Collier Technologies

Technology Description

HCNG

HCNG is the acronym given to mixtures of hydrogen and natural gas used as a motor fuel. This technology represents a number of individual technologies that all rely on the concept that NOx emissions from internal combustion engines can be significantly reduced by using these mixtures. The principle of emissions reduction relies on the fact that NOx emissions are a function of peak combustion temperature. By introducing large amounts of heat capacity that do not participate in the combustion reaction, peak combustion temperatures can be reduced thereby reducing NOx emissions. We call this principle charge dilution. It can be accomplished by excess combustion air (lean burn), dilution with exhaust gases (EGR), or by water injection.

All of these charge dilution techniques are already employed using conventional fuels. The problem is that conventional fuels reach a misfire condition (incomplete combustion) before NOx emissions are reduced to values that can meet many current and future regulations. The addition of hydrogen extends the combustion regime to afford efficient combustion with large values of charge dilution. The addition of hydrogen to gasoline was investigated many years ago by JPL as an alternative to catalytic removal of harmful exhaust emissions. Others also previously investigated hydrogen addition to natural gas. However, the amount of hydrogen addition was always limited to about 20%, by volume, as if the hydrogen was to be viewed as a fuel additive. These modest quantities of hydrogen did not sufficiently extent the "lean limit" of combustion sufficiently to reduce NOx emissions to the values needed, given competing emissions reduction methods.

Hydrogen combustion actually increases NOx emissions with all other things being equal. Early research by Collier Technologies founders Dr. Kirk Collier and Mr. Neal Mulligan while at the University of Central Florida focused on the tradeoffs between NOx emissions, hydrogen content of the fuel, and the degree of lean burn. A synopsis of that research is shown in Figure 1. The major conclusions shown are:

- For a given equivalence ratio, hydrogen addition increases NOx.
- Hydrogen concentration must be above 10% to achieve equal or better NOx emissions through lean burn when compared to natural gas.

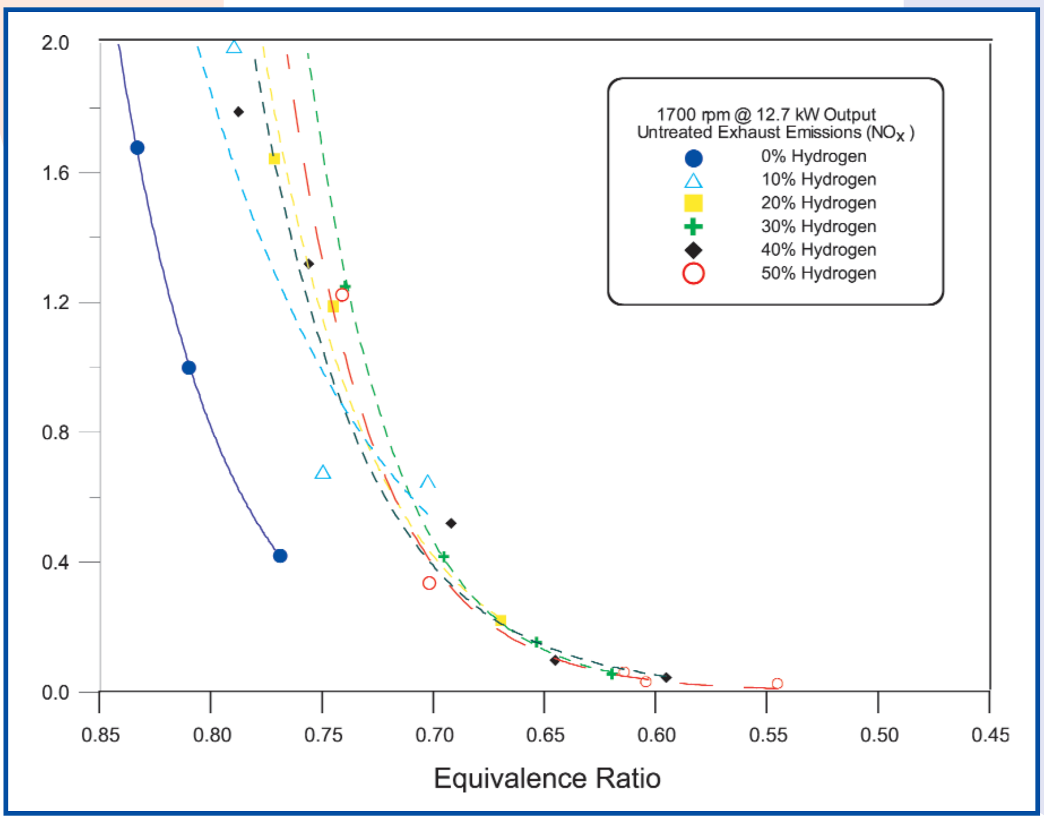

Figure 1. NOx vs. Equivalence Ratio for Varying Hydrogen Content in Natural Gas

- The minimum hydrogen content to reach the "knee" of the NOx curve (the point of diminishing returns) is 30%.
- Hydrogen contents above 30% extend the lean limit considerably, but do not result in commensurate NOx reductions.

This work resulted in patents 5,660,602, 5,666,923, and 5,787,864 being issued to Dr. Collier and Mr. Mulligan that were assigned to the University. These patents cover the use of 21 to 50% hydrogen natural gas mixtures to reduce NOx emissions using lean burn. These patents are now under exclusive license to Collier Technologies (CT). Table 1 shows the engine out emissions for a bus engine developed by CT that is being deployed in the City of Las Vegas using the HCNG lean burn technology.

Patent 6,405,720 B1 was issued to Dr. Collier after leaving the University. This patent is similar to the UCF patents, but EGR is the charge dilution mechanism rather than lean burn. We currently implement the EGR strategy for light-duty vehicles that have OEM computers and three-way catalysts. This results in a much more cost effective conversion of existing vehicles to HCNG operation. This patent is assigned to CT. Table 2 shows the three-bag FTP emissions results for a Ford F150 extended cab pickup truck. This vehicle was tested by CAVTC laboratories in Hayward CA.

An important aspect of successfully achieving the best NOx emissions possible with hydrogen natural gas mixtures is the design of the air intake and the fuel/air mixing systems. These designs are described in patent pending 60/357,941.

Reformer Technologies

<u>HCNG Production:</u>

It was identified early on that our HCNG technology would be limited in the marketplace by the availability of hydrogen at refueling facilities. In addition, applications involving stationary power (including DG and CHP) would not likely be available to us. Dr. Collier developed two reformer technologies that can overcome that limitation.

The first of these technologies is directed at making the appropriate amount of hydrogen directly from natural gas. The reformation of natural gas, and other hydrocarbon fuels, to make hydrogen as well as using these reformates to fuel internal combustion engines has been well documented in the literature. CT's technology is unique in that besides performing the reformation process within the IC engine, it takes advantage of the fact the EGR gases provide both the thermal energy, steam (from combustion), and oxygen to perform autothermal reformation. Therefore, one is able to integrate available catalysts within the EGR plumbing to perform the required reformation of the fuel if engine fuel is injected into the EGR line rather than the air intake of the engine. This reactor is as simple as an automotive catalytic converter system. A schematic of this process is shown in Figure 2.

This type of simple reformation, is applicable because we only need to reform a small fraction of the natural gas to achieve a 30% hydrogen mixture, and because the gas quality need not be controlled for an IC engine. Carbon monoxide is a very good IC engine fuel whereas it is a potent poison for most fuel cells. We need only reform 10% of the methane to result in approximately 30% molar hydrogen content (if the water gas shift of CO and water to hydrogen

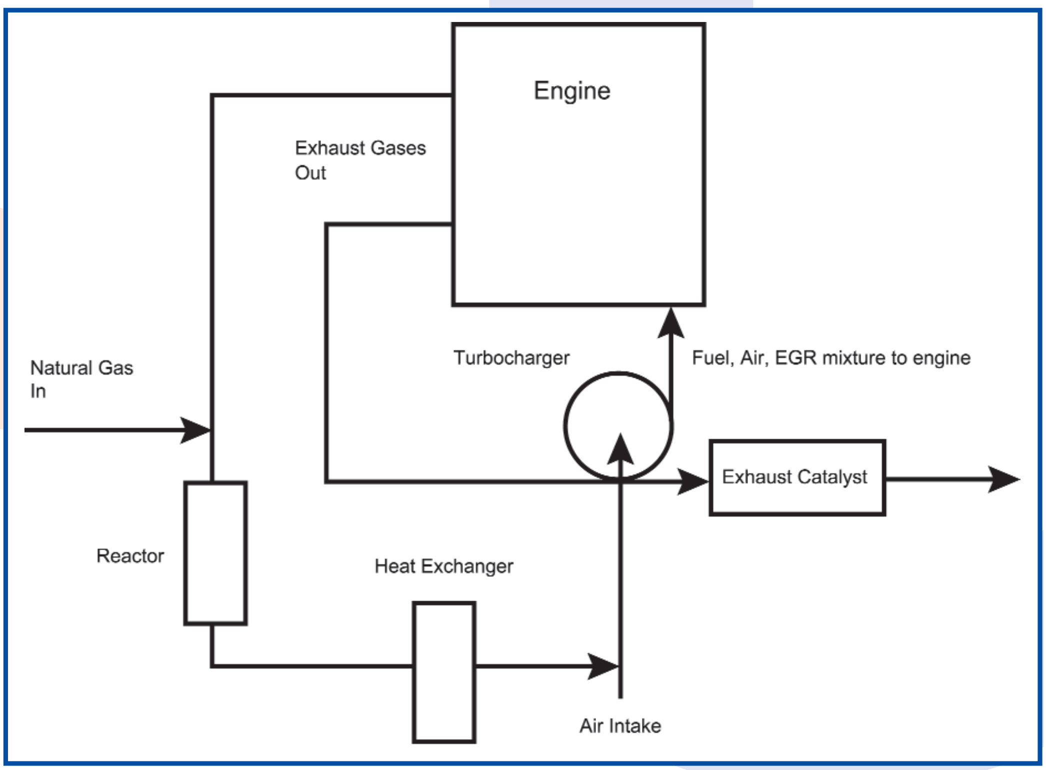

Figure 2. Schematic of Natural Gas Reformer Concept

and CO_2 is accomplished).

Dr. Collier was issued patent #6,508,209 for this invention, which has been assigned to CT.

Octane Enhancement:

The second application of our reformer technology is to improve the octane rating of natural gas. The composition of natural gas can vary dramatically from location to location as well as with time of year. The constituents that vary mostly are the ethane and propane content. Methane has a very high octane rating (~130). Propane and ethane octane ratings are considerably lower (~90 to 95). Engine manufacturers must tune their engines for the worst case gas composition to avoid the catastrophic consequences of engine knock. This significantly compromises engine power and efficiency. By designing the reformer to selectively convert the higher hydrocarbons to hydrogen, the resultant octane rating is consistently at least that of methane in a lean burn application.

Dr. Collier was issued patent #6,397,790 B1 for this invention which has been assigned to CT.

On-Board Ammonia Production for SCR

A third design option to our reformer technology is the production of ammonia in the reactor. The ammonia produced in the reactor is soluble in the water that is condensed from the cooling process before the EGR gases containing the HCNG fuel mixture is introduced into the intake air stream. Although conditions within the reactor are not ideal for ammonia production, the amount of ammonia required to react with exhaust gas NOx is very small when compared to the amounts of hydrogen and nitrogen available for reaction. The solubility of ammonia in the condensed water allows for the separation of ammonia from the reactor outlet gases. This water ammonia mixture is revaporized after separation with heat from the reactor outlet gases. The steam and ammonia vapor are then routed to the engine exhaust that exits to the atmosphere where the ammonia reacts with NOx over an SCR catalyst to essentially eliminate NOx as a pollutant.

Mr. Neal Mulligan developed this invention. It is patent pending #10/293,020 and has been assigned to CT.

Pure Hydrogen IC Engines

CT is currently modifying both stationary and mobile engines to operate on pure hydrogen as the fuel. There is currently an expanding market for this technology as worldwide entities attempt to convert to hydrogen, but cannot accept the current economics of fuel cells. Utility companies, both natural gas and electric and both U.S. and abroad, are investigating the economics of being hydrogen suppliers and implementers. However, the advantages of simple conversions of IC engines with HCNG cannot be easily adopted when dealing with pure hydrogen. Without the combustion modifying effects of methane, hydrogen combustion is extremely rapid and difficult to control in an IC engine. Techniques have been developed by CT that can achieve low emissions, high engine power output, and reliable, backfire-free engine operation with pure hydrogen fuel. These techniques are not patented, but reside as CT intellectual property.

Individual Modes	NOx (g/bhp-hr)	THC (g/bhp-hr)	NMHC (g/bhp-hr)	CO (g/bhp-hr)	Weighting Factor
1800 rpm - 100% Load	0.15	3.70	0.11	0.00	0.15
- 75% Load	0.12	3.86	0.12	0.00	0.15
- 50% Load	0.09	4.86	0.15	0.00	0.15
10% Load	0.13	8.82	0.26	0.00	0.1
2800 rpm - 100% Load	0.21	3.31	0.10	0.00	0.1
- 75% Load	0.15	3.77	0.11	0.00	0.1
- 50% Load	0.10	5.75	0.17	0.00	0.1
- Idle	0.22	7.21	0.22	0.00	0.15
Weighted 8 Mode (g/bhp-hr)	0.15	5.11	0.15		
Weighted 8 Mode (g/kw-hr)	0.20	6.85	0.21		

Table 1. HCNG Eight-Mode Emissions for Collier Technologies-Developed Bus Engine (Lean Burn)

CAVTC

CLEAN AIR VEHICLE TECHNOLOGY CENTER

1975 Federal City Gasoline Test

Test	6224	Vehicle		Fuel	
Date	10/24/01	Control #	A01NRG01	Name	30%hydrogen
Time	10:13	Model	2001 ford f-150 xlt	CWF	0.733
Cell ID	Cell 1	VIN	1FTRX17L51NB70528	OWF	0.014
Test	epa75	Engine	1fmxt05.4pfs	Spc Grv	0.609
Shift	epa75	Odometer	738	NHV	20530
Driver	Gil Rodriguez	Dyno Inertia	5,500	R-Factor	0.60
Operator	Glen Muñoz	Dyno AHP/IHP	20.8/18.4	Control #	TANK1

Ambient Conditions

Baro (inHg)	30.036	30.034	30.035
Dew Pt (F)	45.72	45.69	46.13
Dry Temp (F)	75.49	80.71	82.79
Humidity	34.732%	29.207%	27.764%
Abs (gr/lb)	45.05	45.00	45.77
NOx K Factor	0.877	0.877	0.880

Comments

30%hydrogen 70%natural gas

Tire Pressure=45 psi, Trans. Type=A-4, 40% fill=5.0
EPA fuel economy calculation used.

Phase Variables

	Begin	End	Length	Viol	Dist (mi)	Vmix(ft3)
Phase 1	10:13:19	10:21:48	509	0	3.598	2850.89
Phase 2	10:21:48	10:36:18	870.4	0	3.861	4953.96
Phase 3	10:46:19	10:54:46	507.7	0	3.590	2888.72

Bag Readings

	HC ppmC	CO ppm	NOX ppm	% CO2	CH4ppm	NMHCppm	DF
Phase 1							
Full Scale	100.00	500.00	30.00	2.00	50.00		
Sample Conc.	32.310	87.997	0.521	1.591	26.598	1.908	6.11
Ambient Conc.	9.302	0.000	0.072	0.054	6.823	1.503	
Net Conc.	24.532	87.997	0.461	1.546	20.892	0.652	
Grams	1.142	8.269	0.062	2283.94	0.973	0.030	
Phase 2							
Full Scale	30.00	100.00	30.00	2.00	50.00		
Sample Conc.	9.794	5.832	0.084	0.941	7.655	1.045	10.38
Ambient Conc.	8.905	0.000	0.075	0.053	5.950	1.294	
Net Conc.	2.479	5.832	0.016	0.894	2.278	0.000	
Grams	0.201	0.952	0.004	2293.82	0.184	0.000	
Phase 3							
Full Scale	30.00	100.00	30.00	2.00	50.00		
Sample Conc.	16.297	25.300	0.078	1.392	13.454	0.920	7.01
Ambient Conc.	6.263	0.000	0.073	0.054	4.438	1.190	
Net Conc.	10.927	25.300	0.016	1.346	9.649	0.000	
Grams	0.516	2.409	0.002	2014.67	0.455	0.000	

Test Results	THC	CO	NOx	CO2	CH4	NMHC	MPG
Grams/mi	0.132	0.789	0.004	593.47	0.116	0.0017	11.823

Table 2. Emissions Results for Ford F150 Converted to HCNG by Collier Technologies.

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