NREL/TP-425-6162 • UC Category: 335 • DE94000245

Demonstration of the Fuel Economy Potential Associated with M85-Fueled Vehicles

J.W. Hodgson and S.P. Huff
The University of Tennessee
Knoxville, TN

NREL technical monitor: C. Colucci

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory operated for
the U.S. Department of Energy
under contract No. DE-AC02-83CH10093

Prepared under Subcontract No. XA-2-11247-1

December 1993

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A03

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

Printed on recycled paper

Preface

In the past, gasoline-fueled vehicles converted to operate on methanol fuels have realized a power-based performance benefit because of the characteristics of the methanol fuel. Because it is possible (in theory) to trade off performance to gain fuel economy, we proposed a study in which we would attempt to exploit the potential of methanol to provide improved vehicle fuel economy while maintaining vehicle performance at the gasoline-fueled baseline level.

We want to thank several people who helped us in this study: K. Knapp of the U.S. Environmental Protection Agency for his willingness to conduct the emissions testing; personnel at the Transportation Research Center of Ohio for their hospitality during our fuel economy testing; J. Rohe of A.C. Rochester for providing support to overcome injector and fuel pump problems during the study; and our technical monitors (B. Bailey and C. Colucci) who provided effective interfaces with our sponsor.

Summary

To demonstrate that the characteristics of methanol fuels can be exploited to emphasize vehicle fuel economy rather than vehicle performance, we converted a gasoline-fueled 1988 Chevrolet Corsica to operate on M85. Our conversion took advantage of the well-known power boosting potential of the M85 by turbocharging the engine and decreasing its displacement. We accomplished the displacement decrease by disabling two of the six cylinders, but selected a turbocharger and boost level to maintain essentially the same vehicle performance exhibited by the base gasoline-fueled vehicle.

The results indicate vehicle fuel economy improvements (on an energy adjusted basis) of up to 21% at steady highway speeds and almost 20% on the U.S. Environmental Protection Agency's federal test procedure city and highway cycles. We feel that the results of our study show that dedicated M85-fueled vehicles can be designed to exploit the energy-efficiency characteristics of the fuel.

Contents

List of Tables

Introduction

Background

Using methanol fuels in light-duty vehicles provides energy security and air quality benefits that have led to their implementation—particularly in California, where M85 (a mixture of 85% methanol and 15% unleaded gasoline, by volume) is available at public refueling stations. The substantial cooling effect created as methanol evaporates when mixed with the engine's intake air leads to increased power output from gasoline-fueled engines when they are converted to operate on methanol fuels (U.S. Environmental Protection Agency [EPA] 1989). If additional steps are taken to exploit the high octane rating of methanol fuels (typically, raising the engine's compression ratio or power boosting by turbocharging or supercharging), even higher power levels can be achieved.

Rather than accepting the increased power levels as a benefit, the vehicle designer could, in theory, opt to implement the methanol conversion so that the increased power potential of the engine would be used to realize improved vehicle energy efficiency rather than improved vehicle performance (acceleration potential). The trade-off between performance and fuel economy has been discussed elsewhere (Hellman 1986) and estimates have been made of the fuel economy of an optimized methanol vehicle (EPA 1989). These estimates, however, usually include lean burn concepts that may require advanced hardware or emission control strategies to implement. Figure 1 illustrates the type of thinking that has led to the claims of methanol's potential for improved fuel economy (EPA 1989). This figure is based on retaining a naturally aspirated engine concept.

In essence, using methanol fuels creates an opportunity to operate engines at high brake mean effective pressures (bmep). Because bmep can be interpreted as brake torque per unit displacement, higher pressures can be used to create higher torque from the same displacement (performance enhancement) or can be used to create the same torque using a smaller displacement engine (fuel efficiency enhancement).

The Concept

We wanted to conduct this study to demonstrate one way in which the potential for increased bmep resulting from methanol fuel use could be converted into improved vehicle fuel economy. We took a given vehicle with a V-6 engine and reduced the displacement of its engine by, in essence, "removing" two of the cylinders. We made the power output of the smaller methanol-fueled engine comparable to that of the larger gasoline-fueled engine by turbocharging the methanol engine. The smaller engine should have reduced mechanical friction because two of the cylinders were deactivated. In addition, for a given engine speed and torque output (therefore, for a given brake power output) requirement, the smaller engine should also have lower pumping losses because it would have to operate at a higher bmep and thus would require a higher intake manifold pressure (less throttling).

The obvious question is, "Why not simply install an existing four-cylinder engine rather than modify the six-cylinder engine?" The answer is found primarily in our desire to explore the concept while changing as few variables as possible. If we used a different engine, questions would arise regarding the inherent differences in the two engine designs (combustion chamber shape, intake system design, control system, etc.). By using the same engine, we avoided the need to answer these difficult questions. Another reason we chose to use the same engine was that the particular vehicle used was equipped with an engine control system that was readily modified and the conversion to methanol fuel had already been accomplished.

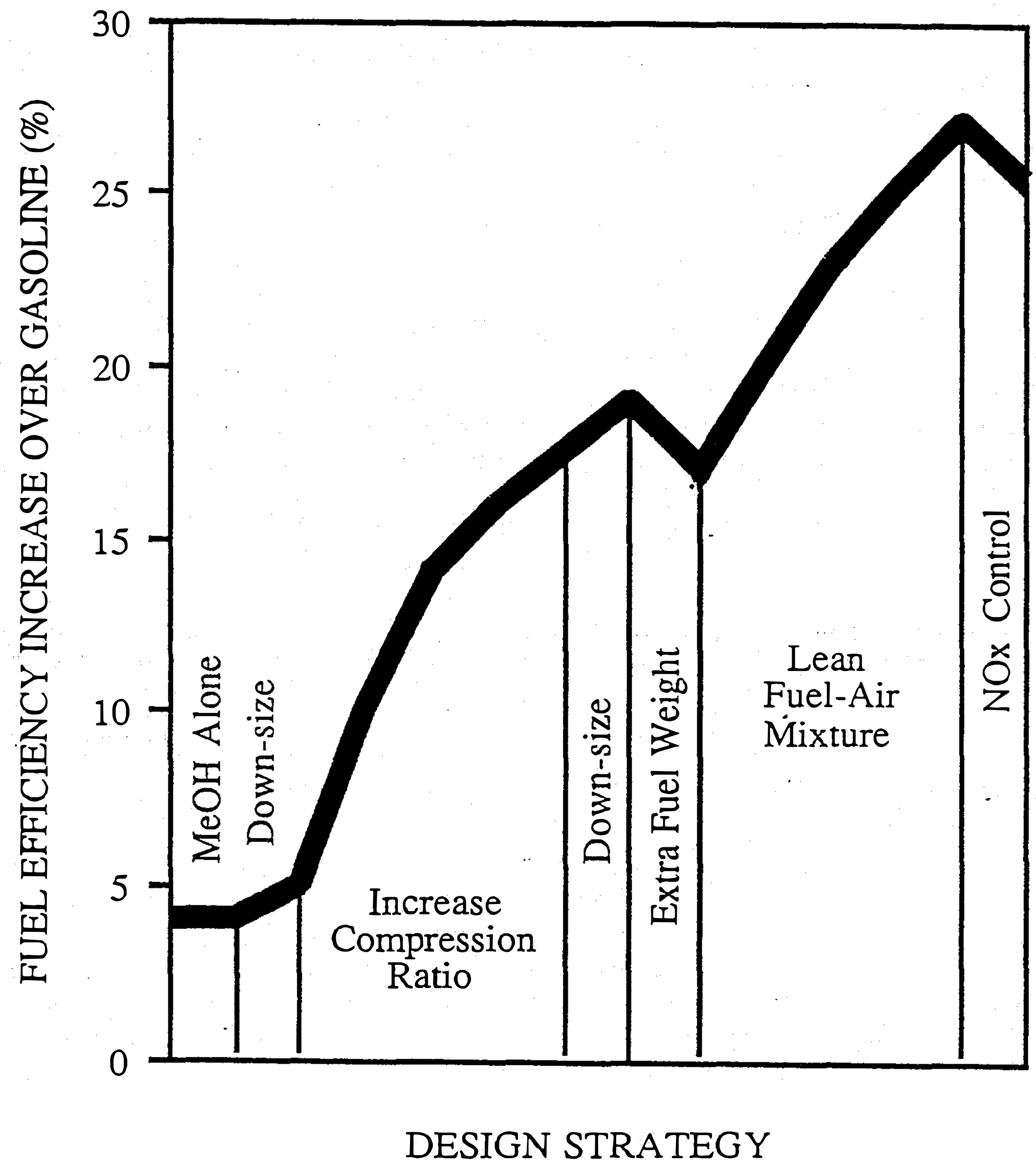

Figure 1. Fuel efficiency potential of methanol (EPA 1989)

The Approach

We used a 1988 Chevrolet Corsica four-door sedan equipped with a five-speed manual transmission and a V-6 push rod engine having a displacement of 2.8 L. The engine had simultaneous double-fire port-fuel injection, a direct-fire ignition system, and an engine control system based on using a mass air flow (MAF) sensor. General Motors Corporation originally supplied this vehicle to the University of Tennessee for use by student teams in the 1989 Methanol Marathon and the 1990 Methanol Challenge competitions (Hodgson 1990). As part of the competitions, General Motors provided methanol-tolerant fuel system components, high flow injectors, and instructions for modifying the various "look-up tables" in the engine control module. More detailed information on this vehicle is available in the literature (Hodgson 1990).

We conducted tests on the gasoline-fueled base engine and the M85-fueled modified engine. We also conducted tests on the vehicle with the base engine installed and on the vehicle with the modified engine installed. We were also able to make comparisons with information from other sources.

Mechanical Engine Modifications

We modified the 2.8-L engine by deactivating two cylinders. The cylinders chosen to be deactivated met the criteria that they should not be on the same cylinder bank and they should not be next to each other in the firing order. The displacement of the resulting V-4 engine was 1.87 L. We deactivated the two cylinders by installing dummy valve lifters that did not contact the cam lobes. (The use of dummy lifters was necessary to maintain oil pressure in the engine.) We also installed springs between the rocker arms and the rocker arm retaining nuts to accommodate thermal expansion of the disabled valve train components.

Although our original plan called for removing the pistons and connecting rods from the disabled cylinders, engine balancing considerations required retaining these and led us to adopt a different approach in which the piston rings were removed from the two pistons and large slots were machined in the piston crowns. We removed the rings to decrease the sliding friction between the pistons and the cylinder walls. We used the slots to allow the crankcase gases to pass freely back and forth past the pistons. There was concern that merely removing the piston rings would create pumping losses if the pistons developed compression pressure as they traveled up the cylinder. To maintain the engine balance, we used steel inserts in the hollow piston pins to compensate for the weight lost by removing the rings and creating the slots.

Control System Modifications

The fuel management control strategy of the Corsica engine is primarily based on engine speed and a load parameter (LV8) that is proportional to the mass flow rate of air divided by the engine speed. For a given engine, the LV8 parameter is proportional to the mass of air drawn into each cylinder on the intake stroke and thus the base injector pulse width is proportional to the LV8 value. To retain the value of this parameter when the engine was converted to four active cylinders, we changed the scaling parameter of this variable so that for a given mass flow rate of air the control system compensated for the fact that this air was being shared with four cylinders rather than six. That is, the "new" LV8 parameter was 1.5 times that of the "old" LV8 parameter.

We did not change the ignition timing from that developed for the six-cylinder version of the engine and we made only minor changes in fuel metering to accommodate an injector change that became necessary during the study.

Power Boosting

To recover the wide-open-throttle power lost by downsizing the engine, we fitted it with a Garrett turbocharger. We first tried the unit used originally on the methanol-fueled six-cylinder version, but it proved to be a poor match in that boost was delayed until high engine speeds were encountered. We then tried a different unit that was similar to one used on a production 1.9-L engine. It performed very well.

Emission Controls

We used the same emission controls on the four-cylinder version as were used in the six-cylinder methanol conversion (Hodgson 1990). These consisted of adding a close-coupled "light-off" catalyst between the engine and the stock catalyst and reprogramming the exhaust gas recirculation (EGR) schedule to yield a 40% decrease in the EGR rate.

It should be noted that other than the steps taken to deactivate the two engine cylinders, the changes made to accommodate the methanol fuel, and installing the turbocharger, we made no other modifications to the stock engine. Specifically, we used the stock camshaft, lifters, and rocker arms; we used stock clearances in assembling the engine; and we made no modifications to the cylinder heads.

Testing

We conducted several tests as part of the study. These included initial engine dynamometer tests, vehicle acceleration tests, vehicle emission tests, and vehicle fuel economy tests. Each is discussed below.

Engine Dynamometer Testing

We coupled the engine to an electric direct current dynamometer to determine engine friction and engine power output at wide open throttle.

Table 1 shows both the six-cylinder (base) engine friction and the four-cylinder (modified) engine friction. As expected, the four-cylinder engine has lower mechanical friction than the base engine. Figure 2 shows the power output of the two engines and that the methanol-fueled turbocharged four-cylinder engine gave power output comparable to that of the stock gasoline-fueled naturally aspirated six-cylinder version of the same engine at speeds above 2,000 rpm. We felt that this curve represented a reasonable achievement for the purposes of this study.

Although the particular vehicle used in the study was equipped with a manual transmission, if the vehicle had been equipped with an automatic transmission, we are sure that the engine would never operate at wide open throttle at engine speeds of less than 2,000 rpm.

After we obtained the dynamometer test results, we installed the engine in the vehicle for road testing. Despite the fact that deactivating two cylinders resulted in uneven firing intervals, the engine operated smoothly, and because the deactivated cylinder valves remained closed at all times, we heard no exhaust sound that one would normally associate with misfiring cylinders.

What was apparent to us, however, was the loss of engine torque at engine speeds below 2,000 rpm. This was particularly noticeable when accelerating the vehicle from a stop. As mentioned above, however, we believe that this would not be a problem in a vehicle equipped with an automatic transmission and torque converter.

Table 1. Motoring Torque Comparison

Engine Speed (rpm)	Manifold Pressure (KPa)	Friction Torque (ft-lb f)		% Reduction
		six-cyl	four-cyl	
1000	100	19	17	10.5
	85	21	18	14.3
1500	100	20	18	10.0
	85	22	19	13.6
	70	24	20	16.7
2000	100	23	21	8.7
	85	24	21	14.3
	70	26	22	15.4
	50	28	23	17.9
2500	100	26	23	11.5
	85	27	23	14.8
	70	29	24	17.2
	50	30	26	13.3
3000	100	32	26	18.8
	85	32	26	18.8
	70	33	27	18.2
	50	33	27	20.6
	30	35	28	20.0

Vehicle Acceleration Testing

Although the engine dynamometer tests clearly indicated that the engine was delivering the same (or slightly greater) brake power than the base engine, we conducted acceleration tests to document the vehicle performance. Because previous acceleration testing (Hodgson 1990) had involved 0- to 500-ft tests, we it was decided to use this distance for the tests.

We conducted the acceleration tests at a local facility using a vehicle-mounted infrared source and detector incorporating a timer. When the infrared beam was reflected back to the detector, a timing circuit was triggered. The triggering was accomplished by positioning a reflector at the point on the track where the acceleration run was initiated and the timing was terminated by positioning a second reflector at the appropriate distance down the track.

Because acceleration results are usually driver-specific, we made several runs using the same driver. The acceleration rates coming off the line were traction limited, but the results in Table 2 verify that the two vehicles had very similar acceleration times.

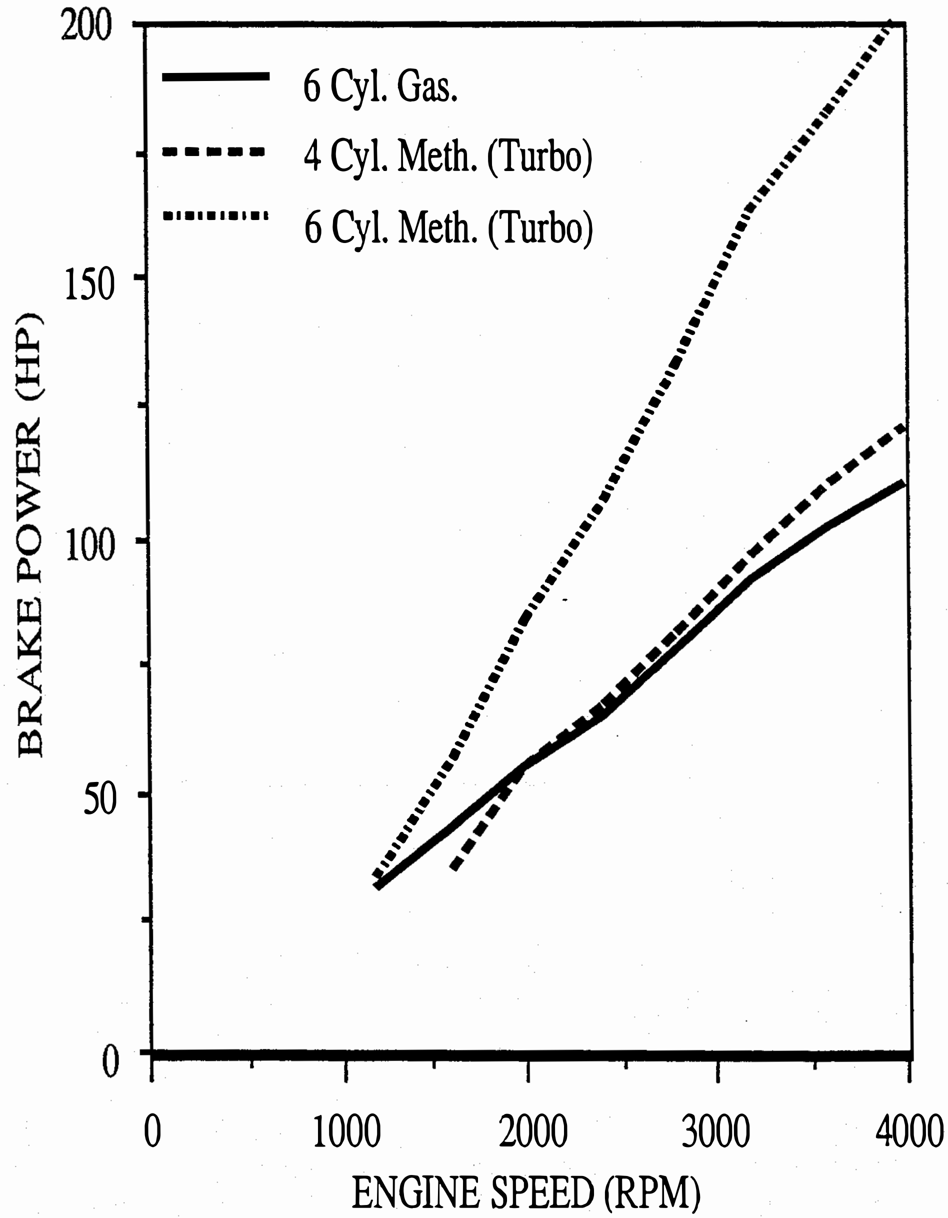

Figure 2. Engine performance

Table 2. Acceleration Results

Configuration	0- to 500-ft Acceleration Time (s)
Base Vehicle	10 ± 0.25
Modified Vehicle	10 ± 0.15

We found it interesting to compare these values with the value given from the results of the 1990 Methanol Challenge competition in which a gasoline-fueled six-cylinder control vehicle had a 0- to 500-ft acceleration time of 8.94 s (Larson 1991). We feel that the difference reflects the aggressiveness of the driving strategies used.

Vehicle Fuel Economy Testing

We used three measures of fuel economy in this study: on-road fuel consumption tests were conducted on a highway at 55 mph and on a test track at 45, 55, and 65 miles per hour; fuel economy was measured during emissions testing using the federal test procedure; and fuel economy was also determined during emissions testing using the federal highway test procedure. Each is discussed below.

On-Road Testing

For the on-road tests, we drove the warmed-up vehicle at a constant speed for a predetermined distance. We filled the fuel tank prior to the test and then carefully measured the amount of fuel required to refill the tank. We discovered that a special procedure had to be used, however, to make sure that reliable data were obtained. The fuel tank on the vehicle has a vapor dome that ensures that the tank cannot be completely filled with liquid under normal refueling conditions. The dome has a restricted vapor outlet that leads to the evaporative emission control system (charcoal canister). As a result, if one "fills" the tank and then observes the fuel level in the filler tube, the level gradually drops as vapor flows from the dome volume into the charcoal canister. It takes a long time for the level to stabilize sufficiently to make a reliable determination of the fuel level, so another approach was adopted.

In this approach, we removed about 4 L of fuel from the tank (to make sure that the dome volume contained no liquid) and then plugged the vapor hose leading to the canister. This sealed the dome and prevented the gradual dropping of the fuel level in the filler neck. We then poured the fuel back into the tank, added more fuel to fill it (defined by having the fuel level rise in the filler neck to a predetermined level), reconnected the vapor hose to the charcoal canister, and replaced the fuel cap. We repeated the process following the completion of the mileage accumulation. We made sure that the vehicle was parked in the same location each time the tank was filled.

We measured the vehicle speed and the distance traveled using a Labeco fifth wheel. Although we were able to conduct tests at 55 mph on a relatively flat interstate highway, traffic density made tests at 45 mph and 65 mph inadvisable on public highways. As a result, we conducted additional tests on the 7.5-mile-long high-speed track at the Transportation Research Center of Ohio.

The results of the road testing are shown in Table 3 along with data reported from the control vehicle used in the 1990 Methanol Challenge competition (Larson 1991). In providing the gasoline equivalent fuel economy, the conversion factor of 1 volume of gasoline is equivalent to 1.754 volumes of M85 was used (California Air Resources Board [CARB] 1988) to put the fuel economy on an equal energy basis. That is, the gasoline-equivalent fuel economy (mpg) is 1.754 times the M85 fuel economy (mpg).

Table 3. On-Road Fuel Economy Results (mpg)

Test Descriptor	Six-Cylinder Gasoline		Four-Cylinder M85
	This Study	(Larson 1991)	
Highway @ 55 mph	37.0	n/a	41.1 - 43.4
Track @ 45 mph	38.6	40.1	44.1
Track @ 55 mph	34.9	32.5	39.4
Track @ 65 mph	31.2	29.2	32.2

The values given in the middle column are for the control vehicle used in the 1990 Methanol Challenge Competition (Larson 1991). The results show improvements ranging from 3% to 17% over the base vehicle and from 10% to 21% over the control vehicle used in the competition.

Repeatability of the Results

We repeated the testing on the highway at 55 mph using the base vehicle. Using a total of six tests, we concluded that the mean fuel economy was 37.0 mpg ± 0.3 mpg with a 95% confidence level.

Fuel Economy from Emissions Tests

Fuel economy results were also obtained from emission testing the four-cylinder vehicle at the EPA facilities in Research Triangle Park, North Carolina. Unfortunately, we could not test the base vehicle, but other data are available. The fuel economy in these tests was determined by a carbon balance technique in which the amount of fuel used is calculated by accounting for all the carbon discharged from the exhaust (in the form of carbon dioxide, carbon monoxide, and hydrocarbons) and assuming that all the carbon in the exhaust came from the fuel. Knowing how much carbon there is in M85 (1314 grams per gallon) allows the volume of fuel consumed to be calculated (CARB 1988). In these tests, however, the carbon contained in any aldehydes and in any methanol not measured by the hydrocarbon analyzer (flame ionization detection) was not accounted for. These systematic errors, however, are believed to be very small.

We show the results of these tests in Table 4 along with the values from the control vehicle used in the Methanol Challenge (Larson 1991) and the EPA certification values for the 1988 Chevrolet Corsica (Larson 1991). Note that the certification results are slightly higher than the values measured from the control vehicle.

Table 4. Fuel Economy from Emissions Tests

	Six-Cylinder Gasoline Vehicles			
FTP Test	Base	Meth Chall. Control	EPA Cer.t Data	Four-Cylinder M85
City	n/a	19.9	21.1	23.9
Highway	n/a	35.8	37.3	42.4

The four-cylinder concept shows about a 20% improvement in fuel economy over the control vehicle used in the Methanol Challenge (Larson 1991).

Overall Fuel Economy Results

Figure 3 shows the overall fuel economy results in which the results from the base six-cylinder gasoline-fueled vehicle are compared with those from the four-cylinder M85-fueled vehicle. The emission tests for the gasoline-fueled version are the results reported for the control vehicle in the Methanol Challenge (Larson 1991).

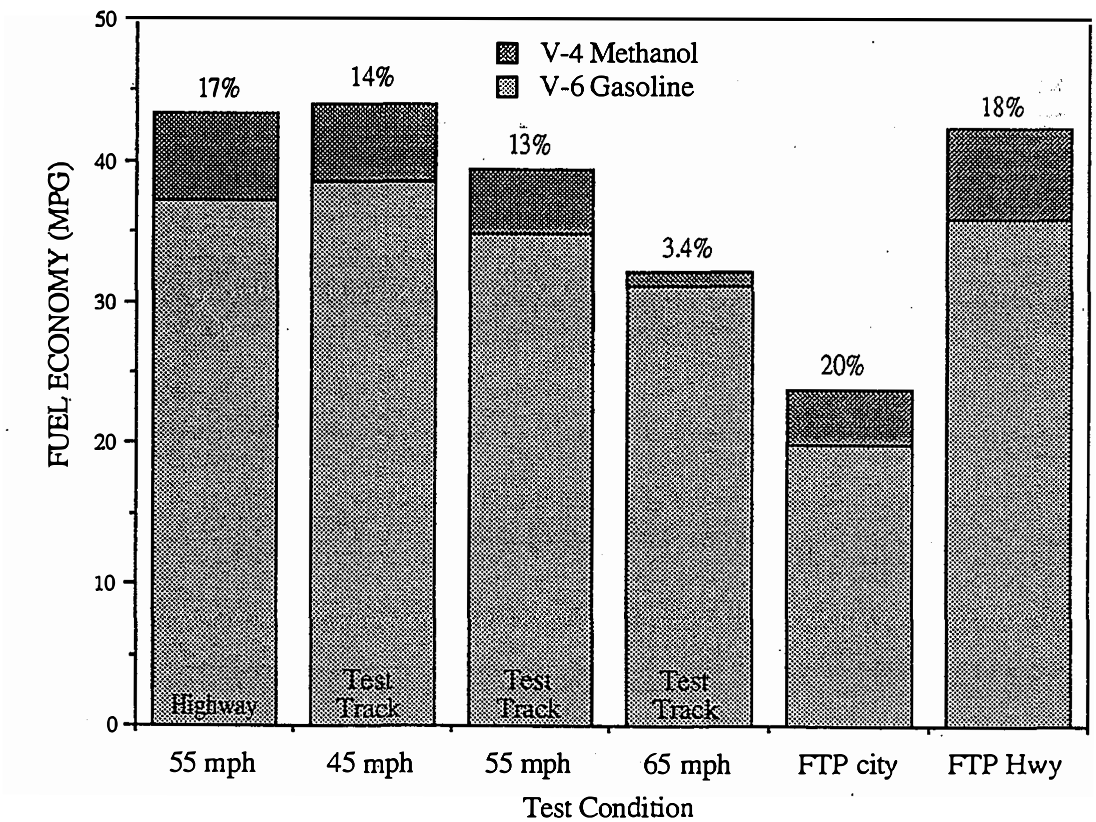

Figure 3. Overall fuel economy results

Emissions Tests

Although the focus of this study was not on reduced emissions, the emissions values were generated as part of the federal test procedure testing to measure fuel economy. We feel that the main value of these results is to indicate that the engine was not operating in a lean burn mode (which we would expect to generate improved fuel economy at the expense of NO_x emissions). The results indicate that, if anything, the engine may have been running a little rich with the slightly high carbon monoxide value. The specific results are shown in Table 5.

Table 5. Emissions Test Results

Component	Emissions
HC	0.40 (gm/mile)
NO_x	0.99 (gm/mile)
CO	5.17 (gm/mile)
CO_2	395.00 (gm/mile)

Conclusions

Based on these results, we concluded that it is possible to exploit methanol to achieve improved fuel economy rather than improved performance when compared to a gasoline-fueled base vehicle. The strategy of using a smaller displacement engine with charge boosting resulted in fuel economy increases of up to 21% at steady highway speeds and almost 20% on the federal test procedure city and highway driving cycles.

Using a single turbocharger to create the charge boosting, although effective at higher engine speeds, may not be as effective as mechanically driven superchargers or more advanced turbocharger concepts that would result in improved low speed torque output.

Although the concept relies on the properties of M85 for its success, it could be incorporated into flexible-fuel vehicle concepts. The performance of such vehicles would be reduced when they operate on gasoline because the octane rating and the cooling effects of gasoline are lower than those of M85, and this would reduce the amount of charge boosting allowable with gasoline.

Recommendations

Based on the results of this study, we recommend that the concept be explored further by implementing it in a manner that would be more representative of the technology involved in production vehicles; that is, since the proof of concept has been demonstrated, an existing vehicle could be retrofitted with a smaller displacement engine having perhaps a different design from its original engine.

References

CARB (1988). "Alcohol Fueled Fleet Test Program - Eighth Interim Report," ARB/MS-88-05, Mobile Source Division, California Air Resources Board.

EPA (1989). "Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel," Special Report, Office of Mobile Sources, Environmental Protection Agency.

Hellman, K. H. (1986). "Adjusting MPG for Constant Performance," note to Charles L. Gray, Jr., Environmental Protection Agency.

Hodgson, J. W., et al. (1990). "The University of Tennessee Methanol Corsica - Engineering for Low Emissions, High Performance," SAE Paper No. 902100, Society of Automotive Engineers.

Larson, Robert P. and Hill, Norman W. (1991). "The 1990 Methanol Challenge: Summary of a Successful Student Design Competition," SAE Paper No. 910570, Society of Automotive Engineers.

Document Control Page	**1. NREL Report No.**	**2. NTIS Accession No.**	**3. Recipient's Accession No.**
	TP-425-6162	DE94000245	

4. Title and Subtitle
Demonstration of the Fuel Economy Potential Associated with M85-Fueled Vehicles

5. Publication Date
December 1993

6.

7. Author(s)
J.W. Hodgson and S.P. Huff

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Mechanical and Aerospace Engineering Department
University of Tennessee
Knoxville, TN 37996-2210

10. Project/Task/Work Unit No.
FU321010

11. Contract (C) or Grant (G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

13. Type of Report & Period Covered
Subcontract report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)
A gasoline-fueled 1988 Chevrolet Corsica was converted to operate on M85 to demonstrate that the characteristics of methanol fuels can be exploited to emphasize vehicle fuel economy rather than vehicle performance. The results of the tests performed indicated fuel economy improvements of up to 21% at steady highway speeds, and almost 20% on the U.S. Environmental Protection Agency's federal test procedure city and highway cycles.

17. Document Analysis

a. Descriptors
alternative fuels, methanol, M85, vehicle fuel economy

b. Identifiers/Open-Ended Terms

c. UC Categories 335

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
12

20. Price
A03

Form No. 0069E (6-30-87)