PHASE II TRANSIT-BASED LPG MICROTURBINE RAPID-INTERVENTION PROJECT

FINAL REPORT

Prepared For:

PROPANE EDUCATION & RESEARCH COUNCIL
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TABLE OF CONTENTS

PHASE II TRANSIT-BASED LPG MICROTURBINE RAPID-INTERVENTION PROJECT

I. EXECUTIVE SUMMARY

ADEPT continued active support of LPG microturbine hybrid electric vehicle (HEV) integration sites in Galveston, TX and Los Angeles, CA. A new site (Santa Clara, CA) was added. This site brought a new and important opportunity for LPG in heavy-duty HEV's. ADEPT conducted problem solving and conciliatory functions among Capstone Turbine Corporation's (Capstone) design and field support engineers, shuttle and bus integrators, an air quality regulating authority, LPG industry safety and fuel system experts, LPG fuel suppliers, LPG fuel testing laboratory, and the shuttle owners, their project managers, operators and maintenance staff. All shuttles covered under Phase II use two (2) Capstone 30 kW LPG microturbines (C30) as "range extenders" (C30s generate electricity to drive motors and/or recharge on-board batteries). The shuttles' prime movers are battery powered electric motors. Some HEV designers prefer an "in series" vehicle strategy, others prefer an "in parallel" approach.[1]

The project objectives were to continue and enhance efforts initiated in Phase I to: (1) troubleshoot LPG-fueled microturbine driven shuttles and buses; (2) eliminate safety concerns; (3) continue to troubleshoot residue oils & heavy contaminants fuel problems; (4) support efforts to convert to a new fully integrated "one party responsible" fuel system;[2] and (5) ensure that LPG is not needlessly blamed (Note: and if fuel quality is found to be a problem, solve it). **These objectives were achieved**.

The mission was two fold:

(1) Keep these LPG powered buses and shuttles going; and
(2) Identify and help solve LPG fuel related problems.

The mission was accomplished.

In November 2001, for reasons outside ADEPT's control, AVS repossessed the three (3) Galveston-based 20-foot HEV shuttles. These shuttles were part of Phase I Rapid-Intervention Project (see November 7, 2001 report). The operator of the Galveston shuttles, Island Transit, and the integrator, Advanced Vehicle Systems (AVS), developed irreparable differences. Budgetary issues were reported to be why these HEVs left Galveston. Since withdrawing the vehicles from Galveston, AVS converted one (1) HEV to diesel (currently used as a demo vehicle), and two (2) other shuttles are in daily operation in Coconut Creek, Florida on LPG. They were reported to meet initial performance expectations.[3]

[1] HEVs may operate on either "in series" or "in parallel." In a series HEV, the internal combustion (IC) engine powers a generator that produces electricity, which is then stored in a battery pack. In a series HEV, the electric motor/s draw power from the battery pack and is/are the HEV prime mover/s. A parallel HEV is typically powered simultaneously by an IC engine and one or more battery powered electric motors.
[2] That starts at the gas cap and ends at the fuel injectors.
[3] These two (2) shuttles were subsequently added to Phase III coverage.

The Los Angeles site shuttles were out of service at the end of Phase I. The shuttle integrator, ISE Research Corporation (ISE), had to first ensure the shuttles met certain minimum performance criteria set by the shuttle operator, Los Angeles Department of Transportation (LADoT). A meeting took place in March 2002 at LADoT with all the various project participants. Partly due to ADEPT's intervention and with ADEPT's support, ISE was granted an extension for the shuttles to meet the LADoT minimum performance criteria. ADEPT continued to support ISE in its LPG fuel system improvements. Following ADEPT's suggestions, ISE instrumented the on-board LPG fuel system with pressure and temperature sensors to detect conditions that might lead to LPG condensation. Lastly, ADEPT helped resolve, with excellent support from Mutual Liquid Gas and Equipment Co. (Mutual), outstanding safety concerns uncovered in Phase I.

In December 2001, the Phase II project was amended to delete the Galveston site and to add the Santa Clara site. Capstone and AVS requested ADEPT's help in Santa Clara [where LPG fuel system related problems were observed on three (3) new LPG microturbine HEV 30-foot buses]. ADEPT thoroughly investigated the Santa Clara site (including fuel analyses). A bus fuel system was instrumented with pressure and temperature sensors to monitor operating conditions.[4] An LPG fuel system safety inspection was also conducted. Based on findings from the safety inspection, data collected from the monitored bus, and input from various LPG experts, specific suggestions were made to upgrade the fuel system. AVS, the integrator of the Santa Clara buses, accordingly modified its fuel system. A major fuel system innovation was achieved by AVS based on an ADEPT suggestion. This modification significantly reduces fuel line pressures upon turbine shut-down, drastically reducing the probability of vaporized fuel in-line condensation.

It should also be noted that ADEPT's conduct of the Phase I project, as well as Phase II, triggered major interest from various Capstone engineers and market developers.

Fuel quality remains a concern at the monitored sites. ADEPT conducted seven (7) new fuel quality and residue analysis tests during the covered reporting period.

ADEPT investigated several approaches to remedy fuel quality issues due to the presence of heavy-end compounds (approximately 16 to 35 carbon atoms per hydrocarbon molecule) in LPG. These approaches included: additives to maintain the heavy-ends in vapor phase; activated carbon (AC) in-line filters; and coalescent filters. Initial examination of these approaches indicates that these various methods merit further development and that their application may not be mutually exclusive. Future developments and demonstrations may provide

[4] Only on AVS's side of the fuel system, as permission was not yet given at that time by Capstone to instrument their part of the fuel system (past the shut-off valve).

practical means to fully resolve the heavy-end contaminants issues in microturbine fuel delivery systems (as well as for other contaminant sensitive systems – e.g. fuel cells).

II. PROJECT SITES

Table 1 lists the sites and entities participating in this Phase II project.

Table 1: LPG Microturbine HEV Site Details

Site[5]	Galveston, TX	Los Angeles, CA	Santa Clara, CA
Owner	AVS	LADoT	City of Santa Clara via its electrical utility: Silicon Valley Power
Operator	Island Transit	First Transit	Serendipity Land Yacht
Maintenance Provider	Island Transit/AVS	First Transit/ISE	AVS/Synergy EV
Hybrid Shuttle Integrator	AVS	ISE	AVS
Microturbine Manufacturer	Capstone	Capstone	Capstone
Fuel Provider	AmeriGas	Mutual Liquid Gas & Equipment Co.	AmeriGas/Delta Liquid Energy

III. WORK PERFORMED

A. Island Transit, Galveston, TX

In November 2001, AVS repossessed its three (3) 20' shuttles from Island Transit. ADEPT twice attempted to restore the relationship between AVS and Island Transit. These attempts failed. Prior to the AVS-Galveston split, ADEPT confirmed that the LPG fuel met HD-5 specifications and that the shuttles' fuel system performed in a satisfactory manner (ADEPT made sure that all appropriate parties knew of these findings).

Before the shuttles were removed from Galveston, they were reported to run and perform to order specifications.

[5] AVS initially intended to take one of the ex-Galveston shuttles to Capstone. Capstone and AVS expressed interest in ADEPT helping with this end-product integration work. ADEPT included in the December 2001 Phase II Amendment to assist Capstone and AVS in the anticipated LPG fuel system trouble-shooting and integration effort. Contrary to previously expressed intentions, a shuttle was never shipped to Capstone. Thus, this additional effort was not possible.

Island Transit initially agreed to allow ADEPT to continue to use the LPG stored on its premises (on which ADEPT collected extensive fuel quality data) for further work to test possible solutions to the heavy-end compounds issue. ADEPT thought this optimal since Dixie Services Inc.[6] (Dixie) is only about one hour away by car. When the previously reviewed additives test protocol was re-sent to Island Transit for final evaluation and formal approval, they suddenly withdrew altogether from this project.

Despite the Island Transit events, two (2) of the three shuttles remain on LPG and in service at a highly visible site. These shuttles are reported to be in buy-off negotiations at Coconut Creek, FL.

B. LADoT, Los Angeles, California

ADEPT visited the LADoT site on several occasions to remedy various safety concerns uncovered in Phase I. ADEPT managed extensive exchanges with and between ISE, LADoT, Capstone, and Mutual to resolve several safety issues. (See Appendix 1 for a final update on the resolved safety concerns.)

The Los Angeles site was on the brink of collapse at the close of Phase I. The shuttles repeatedly failed to meet certain performance requirements set by the shuttle owner/operator. A "GO/NO GO" meeting was held at LADoT in mid-March 2002. ADEPT sat in on the conference among representatives from ISE, LADoT, Calstart, Capstone, and South Coast Air Quality Management District (SCAQMD). SCAQMD is a major contributor to the project. At the conclusion of this meeting, SCAQMD agreed to release additional funds to ISE to bring these shuttles to LADoT specified minimum performance requirements. Less tolerant, Capstone gave ISE a final 90-day extension to prove out one 20' shuttle. It is thought that in the event ISE did not deliver, there was a reasonable probability that the project funders might have turned to other integrator alternatives. The outcome of the meeting was that ISE was given and accepted a 90-day extension to meet a specific set of performance criteria.

ISE brought the three (3) shuttles down to their headquarters in San Diego, CA. In March 2002, per ADEPT's advice, ISE instrumented one shuttle with pressure and temperature sensors to monitor the fuel system during bus operation. (The report of this fuel system

[6] Dixie has conducted numerous LPG fuel quality tests for ADEPT over the last twelve (12) years. Dixie has proven to be reliable, consistent, and trustworthy. Dixie is the originator of the innovative procedure used in the course of this project to measure and identify heavy-end contaminants. Dixie is <u>the</u> lab of choice throughout this project.

monitoring is ISE proprietary information.) Fuel system issues were uncovered and several modifications were made.

In May 2002, LADoT visited ISE to evaluate the performance of one (1) upgraded shuttle. The performance of the evaluated shuttle was found acceptable. However, at the time of this report, the approved shuttle (as well as its yet-to-be LADoT approved sister HEV) remains at ISE's headquarters, awaiting further instructions from LADoT.

C. Santa Clara, California

There are three (3) new 30' buses in Santa Clara owned by the City of Santa Clara via its electric utility, Silicon Valley Power. Serendipity Land Yacht (SLY) operates the buses. These are called the "B.E.E." buses ("Breathe Easy Express"). SLY, Synergy EV,[7] Inc., and AVS oversee and maintain these buses. The City of Santa Clara has not yet bought off on these buses. The original local propane provider was Amerigas. Due to fuel quality issues [too much propene (~19%)], HD-5 propane is now trucked in from Paso Robles, CA by Delta Liquid Energy (DLE). At the conclusion of extensive exchanges, Capstone insisted on HD-5 specification fuel. ADEPT was instrumental to help Synergy EV locate and purchase HD-5 specification fuel.

ADEPT visited the site in November 2001. A review of the visit was prepared and shared with all appropriate parties. This effort yielded a shared and agreed-upon evaluation of the situation at hand and provided clear and common definitions of the challenges to be resolved by the various project participants. All the key players at Santa Clara agreed with ADEPT's assessment (see Appendix 2).

ADEPT and DLE conducted a thorough vehicle safety inspection in December 2001. The fuel system on one of the three HEV's was reviewed [specifically addressing compliance with NFPA 58 (1998) as well as to Title 13 of the California Code of Regulations]. A report was submitted to AVS in January 2002 (see Appendix 3). The required corrections were implemented so the HEV's could pass a California Highway Patrol (CHP) inspection. ADEPT and DLE assisted AVS with parts selection and with proper interpretation of pertinent standards.

[7] Synergy EV is project manager for the City of Santa Clara on the "B.E..E." project.

AVS implemented several fuel system upgrades suggested by ADEPT. ADEPT also played a critical role in assisting AVS with LPG-based technical support ranging from fuel analysis to the selection and the procurement of suitable diagnostic equipment.

One (1) bus' fuel system was instrumented with pressure and temperature sensors to monitor operating conditions. This collected data was analyzed. It was concluded that there were in fact cold weather instances where LPG in the fuel line might have condensed into liquid. ADEPT submitted a report to AVS in January 2002. A revised supplemental report on the same subject was submitted in May 2002 (see Appendix 4).

D. Capstone Turbine Corporation

On February 11, 2002, in an effort to show LPG industry's support of the LPG powered microturbines, PERC's President, Mr. Roy Willis, and Mr. Larry Osgood of Consulting Solutions, along with Mr. Alex Spataru of ADEPT, visited with Capstone executives at their Chatsworth, CA headquarters. ADEPT again suggested to Capstone that the microturbine manufacturer should have control of the entire fuel system, from the gas cap to the injectors. Capstone agreed with this concept on its new 60kW microturbine LPG model (C60). Capstone also indicated that it plans to apply to PERC to help with this major fuel system project. ADEPT was asked to help with the grant application process, and if and when such funds are granted by PERC, with the actual fuel system design. ADEPT agreed to help and requested Capstone to provide certain data to begin the process. ADEPT commented to Capstone that it believes that the addition of appropriate sensing devices is crucial to the LPG fuel delivery system to: (1) allow for feedback/correction of fuel delivery rates and/or fuel/air ratio; (2) detect any residue accumulation; and (3) monitor fuel phase. ADEPT is convinced that such improvements are essential for long-term reliability and performance optimization. ADEPT expressed strong interest to continue to work to resolve these concerns.

E. LPG Fuel Analyses Results

From the onset of the Rapid Intervention Project, ten (10) fuel quality/residue tests were conducted and reported. These reports are supplemented by three (3) prior fuel quality/residue analyses (provided by the operators of the Galveston and Los Angeles sites). ADEPT coordinated the sampling and shipment of all project-related fuel and residue testing, including samples collected from the bottom of coalescent filters in Santa Clara and from drip legs in Galveston, fuel samples from all sites, as well as a coalescent filter element sample and a rubber fuel hose sample from Santa Clara. All project-sponsored fuel/residue tests were conducted by Dixie Services Inc. (Dixie). A summary of the test results is in Appendix 5.

LPG is mainly composed of propane, propylene (or propene), and butanes (see Appendix 6 for HD-5 specification and for HD-10 standard[8]). These main constituents contain 3-4 carbon atoms each. The fuel and residue tests indicated that there is a wide range of heavy-end compounds that are found in a given batch of LPG. Concentrations of these non-volatile compounds varied from a low of 5.3 mg/kg to a high of 116 mg/kg. The bulk of these non-volatile compounds contain from 16 to 35 carbon atoms.

Fuel quality is a concern on LPG microturbine HEV's because of the specification set by microturbine manufacturers. Some of the LPG contaminants identified so far include: rubber hose leachate, lubricating oils from refinery compressors and pumps, as well as heavier hydrocarbon molecules from unspecified sources. These contaminants have been noted in HEV on-board fuel system components such as regulators, fuel metering valves, and manifolds.

In the fuel supply system of Capstone microturbine-powered vehicles, it is critical to maintain temperatures and pressures that will keep all LPG components in gas phase (including butanes and heavier compounds) and/or to filter out the heavier compounds prior to possible interface with key system components. Per Capstone's specifications, 100% gas phase is to be observed at the fuel metering valve and at the microturbine injectors. Liquid phase in the fuel line may lead to mechanical system malfunctions and possibly to injector failures, and it may also cause partial or complete failure of a coalescent filter. Vaporized LPG traveling through the HEV fuel system undergoes several drops in pressure. When pressure is reduced, there is an associated temperature drop due to the adiabatic expansion of LPG. This temperature drop is important, as it will unavoidably reduce the fuel's temperature. Lower temperatures in LPG increase the likelihood of condensation of the heavier components. Under low temperature conditions, liquid butane droplets in the gas stream can collect in the coalescent filter, on the interior surface of the gas lines, and at other "low" points in the fuel lines. Saturation of the coalescent filter with liquids impairs its function. When a coalescent filter is saturated, heavy-end compounds may not be removed from the gas stream. Heavy molecule aerosols may clog the regulator, fuel injectors, and gas lines downstream of the filter.

F. LPG Filtration/Cleaning Methods

Three (3) methods to "clean" (or to maintain heavy contaminants in the vapor phase) LPG were thoroughly investigated. These methods are: (1) treat the LPG in the storage tank with an additive; (2) use an activated carbon (AC) filter on-

[8] HD-5 is a national commonly accepted specification for automotive-grade LPG. HD-10 automotive-grade LPG standard is observed only in California.

board to filter LPG in liquid phase; and (3) use a coalescent filter on-board to filter LPG in vapor phase.

Fuel Additives
In conjunction with two additive manufactures (World Resources Ltd./Bell Additives Inc and Energy Additives, Inc.), ADEPT designed and verified for concurrence an additive testing protocol (see Appendix 7). Oily residue samples and test results from Dixie (from Galveston residues and fuel quality tests) were forwarded to the two additive manufacturers who expressed interest to help resolve the oily residue problem. Due to the halt of the Galveston project, a new potential test site, Ebus, Inc. (in Downey, California) is being explored. The idea is to demonstrate and measure the efficacy of the two additives via a scientific method protocol. To date, the testing protocol has been reviewed by the following parties: Dixie, the additive manufacturers, the LPG provider, Capstone, and Ebus. The fuel storage tank was not yet installed at Ebus at the conclusion of Phase II. Nor was the mandatory fuel analysis available. This work will continue in Phase III as the tanks will be in place and as the fuel will be properly tested (to properly determine the required amount of additive to be injected).

Activated Carbon Filters
ADEPT took initial steps to determine if an on-board AC filter is a viable option to remedy fuel quality issues, including removing the bulk of the heavy-ends prior to the liquid LPG reaching the vaporizer/liquid accumulator. It is thought that for safety reasons, it may be desirable to mount an AC filter system on-board between a "rock catcher" fuel filter and the on-board storage tank. If an AC filter were mounted at the stationary distribution tank, the leak detection compounds (mercaptans) may be removed to an unsafe degree. AC filters are currently used at the refinery level to remove sulfur and heavy compounds from LPG streams. Additional literature search has indicated that this approach is viable and merits further pursuit. This work will continued under Phase III.

Considerable preliminary engineering work has been undertaken to evaluate various AC filter solutions (see Appendix 8). ADEPT commissioned an engineering team at Southwest Research Institute (SwRI) in San Antonio, Texas to design and assemble an on-board AC filter alpha prototype. This work has been completed. ADEPT and SwRI will finalize an AC filter test protocol as part of Phase III.

Coalescent Filters
ADEPT prepared a paper to serve as an initial desktop analysis on the efficacy of coalescent filters to remove heavy contaminants from vaporized LPG fuel (see Appendix 9). Coalescent filters are commonly installed to remove such suspended heavy oils and aerosol contaminants from various gas streams (including vaporized LPG). Coalescent filter fibers can be made of several materials, including cellulose, polymers, and ceramics. Heavy oils suspended in

the gas stream collect on the filter media by one or a combination of the following processes:

(1) Phase change: Heavy oils change from gas to liquid on filter surface at a temperature below their boiling point;
(2) Adhesion: Suspended liquid aerosols come into contact with fiber material and adhere to the fiber surface;
(3) Surface tension: Droplets on fibers tend to come together and resist being pulled away into the gas stream;
(4) Physical entrapment: Particulates/liquids get trapped in filter fibers.
(5) Gravity Separation: Droplets collect in the sump at the bottom of the filter.

ADEPT also examined the filter element as a possible contributor to residues formation. It was determined that the filter element is not a residue contributor.

ADEPT investigated whether the coalescent filters were properly maintained, if they were drained and monitored by the on-site personnel on a regular basis, and if the filters were replaced as often as necessary. ADEPT found that the current methods to determine the failure of a coalescent filter are inadequate and require specific upgrades. Such upgrade work is to be pursued under Phase III.

IV. CONCLUSIONS

With support from PERC, ADEPT and LPG industry leaders have positively conveyed their concerted interest to promote pioneering technologies through Phase I and II of this project. The LPG industry has made high level contacts and has generated favorable relationships with the leading entities in the growing and promising microturbine industry. Another positive development of this work is that microturbine manufacturers and HEV integrators are learning that LPG is the fuel of choice for "range extender" engines.

ADEPT believes that key new components are needed in the LPG fuel delivery system. Such sub-systems and/or components are to provide feedback/correction of fuel phase, fuel delivery rates, and/or fuel/air ratio. We believe that such improvements are essential if the product is to provide long-term reliability and to perform in an optimum fashion.

Fuel quality concerns are far from over. From the fuel test analysis work to date, ADEPT has noted marked variations in fuel quality from site to site. ADEPT believes that specific "off the shelf" and innovative approaches/technologies may resolve the oily residue issues. These applied research efforts may well lead to tangible means to resolve long standing fuel quality issues, which may also help in other propane fuel quality-sensitive applications (e.g. fuel cells).

Capstone has requested assistance with its 60 kW LPG turbine fuel system. Capstone engineers are puzzled why their current fuel injection system, when running on LPG, emits higher NO_x vs. the CNG version of the same system. This issue should be addressed ASAP. Capstone has requested ADEPT to provide assistance with the PERC grant application process, and if and when funds are granted by PERC, with the actual fuel system design process. ADEPT has confirmed its willingness to help Capstone in these matters.

V. RECOMMENDATIONS AND ACTION ITEMS

(1) Consolidate and distribute information gained in Phases I and II to the HEV industry.

(2) Continue development work on specific technologies to mediate various fuel system challenges.

(3) Continue to support in-the-field pioneering HEV projects.

(4) Help E-Bus put together fuel systems that will not repeat prior mistakes.

(5) Investigate and promote LPG microturbine HEV success stories (i.e. Coconut Creek, FL and Christchurch, New Zealand)

(6) Coordinate and conduct LPG additives tests. Evaluate efficacy of additives to help deal with the heavy-ends challenge.

(7) Coordinate and conduct AC filter alpha prototypes tests. Evaluate efficacy of AC filters to clean liquid phase LPG of heavy-ends.

(8) Coordinate and conduct coalescent filter tests.

VI. APPENDICES

1. *Update on Outstanding Safety Issues at First Transit re: LPG Microturbine Hybrid Bus*, ADEPT, January 2002. (CONFIDENTIAL)
2. *Review of Santa Clara Visit*, ADEPT, November 2001. (CONFIDENTIAL)
3. *BEE Line Bus Safety Inspection Report*, DLE/ADEPT, January 2002. (CONFIDENTIAL)
4. *LPG Fuel System of HEV LPG Microturbine Bus in Santa Clara, CA*, ADEPT, May 2002. (CONFIDENTIAL)
5. *PERC Phase II Transit-Based LPG Microturbine Rapid-Intervention Project Fuel Analysis*, ADEPT working document.
6. HD-5 and HD-10 Specifications.
7. *DRAFT Additives Protocol for LPG*, ADEPT, May 2002.

8. *Preliminary Report on Activated Carbon Filtration of Liquid LPG*, ADEPT, February 2002. (CONFIDENTIAL)
9. *Discussion of Coalescent Filters Used by Advanced Vehicle Systems, Inc. (AVS) on LPG Powered Hybrid Electric Vehicles (HEVs)*, ADEPT March 2002. (CONFIDENTIAL)
9a. *Discussion of Flow Rate Concerns for Finite Media Grade 2 Filter*, ADEPT March 2002.

APPENDIX 5

PERC Phase II Transit-Basid LPG Microturbine Rapid-Intervention Project Fuel Analyses

	Test #	1[1]	2[2]	3[2]	4	5	6
Description	Submitted	02/06/01	06/01/01	06/01/01	09/21/01	09/25/01	10/10/01
	Site	LADoT	Galveston	Galveston	Galveston	Galveston	LADoT
	Report #	10226	1064595	1064595s	107974	107989	108187
	Lab	Empact[3]	Dixie[4]	Dixie	Dixie	Dixie	Dixie
	Report Date	02/15/01	06/04/01	06/01/01	11/06/01	10/17/01	10/15/01
	Sample	Fuel	Fuel	Fuel	Coalescer Residue	Fuel	Fuel
General Content Test (D 2163) (vol.%)	Nitrogen (N_2)	0	-	-	Residue Analysis is available upon request.	-	0.01
	Methane (CH_4)	0.09	0.02	-		-	0.02
	Ethane (C_2H_6)	0.55	2.92	-		2.43	0.63
	Propane (C_3H_8)	98.37	94.32	-		94.9	97.75
	Propene (C_3H_6)	-	0.33	-		1.21	0.36
	iso-Butane (C_4H_{10})	0.947	2.3	-		1.11	1.19
	n-Butane (C_4H_{10})	0.04	0.11	-		0.24	0.04
	1-Butene (C_4H_8)	-	-	-		0.04	-
	iso-Butene (C_4H_8)	-	-	-		0.07	-
Particulate Contamination	Mass of Sample Discharged (kg)	-	-	11.03		6.4	-
	Insoluble Part. Matter Retained on Filter (g)	-	-	0.0006		0.0009	-
	Concentration of Particulate in Sample (mg/kg)	-	-	0.05		0.14	-
Nonvolatile Residue	Nonvolatile Residue Recovered (g)	-	-	0.1806		0.7398	-
	Concentration of Nonvolatiles in Sample (mg/kg)	-	-	16.4		116	-
D 5762	Nitrogen (N_2) (mg/g)	-	-	-	5,047	-	-
D 5452	Filter Color[5]	-	-	A-2		B-4	-
Volatile Residues in LPG (D2158)	Residue on Evaporation (mL)	-	-	-	-	-	-
	R Number	-	-	-		-	-
	Oil Stain Observation (mL)	-	-	-		-	-
	O Number	-	-	-		-	-

[1]Historical fuel quality results of the LADoT site provided by Mutual Liquid Gas & Equipment Co.

[2]Historical fuel quality results of the Galveston site provided by Advanced Vehicle Systems.

[3]Empact Analytical Systems, Inc. (Brighton, CO)

[4]Dixie Services Inc. (Galena Park, TX)

[5]ASTM D 5452 "Standard Test Method for Particulate Contamination of Aviation Fuels by Laboratory Filtration" A-2 = acceptable; B-4 = borderline acceptable; B-6 = marginal-unacceptable; B-8 = unacceptable

PERC Phase II Transit-Basid LPG Microturbine
Rapid-Intervention Project Fuel Analyses

Description	**Test #**	**7**	**8**	**9**	**10**	**11**
	Submitted	11/01/01	11/29/01	01/04/02	01/04/02	01/04/02
	Site	Galveston	Santa Clara	Santa Clara	Santa Clara	Santa Clara
	Report #	108435	108724	109075	109076	109077
	Lab	Dixie	Dixie	Dixie	Dixie	Dixie
	Report Date	11/05/01	01/21/02	02/18/02	02/18/02	02/18/02
	Sample	Fuel	Drip Leg Residue	Drip Leg Residue	Coalescer Element	Rubber Hose
General Content Test (D 2163) (vol.%)	**Nitrogen (N_2)**	-	Residue Analysis is available upon request.	Residue Analysis is available upon request.	Residue Analysis is available upon request.	Residue Analysis is available upon request.
	Methane (CH_4)	-				
	Ethane (C_2H_6)	-				
	Propane (C_3H_8)	-				
	Propene (C_3H_6)	-				
	iso-Butane (C_4H_{10})	-				
	n-Butane (C_4H_{10})	-				
	1-Butene (C_4H_8)	-				
	iso-Butene (C_4H_8)	-				
Particulate Contamination	**Mass of Sample Discharged (kg)**	12.39				
	Insoluble Part. Matter Retained on Filter (g)	0.0029				
	Concentration of Particulate in Sample (mg/kg)	0.23				
Nonvolatile Residue	**Nonvolatile Residue Recovered (g)**	1.4214				
	Concentration of Nonvolatiles in Sample (mg/kg)	114				
D 5762	**Nitrogen (N_2) (mg/g)**	-				
D 5452	**Filter Color[5]**	B-8				
Volatile Residues in LPG (D2158)	**Residue on Evaporation (mL)**	<0.05				
	R Number	0				
	Oil Stain Observation (mL)	0.4				
	O Number	25				

File: Fuel Analyses Report Attachment.xls

PERC Phase II Transit-Basid LPG Microturbine
Rapid-Intervention Project Fuel Analyses

Description	**Test #**	**12**	**13**
	Submitted	02/06/02	02/06/02
	Site	Santa Clara	Santa Clara
	Report #	109413	109413s
	Lab	Dixie	Dixie
	Report Date	02/04/02	03/08/02
	Sample	Fuel	Fuel
General Content Test (D 2163) (vol.%)	**Nitrogen (N_2)**	-	-
	Methane (CH_4)	-	-
	Ethane (C_2H_6)	0.032	-
	Propane (C_3H_8)	79.74	-
	Propene (C_3H_6)	19.41	-
	iso-Butane (C_4H_{10})	0.5	-
	n-Butane (C_4H_{10})	0.03	-
	1-Butene (C_4H_8)	-	-
	iso-Butene (C_4H_8)	-	-
Particulate Contamination	**Mass of Sample Discharged (kg)**	-	9.75
	Insoluble Part. Matter Retained on Filter (g)	-	0.0001
	Concentration of Particulate in Sample (mg/kg)	-	0.01
Nonvolatile Residue	**Nonvolatile Residue Recovered (g)**	-	0.0521
	Concentration of Nonvolatiles in Sample (mg/kg)	-	5.3
D 5762	**Nitrogen (N_2) (mg/g)**	-	-
D 5452	**Filter Color[5]**	-	B-6
Volatile Residues in LPG (D2158)	**Residue on Evaporation (mL)**	<0.05	-
	R Number	-	-
	Oil Stain Observation (mL)	1.5	-
	O Number	-	-

APPENDIX 6

SECTION 2

Product Specifications

This Section contains the following specifications for natural gas liquid products:

Fig. 2-1: GPA specifications for commercial propane, commercial butane, commercial butane-propane mixtures, and Propane HD-5.[1]

Fig. 2-2: GPA specifications for natural gasoline.[2]

These are "official" industry standards, representing a broad industry consensus for minimum quality products. Producers, purchasers, or pipeline companies may adopt variations of these specifications.

The gas plant designer and operator, as well as purchasers, will also be concerned with specifications for other plant products, including residue gas, raw mix streams, ethane, propane, ethane-propane mixes, normal butane, iso-butane, and plant condensate. Although there are no "official" industry specifications for normal butane, common commercial transactions for normal butane stipulate that the product shall meet all specifications for commercial butane and, in addition, be composed of a minimum of 95 volume percent normal butane. Common commercial specifications for iso-butane stipulate that the product contain a minimum of 95 volume percent iso-butane, and also meet all specifications for commercial butane.

Likewise, there are no industry standard specifications for ethane or ethane-propane (EP) mixes. However, GPA Technical Section C on product specifications has provided a summary of typical quality criteria in industry use as shown in Fig. 2-3.

Quality specifications for natural gas have historically been individually negotiated and prescribed in contracts between purchasers or pipeline companies and the producer or processor. Specification parameters for pipeline quality natural gas may include heating value, composition, contaminants, water content, and hydrocarbon dew point. Specification limits for these parameters may vary widely depending on the pipeline system, climatological conditions, end use, and other factors. Example pipeline quality gas specification parameters are shown in Fig. 2-4.

FIG. 2-1

GPA Liquefied Petroleum Gas Specifications (This Table Extracted From GPA Standard 2140-92)

Product Characteristics	Product Designation				
	Commercial Propane	**Commercial Butane**	**Commercial B-P Mixtures**	**Propane HD-5**	**Test Methods**
Composition	Predominantly propane and/or propylene.	Predominantly butanes and/or butylenes.	Predominantly mixtures of butanes and/or butylenes with propane and/or propylene.	not less than 90 liquid volume percent propane; not more than 5 liquid volume percent propylene.	ASTM D-2163-87
Vapor pressure at 100°F, psig, max. at 37.8°C, kPa (ga), max.	208 1434	70 483	208 1434	208 1434	ASTM D-1267-89
Volatile residue:					
temperature at 95% evaporation, °F, max. or °C, max.	–37 –38.3	36 2.2	36 2.2	–37 –38.3	ASTM D-1837-86
butane and heavier, liquid volume percent max.	2.5	—	—	2.5	ASTM D-2163-87
pentane and heavier, liquid volume percent max.	—	2.0	2.0	—	ASTM D-2163-87
Residual matter:					
residue on evaporation of 100 ml, max.	0.05ml	—	—	0.05 ml	ASTM D-2158-89
oil stain observation	pass (1)	—	—	pass (1)	ASTM D-2158-89
Corrosion, copper strip, max.	No. 1	No. 1	No. 1	No. 1	ASTM D-1838-89 (Note A)
Total sulfur, ppmw	185	140	140	123	ASTM D-2784-89
Moisture content	pass	—	—	pass	GPA Propane Dryness Test (Cobalt Bromide) or D-2713-86
Free water content	—	none	none	—	—

(1) An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper in 0.1 increments and examined in daylight after 2 minutes as described in ASTM D-2158.

NOTE A: "This method may not accurately determine the corrosivity of the liquefied petroleum gas if the sample contains corrosion inhibitors or other chemicals which diminish the corrosivity of the sample to the copper strip. Therefore, the addition of such compounds for the sole purpose of biasing the test is prohibited."

Division 3. Air Resources Board

Chapter 5. Standards for Motor Vehicle Fuels

Article 3. Specifications for Alternative Motor Vehicle Fuels

§ 2292.6. Specifications for Liquefied Petroleum Gas.

The following standards apply to liquefied petroleum gas
(The identified test methods are incorporated herein by reference):

Specifications for Liquefied Petroleum Gas

Specification	*Value*	*Test Method*
Propane	85.0 vol. % (min.)[a]	ASTM D 2163-87
Vapor pressure at 100°F	208 psig (max.)	ASTM D 1267-89 ASTM D 2598-88[b]
Volatility residue:		
evaporated temp., 95%	-37°F (max.)	ASTM D 1837-86
or		
butanes	5.0vol. % (max.)	ASTM D 2163-87
Butenes	2.0 % (max.)	ASTM D 2163-87
Pentenes and heavier	0.5 vol. % (max.)	ASTM D 2163-87
Propene	10.0 vol. (max.)	ASTM D 2163-87
Residual matter residue		
on evap. of 100 ml	0.5 ml (max.)	ASTM D 2158-89
oil stain observ.	pass[c]	ASTM D 2158-89
Corrosion, copper strip	No. 1 (max)	ASTM D 1838.89
Sulfur	80 ppmw (max.)	ASTM D 2784-89
Moisture content	pass	ASTM D 2713-86
Odorant	[d]	

[a] Propane shall be required to be a minimum of 80.0 volume percent starting on January 1, 1993. Starting on January 1, 1999, the minimum propane content shall be 85.0 volume percent.

[b] In case of dispute about the vapor pressure of a product, the value actually determined by Test Method ASTM D 1267-89 shall prevail over the value calculated by Practice ASTM D 2598-88.

[c] An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper, in 0.1 ml increments and examined in daylight after 2 min. as described in Test Method ASTM 2158-89.

[d] The liquefied petroleum gas upon vaporization at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air of not over 1/5 (one-fifth) of the lower limit of flammability.

Within five years from the effective date of adoption or implementation, whichever comes later, of the amendments approved December 11, 1998, the Air Resources Board, in consultation with the Secretary for Environmental Protection, shall review the provisions of this chapter to determine whether it should be retained, revised or repealed.

NOTE: Authority cited: Sections 39600, 39601, 43013, 43018 and 43101, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975). Reference: Sections 39000, 39001, 39002, 39003, 39010, 39500, 40000, 43000, 43013, 43016, 43018 and 43101, Health and Safety Code; and *Western Oil and Gas Ass'n. v. Orange County Air Pollution Control District*, 14 Cal. 3d 411, 121 Cal. Rptr. 249 (1975).

REFERENCE

APPENDIX 7

The ADEPT Group, Inc.

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file: microturbine086_additive E-Bus.doc

June 28, 2002 (Revision 2)

DRAFT Additives Protocol for LPG Powered HEVs

Mr. Mike Mamakos, Project Engineer

Introduction:

It is proposed to test additives in HD-5 propane to determine to what degree they can keep “heavy” contaminants found in vapor phase LPG from dropping out in a microturbine’s fuel supply system. Two problems have been found to effect hybrid electric vehicle (HEV) LPG fuel delivery systems used to feed microturbines: (1) recondensation, and (2) deposits of “heavy” contaminants. Additives are claimed to be an effective way to deal with the second issue. The idea is that these additives will keep the “heavy” compounds (~18-35 carbon atoms) suspended in vapor phase all the way from the vaporizer’s exit to and through the microturbine’s injectors. Right now, these deposits accumulate within key components, interfering with their proper function.

Two additive manufacturers have expressing strong interest to participate in the project: World Resources Ltd./Bell Additives Inc and Energy Additives, Inc. The additives to be tested are PRO 2000-V (made by Bell Additives) and a specially customized blend (made by Energy Additives).

These tests are to assess the potential benefits offered by two LPG specific additives in a microturbine driven HEV. The proposed tests are to take about five (5) weeks.

The relative efficacy of the two additives is to be measured via a scientifically designed protocol. It is desirable that this protocol be reviewed and agreed upon by at least the following parties: E-Bus, the additive manufacturers, the LPG provider, and Capstone.

First, “gooey oil”[1] will be collected at key points from the microturbine’s fuel system while running on unadditized LPG. This will establish a base line in terms of quantity and composition of collected contaminants. Next, “gooey oil” will be collected from the fuel system in the exact same fashion using unadditized LPG+ADD1[2], and then unadditized LPG+ADD2[3]. Such collections are to be made from the bottom of the coalescent filter and/or the “drip-leg” outlet. These residues will be analyzed to determine the effectiveness of each additive to keep contaminants suspended in vapor phase. The quantity and composition of the resultant “gooey oils” will be noted and compared.

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[1] Commonly used for the heavy “soup” of contaminants that drop out after protracted bus operation.

[2] ADD1 = Additive #1.

[3] ADD2 = Additive #2.

Proposed Procedure:

Step 1: Rent one (1) 500 gallon clean tank and two (2) 250 gallon clean tanks.
Step 2: Install tanks at E-Bus' facility.
Step 3: Purchase one 800 gallon batch of unadditized HD5 specified LPG. This initial LPG stock is to be called "HD5."
Step 4: Fill Tank #1 with 400 gallons of HD5.
Step 5: Fill Tanks #2 and #3 with 200 gallons of HD5 each.
Step 6: Ship a 10 gallon sample of HD5 to Dixie Services. Run test procedures D2158 and D2163.
Step 7: Send test results to additive manufacturers #1 and #2. Ask for advise on amounts of additive to be injected into the HD5 on a wt./wt. basis.
Step 8: In LPG storage tank #2, inject appropriate amount of additive #1.
Step 9: In LPG storage tank #3, inject appropriate amount of additive #2.

Step 10: Run HEV for the same amount of time and on the same route on HD5 for two (2) days.
Step 11: Collect, weigh, record weight, and store "gooey oil" collected from the HEV's drip leg and/or coalescent filter each morning (by 9:00 AM).[4]
Step 12: Record start-up and shut-down times and ambient temperatures each day.
Step 13: Record amount of HD5 fuel consumed each day.

Step 14: Run HEV for the same amount of time and on the same route on HD5+ADD1 for two (2) days.
Step 15: Collect, weigh, record weight, and store "gooey oil" collected from the HEV's drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 16: Record start-up and shut-down times and ambient temperatures each day.
Step 17: Record amount of HD5 fuel consumed each day.

Step 18: Run HEV for the same amount of time and on the same route on HD5 for two (2) days.
Step 19: Collect, weigh, record weight, and store "gooey oil" collected from the HEV's drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 20: Record start-up and shut-down times and ambient temperatures each day.
Step 21: Record amount of HD5 fuel consumed each day.

Step 22: Run HEV for the same amount of time and on the same route on HD5+ADD2 for two (2) days.
Step 23: Collect, weigh, record weight, and store "gooey oil" collected from the HEV's drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 24: Record start-up and shut-down times and ambient temperatures each day.
Step 25: Record amount of HD5 fuel consumed each day.

[4] A separate bottle type container will be used for each day of "gooey oil" collection. Each bottle will be identified as to the date and time of collection.

Step 26: Run HEV on HD5 for two (2) days.
Step 27: Collect, weigh, record weight, and store “gooey oil” collected from the HEV’s drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 28: Record start-up and shut-down times and ambient temperatures each day.
Step 29: Record amount of HD5 fuel consumed each day.

Step 30: Run HEV for the same amount of time and on the same route on HD5+ADD2 for two (2) days.
Step 31: Collect, weigh, record weight, and store “gooey oil” collected from the HEV’s drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 32: Record start-up and shut-down times and ambient temperatures each day.
Step 33: Record amount of HD5 fuel consumed each day.

Step 34: Run HEV on HD5 for two (2) days.
Step 35: Collect, weigh, record weight, and store “gooey oil” collected from the HEV’s drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 36: Record start-up and shut-down times and ambient temperatures each day.
Step 37: Record amount of HD5 fuel consumed each day.

Step 38: Run HEV on HD5+ADD1 for two (2) days.
Step 39: Collect, weigh, record weight, and store “gooey oil” collected from the HEV’s drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 40: Record start-up and shut-down times and ambient temperatures each day.
Step 41: Record amount of HD5 fuel consumed each day.

Step 42: Run HEV on HD5 for two (2) days.
Step 43: Collect, weigh, record weight, and store “gooey oil” collected from the HEV’s drip leg and/or coalescent filter each morning (by 9:00 AM).
Step 44: Record start-up and shut-down times and ambient temperatures each day.
Step 45: Record amount of HD5 fuel consumed each day.

Step 46: Ship a 10-gallon sample of HD5 to Dixie Services. Run test procedures D2158 and D2163.
Step 47: Ship all collected “gooey oil” samples to Dixie Services.
Step 48: Analyze the compositions of the various collected “gooey oil” samples.
Step 49: Compare results of Steps 6 and 46.
Step 50: Prepare final report.