gallon (useable) LNG tank	
T-71000	Flow control assembly structural interface - 100 gallon (useable) LNG fuel tank	
T-73000	Flow control assembly tank shroud plumbing interface 100 gallon (useable) LNG fuel tank	
T-75000	Fill/vent cap assembly 100 gallon (useable) LNG fuel tank	
T-77000	Flow control assembly entrant tube fill & vent plumbing interface - 100 gal. (useable) LNG fuel tank	
T-81000	Test schematic - LN ₂ loading plan for LNG tank drop testing.	

100 Gallon LNG Fuel Tank Drawing List (Continued)

Drawing No.	Title	Revision
T-87000	Electrical wiring installation 100 gallon LNG tank	
T-89000	Bracket, support-tank fluids control and conditioning	D
T-91000	Placard - 100 gallon LNG fuel tank flow control assy	
T-90000	Closed cell foam pipe insulation - 100 gallon LNG fuel tank	
T-92000	Roadway - dual tank fill plumbing schematic	1/9/95
T-95000	Cross interface assy	1/11/95
T-96000	Tee interface assy	1/11/95
T-97000	Tube assembly brackets	2/28/95
T-98000-1	-Baseline- Electrical schematic - LNG fuel system - models SC 20 thru 100 gallon	3/20/95
T-99000-1	-Baseline- Plumbing schematic - cascade multiple tank fill system models SC 20 thru 100 gal.	6/1/96
T-100000	-Specification Control - Valve - solenoid	6/2/96
T-101000-1	LNG Fuel system -Specification Control-100 gal. Pressure switch	
T-102000	LNG Fuel System -Specification Control- 100 gal. Valve -relief	
T-103000	LNG Fuel System -Specification Control- Rupture Disc	
T-104000	LNG Fuel System Specification Control Quick Disconnect Plug	
T-105000	Specification Control LNG Fuel System - Vacuum "Seal Off" valve	
T-107000	Tank Vent Tube	

Exhibit C
Mack Truck Inc.
Structural Test

**MACK TRUCKS, INC.
VEHICLE DEVELOPMENT LABORATORY
ENGINEERING REPORT**

TITLE: E7 WITH NATURAL GAS - SNYDER LNG TANK BUMP
TEST

REPORT NO. ERV 96-194-C
DATE 11/4/97
REF. FILE NO. 17-B-1

PROJECT:

Snyder Tanks has recently entered the market as an LNG fuel tank and fuel system supplier and has proposed an LNG system for MR/LE models. RFV 96-194 was written requesting the VDL to conduct performance and durability evaluations on the proposed system. TP96-194-B was written to conduct a bump machine test on the proposed Snyder tank. ERV 96-194-B was issued with the results of this testing. The first sample did not meet the test criteria.

A second sample with design iterations was submitted for testing and TP 96-194-C was issued to cover this testing.

Bump testing was conducted per VDLP- 3.03. The tank was filled with nitrogen prior to testing to a combined tank and nitrogen weight of 808 lbs. The tank met the test criteria and is acceptable for production.

☒ **NO ACTION REQUIRED**

☒ **ORIGIN:** RFV 96-194 DATED 9/23/96 BY JOHN O'GRADY

☒ **KEY WORDS:** MR, LE, BUMP MACHINE, FUEL SYSTEM

ASSIGNED TO: W.J.BALDWIN

REVIEWED BY: W. J. Baldwin

REPORTED BY: W.J.BALDWIN

DATE: 11/4/97

MANUFACTURING ENGINEERING APPROVAL (when applicable) :

DATE:

VDLP NO. 3.03

☒ **Acceptable As Is**

ATTACHMENTS: RFV 96-194

MAILING LIST NO. ESML - 14A + J.J.O'GRADY,(T.FICHET), E.C. Merkel

277
311

MACK TRUCKS, INC.
VEHICLE DEVELOPMENT LABORATORY
REQUEST FOR VALIDATION

RFV NO.
DATE

96-194
09/23/96

RFV TITLE E7 WITH NATURAL GAS

(Model / Part or Assembly Name, Part No. & Rev Level / Validation Process)

Background Information: (Use additional Pages as Needed)

RFV 95-046 originally requested a natural gas engine and LNG fuel system installed in an LE for demonstration purposes. Since the start of that activity, the scope of the project has expanded. In addition to the LE with LNG, an LE with CNG, an MR with LNG and an MR with CNG are also required to fulfill marketing and project planning projections. These configurations have many common components except for fuel tank mounting and piping.

Also, Snyder tank has recently entered the market as an LNG fuel tank and fuel system supplier. This new entry is offering a system which should be evaluated, both from a performance and durability aspect.

Tank mounting and configuration is critical to the acceptability of these installation. Previous testing has included bump testing of mounting systems.

Objective

Develop and document an LE with CNG, an MR with LNG and an MR with CNG.

Validate the durability and performance of the LNG tank system being offered by Snyder Tanks.

Validation Method: (Use VDLP's if known) VDLP-10
Drivability, manufactuability, cold starting, durability

Validation Criteria

Requestor John O'Grady Ext. 8140 Date 09/16/96
Requestor's Supervisor T. Fichter Ext. 8253 Date 09/30/96
Requested Completion Date _____

FOR LAB USE ONLY	
VDL Engineer <u>J.O'Grady</u>	VDL Section Manager <u>T. Fichter</u>
RFVCC Chairman <u>D. McVicker</u>	Date <u>10/15/96</u>
Automatic acceptance based on New Product criteria	
Accepted based on corporate criteria	
☒ Accepted with following conditions: (a) Do MR with LNG, (b) validate Snyder Tank durability & performance.	
Rejected (explain in "Remarks" section)	
Remarks:	
WTF <u>13</u> = % of Production	<u>2%</u> x Detection <u>5</u> x Frequency <u>5</u> x Severity <u>5</u> x Cost <u>5</u>
MWF <u>1</u> Lab Category	<u>2A</u> Charge No. <u>30-00624 (CNG) / 30-00651 (LNG)</u>
Distribution: RFV Mailing List + <u>E.C. Merkel</u>	
Original: Project Files—J.J.O'Grady (TP-A), J.D.Gardus (TP-B)	
Copies: B.P.Hollenbeck—J.W.Frankenfield—E.C.Merkel	
L.A.Meacock—T.Fichter—W.J.Baldwin—RFV Book	
Hqstn.Circ.Copy: C.K.Salter—C.H.Nyers—S.W.Haffner	

10/25

LAM. OCT 17 1996

40
MACK TRUCKS, INC.
VEHICLE DEVELOPMENT LABORATORY
TEST PLAN

TEST PLAN NO. TP-96 194-
DATE ASSIGNED: 8/21/97
ASSIGNED TO: W.J.Baldwin

OK RFVCC
DM=V/ 8/24/97

TITLE: MR/LNG FUEL TANK/BUMP MACHINE

RFV NO. 96 194 CHARGE NO. 30 00651 LAB CATEGORY 2A

VDLP (or test name if no VDLP)	3.03 BUMP MACHINE		
Standard Cost \$ 4900.00	Material \$ 25.00	Date Prepared	8/21/97
VDL Engineer / Ext. W.J.Baldwin/8124	VDL Technician J.F.Yost		
VDL Section Manager W.J.Baldwin	Requester J.J.O'Grady		
Will Requester Be Involved During Testing? ☒ Yes ☐ No		Piggyback Only? ☐ Yes ☒ No	

List estimated labor (man hours, elapsed time); material (Lab Fabrication, purchased); and resources / facilities (vehicles, test equipment) for each task.

Standard estimate: Technician - 70 hrs.

Engineer - 16 hrs.

Material - \$25

LAM AUG 27 1997

TESTPLAN.DOT REV A 2/95

1/22/96

Original: Project File-W.J.Baldwin (TP-C)
Copies: B.P.Hollenbeck-J.W.Frankenfield-E.C.Merkel-J.J.O'Grady
L.A.Meacock-T.Fichet-W.J.Baldwin-RFV Book
Hagerstown Ctr. Conv. C.K.Salter-C.H.Myers-S.W.Haffner

815 ideal

PROJECT LOG

DATE	ACTION
8/12/97	1. Test started 8/12/97
8/28/97	2. Test Completed 8/28/97
	3. No problems encountered. Tank OK
	4. Report written 11/4/97
	5. Engineering completed, 9/2/97

ENGINEERING STANDARDS AND REFERENCE MANUAL CHAPTER: 3.03

SECTION VI

VEHICLE DEVELOPMENT LAB PROCEDURES

DATE: 12/05/94

BUMP TEST DURABILITY PROCEDURE

REV: 00

FOR CHASSIS COMPONENTS

TEST NO. 148

BUMP MACHINE TEST COVER SHEET

RFV# 96-194-A REQUESTOR J.S. OGRADY TEST ENGINEER F. Sloskey

TEST DESCRIPTION/PURPOSE Bump test LRG fuel tank mount * filled
w/ liquid nitrogen and weighing 808 lbs for durability

BUMP MACHINE "C" X "D" _____

CAB: MODEL PCA-26-C-PC-PB
PART # _____
SERIAL # 009 mfg date 3/28/95
DESC. _____

SUSPENSION: FIXED _____ ARRGT. # _____

ARRANGEMENT#

BATTERY BOX
AIR RESERVOIRS
FUEL TANKS
STEPS
SPLASH SHIELDS/FENDER EXT.
CAB FAIRINGS
CAB MOUNTED EXHAUST
FRAME MOUNTED EXHAUST

NOTES: _____

TEST START DATE/CYCLES 8/12 / 0
TEST END DATE/CYCLES _____ / _____

TOTAL CYCLES _____

SHEET B

SECTION VI

VEHICLE DEVELOPMENT LAB PROCEDURES

BUMP TEST DURABILITY PROCEDURE

FOR CHASSIS COMPONENTS

DATE: 12/05/94

REV: 00

MACK TRUCKS ED&TC BUMP MACHINE LOG

BUMP MACHINE TEST # 148

[illegible]

Exhibit D
Nova Incorporated
White Book Test

8/11/98 4.56 gears
 snyder 108.5
 Advanced Design Bus (ADB)
 lap 14
 speed 17.8
 time 47.16
 fuel 3.410138

Nova Inc.
 Transit Bus Division
 Roswell New Mexico

	milage	per lap	time	per lap	minutes	m.p.h.	error m.p.h.	% error m.p.h.	weight gross	weight net	lbs lap	lbs/mi	mi/gal	pressure
start	5305.0		16:30	0	0				920	370				50
	5321.0	16	17:25	0:55	55	17.5	-0.35	-1.98%	906	356	14	1.0	3.9	48
	5335.0	14	18:15	0:50	50	16.8	-1.00	-5.95%	882	332	24	1.7	2.0	48
	5350.0	15	19:05	0:50	50	18.0	0.20	1.11%	859	309	23	1.6	2.2	44
	5364.0	14	19:55	0:50	50	16.8	-1.00	-5.95%	838	288	21	1.5	2.3	44
	5378.0	14	20:47	0:52	52	16.2	-1.65	-10.19%	816	266	22	1.5	2.2	44
	5393.0	15	21:37	0:50	50	18.0	0.20	1.11%	793	243	23	1.6	2.2	44
	5407.0	14	22:30	0:53	53	15.8	-1.95	-12.31%	769	219	24	1.7	2.0	44
	5421.0	14	23:19	0:49	49	17.1	-0.66	-3.83%	746	196	23	1.6	2.1	44
	5436.0	15	0:15	0:56	56	16.1	-1.73	-10.76%	724	174	22	1.5	2.3	45
	5450.0	14	1:06	0:51	51	16.5	-1.33	-8.07%	701	151	23	1.6	2.1	45
	5464.0	14	1:56	0:50	50	16.8	-1.00	-5.95%	681	131	20	1.4	2.4	48
	5479.0	15	2:49	0:53	53	17.0	-0.82	-4.82%	658	108	23	1.6	2.2	49
	5493.0	14	3:38	0:49	49	17.1	-0.66	-3.83%	636	86	22	1.5	2.2	50
	5507.0	14	4:25	0:47	47	17.9	0.07	0.40%	614	64	22	1.5	2.2	50
	5521.0	14	5:19	0:54	54	15.6	-2.24	-14.43%	592	42	22	1.5	2.2	51
	5536.0	15	6:08	0:49	49	18.4	0.57	3.09%	573	23	19	1.3	2.7	54
finish	5548.0	12	6:52	0:44	44				550	0	42	3.5	1.0	0

total time	total miles	miles per lap	% error	minutes per lap	% error	ave m.p.h.	% error
14.36	243.0	14.3	2.10%	51.3	8.71%	16.9	-4.93%

ave lbs/mi	ave mi/gal
1.5	2.3

Nova Inc.

Transit Bus Division

Rosswell New Mexico

7/27/98 5.13 gears
 snyder 108.5
 Advanced Design Bus (ADB)
 lap 14
 speed 17.8
 time 47.16
 fuel 3.456221

	milage	per lap	time	per lap	minutes	m.p.h.	error m.p.h.	% error m.p.h.	weight gross	weight net	lbs lap	lbs/mi	mi/gal	pressure
start	4383.0		12:00	0	0				944	375				58
	4398.0	15	12:58	0:58	58	15.5	-2.28	-14.71%	914	345	30	2.1	1.7	22
	4412.0	14	13:57	0:59	59	14.2	-3.56	-25.02%	885	316	29	2.0	1.7	30
	4427.0	15	14:51	0:54	54	16.7	-1.13	-6.80%	861	292	24	1.7	2.2	55
	4441.0	14	15:38	0:47	47	17.9	0.07	0.40%	841	272	20	1.4	2.4	35
	4455.0	14	16:27	0:49	49	17.1	-0.66	-3.83%	818	249	23	1.6	2.1	35
	4469.0	14	17:13	0:46	46	18.3	0.46	2.52%	798	229	20	1.4	2.4	35
	4484.0	15	18:09	0:56	56	16.1	-1.73	-10.76%	771	202	27	1.9	1.9	35
	4498.0	14	18:59	0:50	50	16.8	-1.00	-5.95%	751	182	20	1.4	2.4	35
	4512.0	14	19:48	0:49	49	17.1	-0.66	-3.83%	725	156	26	1.8	1.9	37
	4527.0	15	20:36	0:48	48	18.8	0.95	5.07%	699	130	26	1.8	2.0	37
	4541.0	14	21:28	0:52	52	16.2	-1.65	-10.19%	681	112	18	1.3	2.7	39
	4555.0	14	22:17	0:49	49	17.1	-0.66	-3.83%	654	85	27	1.9	1.8	40
	4569.0	14	23:07	0:50	50	16.8	-1.00	-5.95%	631	62	23	1.6	2.1	41
	4584.0	15	0:04	0:57	57	15.8	-2.01	-12.73%	606	37	25	1.7	2.1	43
	4598.0	14	0:56	0:52	52	16.2	-1.65	-10.19%	584	15	22	1.5	2.2	45
finish	4605.0	7	1:30	0:34	34				569	0	15	2.1	1.6	0

total time	total miles	miles per lap	% error	minutes per lap	% error	ave m.p.h.	% error
13.50	222.0	14.3	2.30%	51.7	9.70%	16.7	-6.18%

ave lbs/mi	ave mi/gal
1.7	2.1

Exhibit E
Roadway Express Inc.
Operational Test

Roadway Express Test Program, November 1995 thru November 1998: This test program was a cooperative effort between Roadway, Cummins and Snyder Tank that was planned in early 1995. The LNG fuel system consisted of two (2) Model SC-26-100 tanks installed on Ford LN-8000 pick up and delivery (P & D) trucks. These were the first LNG fuel tanks equipped with an on-board, self pressurizing capability, or to be operated in a "liquid only" fuel withdrawal mode. Fuel delivery was in parallel since Roadway required tank equal depletion as part of the vehicle's normal duty-cycle.

The operational test results of this three year test program are summarized below:

ENGINE	Cummins 5.9 L 195 HP	CUMMINS 5.9 L 230 HP
MILEAGE (mpd)	65 avg	65 avg.
FUEL USE (gpd)	32.5 avg.	29 avg.
TEST MILES	36,984	24,867
PAYLOAD	40,000 max.	40,000 max.
FUELING PRESS.	45 psi	45 psi
OPERATING PRESS.	55 psi	55 psi
FUEL DISCONNECT	MOOG	CFI

Exhibit G
Cryogenic Fuels Inc.
Thermal Analysis

Thermal Performance Analysis

LNG is a very dynamic liquid (properties constantly changing) and will boil at approximately -220°F @ 80 psig pressure. Therefore, a high degree of tank thermal performance is essential, not only to meet specification minimum "no vent" standby time, but also to allow for fuel stability to control fueling operations, and fuel conditioning within a specified range of temperature, pressure and density for satisfactory engine performance. Also, in no case should vapor be extracted from the tank vapor space for engine supply or pressure control. Removal of the methane can cause fuel "weathering" which results in engine performance degradation.

The thermal performance analysis consists of three basic areas of heat transfer:

1. Radiation from the outer jacket into the pressure vessel fluid.

The radiation is minimized by an appropriate number of radiation shields separated with low conductive spacing material. Between the shells (in the annulus space) a high vacuum in the 10^{-5} mmHg range essentially eliminates gas conduction thus increasing radiation shielding to maximum efficiency (Ref. page G-2).

2. Pressure vessel support conductive heat leak.

The STC tank pressure vessels are supported by a low thermal conductivity fiberglass beam with support pads located to carry high loading and also provide a long heat path from the conductive contacts to the warm outer shell (ref. page G-3).

This support system is "key" to the STC tank thermal performance. Conductive heat leak on other support system designs are estimated to be 3 to 4 times as high as the STC system.

3. Plumbing conductive heat leak

The only plumbing lines on the STC tanks are a 5/8 O.D. fill and a 5/8 O.D. vent line in serpentine configurations. The tubes are housed within an entrant tube pipe which communicates with the vacuum annulus (ref. page G-3). The long tube conductive heat path from the cold end of the entrant tube to the hot outer shell is over 30 inches, thus producing very low heat leak ($< .70$ B/hr.).

The tank thermal performance is summarized in page G-4. It must be noted that the pressure vessel support conductive heat leak on the 60 gallon tank is only 13% of the total tank heat leak and only 19% for the 100 gallon tank.

LNG FUEL TANK ANNULAR VACUUM VS "NO VENT" STANDBY TIME
100 GALLON - 26" O.D. TANK

NOTES:

- ULLAGE ————— 10%
- WORKING FLUID ————— LNG (FOR PLOTTED CURVE)
- WORKING PRESSURE RANGE — 25 TO 78 PSIG
- ENVIRONMENTAL TEMPERATURE — 90°F
- TEST DATA WORKING FLUID — LN₂
- TYPE PLOTS (LNG PERFORMANCE) — EMPIRICAL-TEST/ANALYTICAL
- REFERENCES ————— CFI REPORTS 26000 & 27000

Superinsulated Fuel Tank with Pressure Vessel Beam Support

Heat transfer/Mode	LNG Tank Size			
	60 Gallon (22 in. dia.)		100 Gallon (26 in. diameter)	
	Heat Leak (BTU/hr)	% of Total	Heat Leak (BTU/hr) "	% of Total
<u>Radiation</u> & annulus gas conduction @ 10 ⁻⁵ mmHg	7.20	79	7.80	74
<u>Conduction</u> Pressure vessel support	1.17	13	2.00	19
<u>Conduction</u> Plumbing	.75	8	.75	7
Total Tank Heat Leak	9.12	100	10.55	100
Boil off rate (lb/hr) @ relief valve (RV) crack pressure	@ RV crack 89 psig .045		@ RV crack 70 psig .055	

LNG Fuel Tank Thermal Performance

Exhibit H

Cryogenic Fuels Inc.

Structural Analysis

1.0 INTRODUCTION

This report documents the structural analysis of a 60-gallon tank pressure vessel as defined on Snyder Tank, Inc. (STC) drawing TBD.

The analysis of the cylinder and head shells, under pressure loading, conforms to applicable paragraphs of DOT 178.57 specification 4L and uses the allowable tensile and yield stress, for the ASTM A240 type 304 stainless steel material, as given in Table 1, paragraph 178.57-21.

As a result of this analysis, the maximum service pressure and corresponding minimum test pressure is specified. This structural analysis shall be substantiated by pressure vessel proof and cyclic pressure testing.

The analysis of the cylinder and heads conforms to DOT 178.57 specification 4L. All material is ASTM A 240 type 304 stainless steel. The following analysis includes applicable paragraphs from this specification along with the appropriate calculations and assessments.

2.0 Analysis

Code Requirements vs. Calculations

Specification Paragraph	Calculation
Allowable physical properties:	
Paragraph 178.57 - 15 - physical test	
<u>STC Test Lab Results</u> <u>are Pending</u>	
Paragraph 178.57 - 16 - acceptable results for physical tests	
Physical properties must meet the limits specified in paragraph 178.57-21 (a) Table I. Properties for ASTM A240 Type 304 stainless steel are as follows:	
Tensile strength - 75,000 psi	
Yield strength - 30,000 psi	
Elongation in 2" min. = 30.0 %	
Paragraph 178.57 - 17(a) test of welds	
<u>STC Test Lab</u> <u>Results are Pending</u>	
Paragraph 178.57 - 10 Item (5)	
Max. longitudinal weld stress must not exceed 85% of base metal properties	Weld efficiency = 85%
Note: Weld test specimens must meet or exceed this requirement	
<u>Cylinder Wall Thickness</u>	
Paragraph 178.57-10 (a) wall thickness	
The minimum wall thickness of the cylinder must be calculated from the min. of the following stress values:	
(1) 45,000 psi	
(2) & (5) One half the min. tensile strength across the welded seam x .85	$S_u = (75,000 \times .85)/2 = 31,875 \text{ psi}$
(3) & (5) Yield strength of the base metal x .85	$S_y = 30,000 \times .85 = 25,500$
This min. value off yield is the governing allowable stress.	

Specification Paragraph

Paragraph 178.57-10(b) wall thickness (t)

calculation formula

$$S = [P(1.3D^2 + 0.4d^2)]/(D^2 - d^2)$$

Calculation

The wall thickness of the cylinder and head is 14 ga. (.0745 t) and outside diameter (D) is 20 in.

$$\text{Inside diameter (d)} = D - 2t = 20 - 2 \times .0745$$

$$d = 20 - .15$$

$$d = 19.85$$

$$P = S (D^2 - d^2) / (1.3 D^2 + 0.4 d^2)$$

Where;

S = allowable wall stress -- lb/in.²

P = minimum test pressure -- lb/in.²

D = outside diameter -- in.

d = inside diameter -- in.

$$P = 25,500 (20^2 - 19.85^2) / (1.3 \times 20^2 + .4 \times 19.85^2)$$

$$P = 25,500 (400 - 394.02) / 520 + 157.61$$

$$P = 25,500 (5.98) / 677.61$$

$$P = 225.04 \text{ psig}$$

Service Pressure & Test Pressure

Paragraph 178.57-14 -- test pressure

Before insulation and jacketing the cylinder must be examined under a pressure of at least 2 times the service pressure

$$\text{Maximum service pressure in one (1) atmosphere environment} = 225.04/2 = 112.52 \text{ psig.}$$

Full flow relief valve set pressure must be 112.52 psig - 15 psi (one atmosphere) = 97.52 psig with vessel contained within an evacuated jacket (tank outer shell).

Head Requirement

Paragraph 178.57-8 (b) manufacture

2:1 ellipse major dia. not more than twice the minor diameter

Minimum thickness shall not be less than 90% of the required thickness of the side wall (cylinder).

Ref. STC head drawing 60-4001-1

Head thickness is greater than 90% of the cylinder thickness, therefore the thickness complies with the code.

Welding

Paragraph 178.57-57-8 (c)

Welding procedures and operators must be qualified in accordance with CGA pamphlet C-3

Cyl thickness = 14 ga. (.075)

Head thickness = 14 ga. (.075) > 90% of cyl. thickness

(Ref. STC drawing)

Paragraph 178.57-11

Heat Treatment not permitted

Ref. STC head drawing 60-4001-1 for compliance

Paragraph 158.57-12 openings in cylinder

They must be circular and shall not exceed 3 inches diameter or one third of the cylinder diameter whichever is less.

The central support beam tube hole diameter in both heads is 4.520 to 4.521 in.

This hole diameter (ref. drawing TBD) is greater than the 3 in. maximum allowable. A waiver will be requested on the basis of this report's analysis for the support beam tube that welds into this hole along with supportive test data.

3.0 RESULTS AND CONCLUSIONS

The analysis shows that the pressure vessel structure (in a one atmosphere environment) has a maximum service pressure capability of 112.52 psig. The corresponding min. test pressure is 225.04 psig. However, because of the vacuum around the vessel after installation within the outer shell, the tank relief valve maximum full flow pressure setting is 97.52 psig.

Normal procedures for garaged repair and maintenance should specify attachment of a facility vent hose to the vehicle tank vent line. The vent line directs any vented gas out of the building in case of a relief valve open condition on any tank. In some cases, such as a complete overhaul, a detank would be appropriate prior to garaging the vehicle.