ARIELI ASSOCIATES
MANAGEMENT, ENGINEERING AND OPERATIONS CONSULTING

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MIXED HYDROGEN/NATURAL GAS (HCNG) TECHNOLOGY- VISIT AT COLLIER TECHNOLOIES

1. INTRODUCTION

As a California transit bus operator with more than 200 buses in its fleet, LACMTA is subject to very stringent emission standards- see Figure 1.

Summary of Transit Bus Regulation
Adopted Urban Transit Bus Fleet Rule
Requirements and Emission Standards

	DIESEL PATH		ALTERNATIVE-FUEL PATH	
Model Year	**NOx (g/bhp-hr)**	**PM (g/bhp-hr)**	**NOx (g/bhp-hr)**	**PM (g/bhp-hr)**
2000	4.0	0.05	2.5 optional	0.05
10/2002	2.5 NOx+NMHC	0.01	1.8 NOx+NMHC optional	0.03
10/2002	4.8 NOx fleet average		4.8 NOx fleet average	
2003-09	Accelerated PM Retrofit Requirements <=15 PPM sulfur diesel fuel		PM Retrofit Requirements	
7/2003	3 bus demo of ZEB's for large fleets (>200)			
2004	0.5	0.01		
2007	0.2	0.01	0.2	0.01
2008	15% of new purchases are ZEB's for large fleets (>200)			
2010			15% of new purchases are ZEB's for large fleets (>200)	

FIGURE 1- SUMMARY OF THE CARB ADOPTED RULES

The technological avenues to meet the above standards are: (i) modified propulsion with or without energy storage devices ; (ii) modified fuels; and, (iii) modified drivetrains. Figure 2 shows the current options available for evaluation.

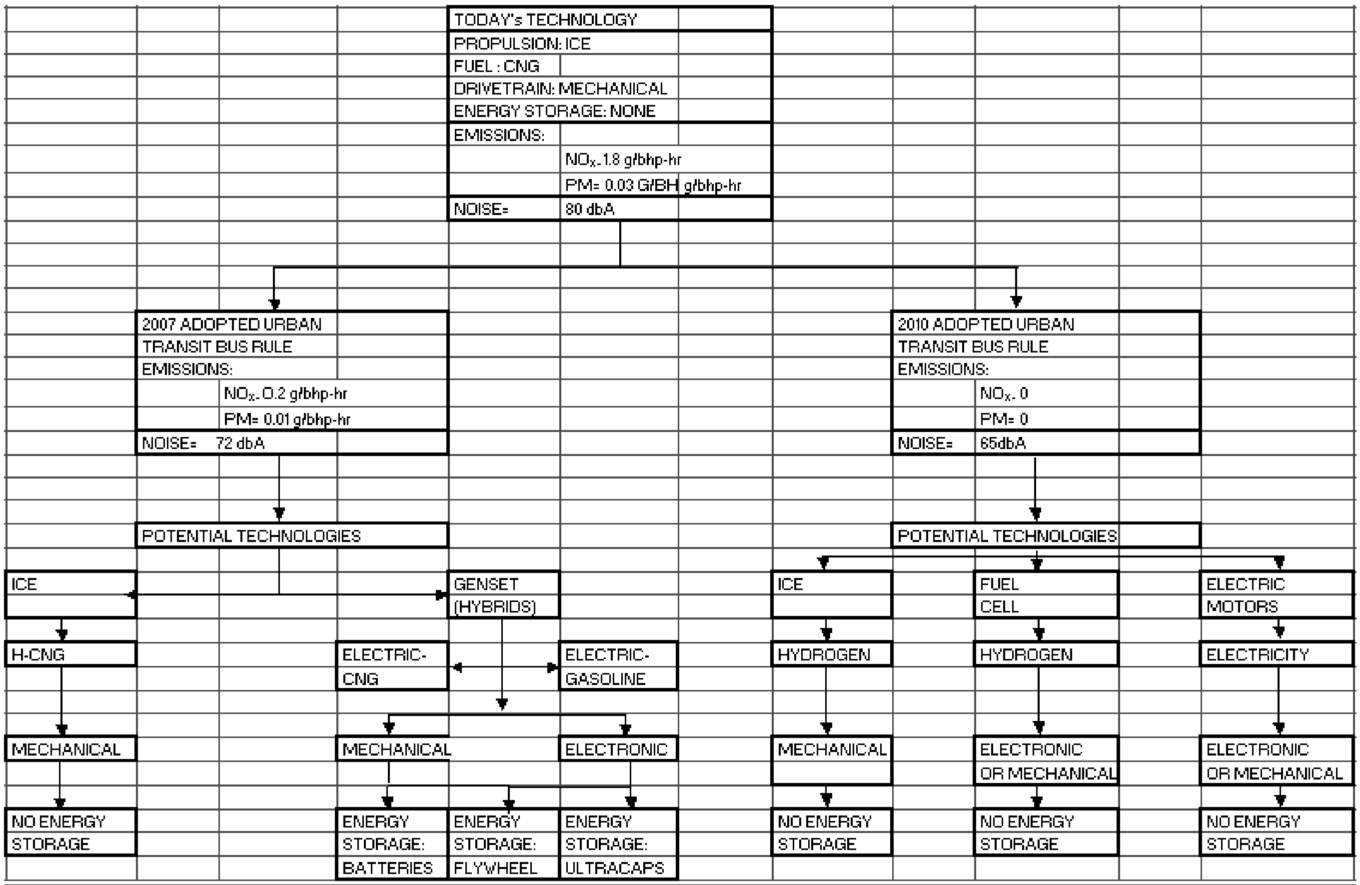

FIGURE 2- TECHNOLOGY EVALUATION MATRIX

The fuel modified path is by far the most appealing one for, both, the operator of buses and for the manufacturer of buses. This path requires modifications to the Internal Combustion Engine (ICE) and the CNG fuelling stations but is largely transparent to the manufacturer and the user. Economically, modified fuels are probably the most attractive option.

This report addresses a modified fuel by blending Compressed Natural Gas (CNG) and hydrogen. It includes, both, the trip report of the visit to Collier Technologies and literature search.

2. VISIT TO COLLIER TECHNOLOGIES

On 5/7/2004 we visited Collier Technologies at their facilities in Reno, NV. Collier was represented by Mr. J. Jones, CEO; Dr. K. Collier, Chief Technology Officer; and, Mr. N. Mulligan, COO. The facility is modern with office and shop space, including a machine shop. There are four (4) fully instrumented dynamometer test cells. At the time of the visit they were working on a bus for University of California-Davis and, separately, on modifying a Dewoo 11L CNG engine.

The Company is small (less than 10 employees) and entrepreneurial. They focus in three technological areas, namely: HCNG technologies; pure hydrogen technologies; and, reformer technologies. The principals of the company are well versed in these technologies having worked in these and related fields for more than 25 years.

The business model for Collier Technologies is to stay small, develop technologies to the point of commercialization and license them widely. The company holds six (6) US patents and several pending US patents on their technology development.

3. COLLIER TECHNOLOGIES APPROACH TO HCNG FOR TRANSIT BUSES

Collier's HCNG technology addresses specifically the NO_x emissions. The oxides of nitrogen (NO_x) are combustion by-products from atmospheric nitrogen. The nitrogen oxide (NO) is a colorless, tasteless, and odorless gas. In air, it gradually transforms into NO_2 a poisonous, reddish-brown gas with a penetrating odor. The NO_x emissions are particularly influenced by the combustion temperature. Higher combustion temperatures induce an overproportional increase in the formation of NO_x and because addition of hydrogen to the CNG reduces combustion temperatures, it represents a particularly effective method of controlling NO_x emissions. Although the addition of hydrogen by itself (everything else being equal) increases the NO_x emissions, it also increases the lean limit. The air/fuel ratio exercises a decisive effect on the engine's operating characteristics. A rich mixture of around 1.1 equivalence ratio (theoretical air requirement/quantity of intake air) will furnish maximum torque and smoothness but lead to increases in emissions and specific fuel consumption. On the other hand lean burning, i.e. equivalence ratios of up to .78 will lead to lower emissions and better fuel economy. With pure hydrocarbon fuels equivalence ratios lower than .78 lead to incomplete combustion, the worst condition for air emissions. Recently, new designs employing induced turbulence and controlled vortices in the intake mixture are employed to extend the lean limit to .63 equivalence ratio. As it can be seen in Figure 3, addition of 30% + of hydrogen has the same effect of extending the lean limit to .63 to .62 equivalence ratio.

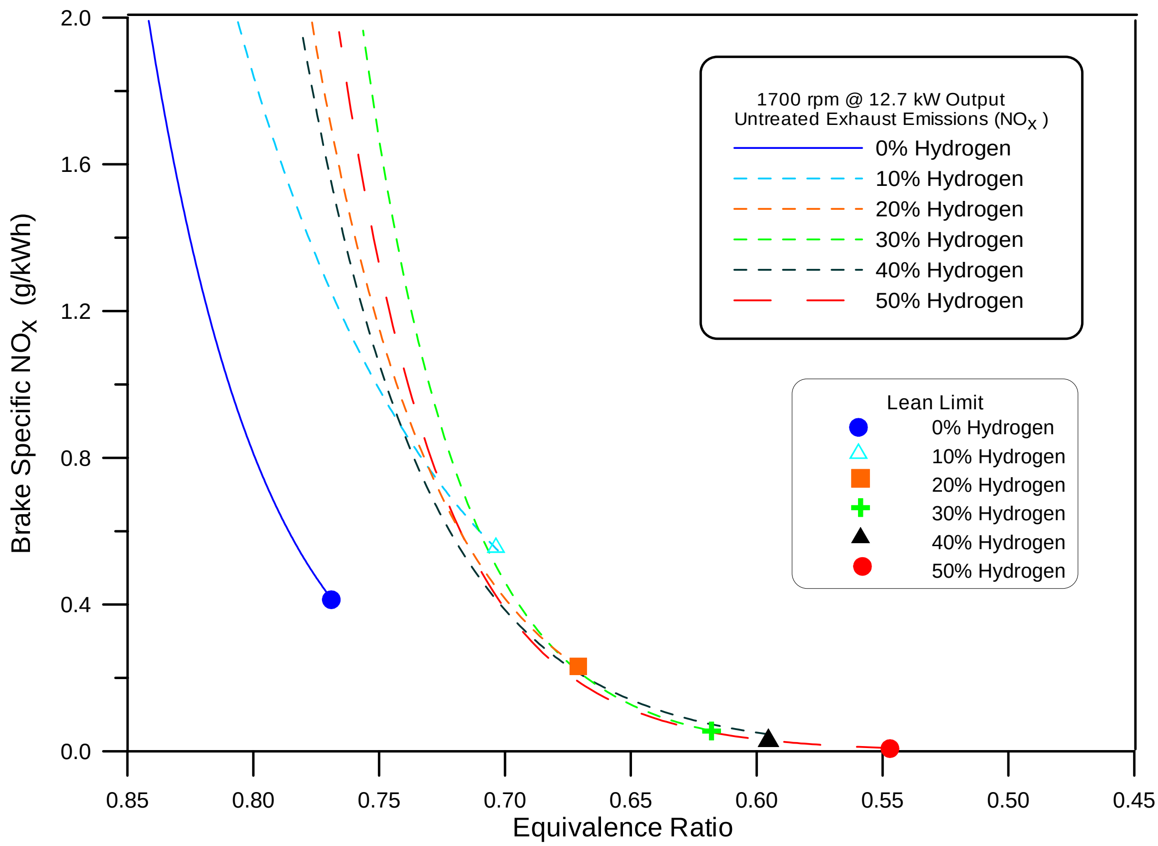

Figure 3- NOx emissions versus equivalence ratio (lean burn) for various hydrogen contents

Higher hydrogen concentration will extend the lean limit further to lower equivalence ratios, but as it can be seen in Figure 3, without the attendant benefit of additional reductions in the NO_x emissions.

In addition to blending H and CNG, Collier is working on modifying an 11 L Dewoo engine for use, with HCNG fuel, in transit applications. The modifications focus on the redesign of the air intake and HCNG/air mixing systems. The function of the mixture formation system is to produce a combustible, homogeneous air-HCNG mixture. Homogeneity can only be achieved by gas/vapor mixtures, i.e. all fuel (HCNG) must be vaporized before the ignition is initiated. In addition of forming a homogeneous mixture, the mixture formation system must also provide engine load control. As the load decreases, the intake manifold pressure drops producing HCNG vaporization. The manifold intake redesigned is aimed to control the air flow.

The ignition timing must be controlled in accordance with: (i) air/HCNG ratio; (ii) combustion chamber turbulence patterns; and, (iii) constant-duration ignition and flame propagation processes. Subsequent combustion processes are dependent on the available flame velocity (combustion speed) and the resulting combustion duration. To this end, Collier is working with an engine control manufacturer to develop the most efficient control schemes for the Dewoo engine.

In summary, Colliers's approach is fourfold, namely:

- Modified fuel chemistry by blending hydrogen and CNG.
- Modified air/ fuel ratios by using low equivalence ratios between .65 and .55.
- Modified ICE physical configuration to allow better mixture formation and air flow.
- Modified engine control schemes by using proprietary (but visible to user) engine control software.

SAFETY CONSIDERATIONS FOR HCNG

Although more research is needed, at this time it appears that for hydrogen contents of less than 50% in the HCNG blend, leakage and flammability risks are similar to those for CNG alone. With the hydrogen being part of the mixture, there are no special precautions needed to avoid hydrogen embrittlement of the materials coming in contact with the mixture. Any design conforming to the existing standards should suffice.

REFORMING

A further enhancement is possible by producing ammonia using Collier's reformer technology. This involves a small reactor (the size of a desk printer). The amount of ammonia needed to react with the exhaust NO_x is very small. The vaporized water ammonia mixture is routed to the engine exhaust where it reacts, over a catalyst, with NO_x in the exhaust gases reducing the amount of NO_x that escapes to atmosphere below the ambient. It must be pointed out that no actual test data was available for analysis.

OTHER CONSIDERATIONS

- The Dewoo engine is reported to operate at 2200 rpm that is compatible with the current transmissions used in the transit buses.
- The Deewo engine seems to be longer than the equivalent Cummings and Detroit Diesel engines used in the transit applications, but according to Colliers Technologies will fit in the existing transit buses. The Deewo engine is reported as being lighter than its counterparts.
- The loss of range due to the addition of hydrogen to the CNG fuel is approximately 12%.
- The HCNG blend can be made available by modifying the existing CNG delivery stations. Trillium USA is contemplating work along these lines.

CONCLUSIONS

HCNG technology when combined with ultra lean burn, air-fuel mixture formation system and intake manifold design changes, and electronic engine control scheme modifications show tremendous potential for enabling current technology transit buses to meet CARB 2007 NO_x requirements. It also has the potential to approach zero NO_x emissions if the addition of reformer technology will pan out.

This solution will be, by far, the easiest and most economical to implement for the bus manufacturers. It will involve integrating a new engine into their existing designs and, probably, some modifications to the fuel storage and delivery systems. For the bus operator these changes will be, in most part, transparent. The fuel delivery stations will have to be modified to an unknown , at this time, extent.

RECOMMENDATION

LACMTA should engage in an accelerated evaluation program. To this end it should encourage bus manufacturers to produce several prototypes for the program.