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Potential Impacts of Compressed Natural Gas in the Vehicular Fleet of Mexico City

I. SCHIFTER,* L. DIAZ,
E. LÓPEZ-SALINAS, AND S. AVALOS

Instituto Mexicano del Petróleo, Gerencia de Transformacion de Energeticos, Eje Lázaro Cardenas 152, Gustavo A. Madero, 07730 México D.F., Mexico

One of the control measures to decrease urban air pollution in Mexico City is the introduction of compressed natural gas in gasoline-powered vehicles. In this study, an in-use vehicular fleet, representative of Mexico City's total vehicle population, was selected and converted to use natural gas. A comparison of emission factors for total hydrocarbons, CO, and NO_x were obtained from the gasoline- and gas-powered vehicles using the Federal Test Procedure (FTP-75). Average emissions reductions from private cars and taxis, the most numerous fleet type, were 88% for CO, 91% for non-methane hydrocarbons, and 40% NO_x. However, there is a 13% emissions increase in total hydrocarbons (that is, including methane). Speciated hydrocarbon data were used to estimate the potential of the emissions to form ozone and to predict the impact of fuel changes on air quality. In average, emissions from natural gas-converted vehicles were 2.3 times less reactive to form ozone than those from same vehicle fleet when gasoline-powered. Considering present natural gas-powered vehicles growth rate, regulated emissions reductions until the year 2007 were estimated.

Introduction

Prominent alternative fuels include natural gas and liquefied petroleum gas (LPG). There are two major reasons for advancing these fuels. The first one is the potential for reducing harmful vehicle emissions; the second one is that their use could displace a portion of the petroleum required by the transportation sector. Since 1991, several actions were taken to decrease environmental pollutants in the Metropolitan Area of Mexico City (MAMC). For instance, gasoline reformulation, decrease of sulfur content in diesel and gasoline, an inspection/maintenance program, vapor recovery systems installed in distribution and service stations, and emergency actions to be taken during days of high pollutants concentration among others have been instigated (*1*). If all of the above actions had been taken, 4356 thousand ton of CO, 1516 ton of total hydrocarbons (THC), 64 ton of NO_x, 318 ton of particle matter (PM), and 257 thousand ton of sulfur dioxides (SO_x) would not have been produced.

The MAMC is one of the largest urban centers in the world, with an area of 1250 km (*2*). The jurisdiction of the MAMC includes the Federal District and 17 municipalities in the State of Mexico. Its 16.6 million inhabitants comprise 18% of Mexico's population, and the growth in transportation energy demand has caused a large increase in air pollution. Ambient pollutant concentrations in the MAMC have consistently exceeded the World Health Organization guidelines (nearly 90% of the days in the last 4 years), despite significant control efforts of NO_x and hydrocarbons emissions. Ozone, the most critical air pollutant, exceeds the 1-h standard on 89−97% of the days of the year. Total suspended particles are the second most important air pollutant in the MAMC with concentrations above the standard 50% of the days of the year (*2*). Total pollutant emissions in the country surpass 16 million ton per year; 65% of them are attributed to vehicles. On the basis of the emission inventory for 1994, road-based motor vehicles contributed 99% of CO, 54% of THC, 70% of NO_x, 27% of SO_x, and 4% of PM (*2*). Stagnation of urban and suburban public bus supply led to an increase in the use of low-capacity private vehicles with higher tariffs than public buses. In the last 10 years, the number of collective taxis increased, and the traditional pattern of large cars carrying a maximum of six passengers along a few set routes was overtaken by a widespread use of vans carrying 10−11 people. More recently, larger microbuses (with 40% less capacity than the conventional urban buses) have appeared on many important routes (*3*). In an attempt to decrease the participation of commercial fleets in pollutant emissions, the government encouraged enterprises having a large number of vehicles to convert them into dedicated LPG vehicles as well as compressed natural gas (CNG) vehicles. Enterprises had to demonstrate compliance with emissions standards by certifying a small representative number of vehicles in a designated laboratory. If the vehicles passed the certification, they were exempt from the One-Day-Without-the-Car Program, which is mandatory in the MAMC. Nowadays in the MAMC, some 28 000 light-duty vehicles and light- and heavy-duty trucks, most of them after-market converted vehicles, run using LPG. Additionally as in the case of gasoline vehicles, emissions must be verified twice a year through the local Inspection/Maintenance Program. A detailed study of the LPG fleet exhaust emissions and their impact in the MAMC pollution was made by our laboratory (*4, 5*). As of 1999, there are around 700 vehicles using alternate CNG−gasoline systems and approximately 2000 that exclusively use CNG. Use of natural gas may be essential to the achievement of long-term air quality goals in the MAMC as well as in other big cities of the country. Opportunities include retrofitting existing gasoline delivery vehicles and microbuses with closed-loop natural gas fuel systems and three-way catalytic converters (3-WCC) as well as the purchase of new light- and heavy-duty natural gas vehicles. In an attempt to encourage the use of alternative fuels, authorities are now evaluating the viability of CNG as an important strategy to decrease air pollution of private and commercial vehicles, police patrols, and microbuses.

In this paper, an assessment of emissions performance of a representative fleet of the MAMC is made, and the nature of the unburned hydrocarbons emitted is characterized. The experiments were aimed at estimating the decrease in emissions by the change of fuel with and without a catalytic converter installed in the vehicle. Second, a fleet of vehicles designed to serve as dedicated alternative fuel vehicle (kit-vehicle combinations are of interest because the environmental policy is to certify engine families not just the kit) was tested. With resolution of the natural gas taxation issue, economic incentives for using natural gas rather than gasoline are suggested.

* Corresponding author phone/fax: +52 (5) 5368-9226; e-mail: ishifter@www.imp.mx.

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TABLE 1. Effect of Conversion of Gasoline to GNC in the Polluting Emissions and Fuel Economy of Light- and Heavy-Duty Trucks

vehicle	fuel	CO (g/km)	THC (g/km)	NMHC (g/km)	NO_x (g/km)	fuel economy (km/L)
		Light-Duty Trucks				
Chrysler pickup	gasoline	56.5	3.9	3.8	1.6	5.9
1987[a]	GNC	1.1	0.4	0.1	0.3	6.8
Ford pickup	gasoline	52.7	3.7	3.6	1.5	5.6
1981[a]	GNC	1.1	1.0	0.1	1.0	6.8
Nissan pickup	gasoline	15.5	2.4	2.2	1.7	10.2
1990[a]	GNC	4.2	0.6	0.1	0.1	9.4
GM pickup	gasoline	41.0	3.5	3.3	1.7	7.2
1990[a]	GNC	1.8	0.7	0.1	0.6	8.9
GM Suburban	gasoline	1.4	0.1	0.1	2.1	5.4
1996[b]	GNC	0.0	0.3	0.0	0.8	5
GM panel LTD	gasoline	2.0	0.4	0.4	0.9	7.1
1994[b]	GNC	1.5	0.7	0.1	0.1	6.9
		Heavy-Duty Trucks				
GM vanette	gasoline	2.0	0.4	0.4	1.0	3.8
1992[b]	GNC	1.1	0.5	0.0	0.7	4.2
Chrysler vanette	gasoline	61.6	3.5	3.4	2.2	3.6
1989[a]	GNC	0.8	0.4	0.1	1.0	3.8
GM vanette	gasoline	38.0	1.3	1.2	0.9	4.5
1992[b]	GNC	0.1	0.2	0.0	0.8	3.9
Dodge Ram	gasoline	33.9	1.7	1.3	1.4	2.6
1992[a]	GNC	0.9	0.5	0.1	0.9	3.8
Dodge Ram	gasoline	5.1	0.2	0.2	0.2	4.0
1999[b]	GNC	0.9	0.3	0.0	0.3	3.6

[a] Nonexhaust emissions control. [b] Emissions control.

TABLE 2. Effect of Conversion of Gasoline to GNC in the Polluting Emissions and Fuel Economy for Microbuses, Private Cars and Taxis

vehicle	fuel	CO (g/km)	THC (g/km)	NMHC (g/km)	NO_x (g/km)	fuel economy (km/L)
		Microbuses				
Chrysler microbus	gasoline	19.1	2.1	2.0	2.0	3.4
1990[a]	GNC	0.3	2.2	0.3	1.5	3.9
GM microbus	gasoline	1.9	0.2	0.2	0.8	3.0
1992[b]	GNC	0.9	1.4	0.1	0.3	3.8
Ford microbus	gasoline	13.1	0.5	0.5	0.8	4.2
1992[b]	GNC	1.1	0.9	0.0	0.9	4.3
GM microbus	gasoline	3.9	0.6	0.5	1.6	4.1
1992[b]	GNC	1.3	0.7	0.3	0.3	4.1
Ford microbus	gasoline	23.2	1.6	1.5	0.1	3.8
1995[b]	GNC	0.1	0.7	0.0	0.7	3.6
		Private Cars and Taxis				
VW sedan	gasoline	8.9	1.2	1.2	0.7	11.2
1992[a]	GN	0.3	0.4	0.0	0.5	11.2
Nissan Tsuru	gasoline	26.2	2.6	2.5	0.8	9.2
1984[a]	GNC	0.9	0.6	0.0	0.4	13.7
VW Jetta	gasoline	9.8	1.5	1.4	2.0	12.4
1990[a]	GNC	0.2	0.2	0.1	1.2	13.9
Nissan Tsuru	gasoline	23.6	2.0	0.8	0.2	10.4
1988[a]	GNC	1.1	0.7	0.1	0.5	13.5
GM Cutlass	gasoline	3.6	0.4	0.4	0.4	7.8
1996[b]	GNC	0.4	0.4	0.0	0.3	6.7

[a] Nonexhaust emissions control. [b] Emissions control.

TABLE 3. Average Emissions Reductions (%) in Vehicles Converted to CNG

	control	CO (%)	THC (%)	NMHC (%)	NO_x (%)
taxis and	no	−96	−73	−96	−30
private cars	yes	−88	13	−91	−40
light-duty trucks	no	−95	−80	−98	−71
	yes	−56	116	−80	−68
heavy-duty trucks	no	−98	−82	−96	−45
	yes	−95	−48	−95	−17
microbuses	no	−98	3	−85	−25
	yes	−92	28	−83	−37

Experimental Section

CNG was blended by the State-owned oil company and is designed to represent industry average fuel composition: 93.05 wt % methane, 3.47 wt % ethane, 1.67 wt % nitrogen, 0.81 wt % carbon dioxide, and 0.66 wt % propane as the main components. The gasoline was a commercial unleaded regular type fuel, whose composition as been described elsewhere (*5*).

An emissions test was completed on a randomized back-to-back sequence for each vehicle in duplicate runs. The evaluation was performed according to the Mexican Official Procedure NMX-AA-11-1993, similar to the FTP-75 of the Federal Regulation Code of the United States (*6*). A Clayton model ECE-50-250 chassis dynamometer with a direct-drive variable-inertia flywheel system was used for testing. Our emissions laboratory is equipped with a Venturi constant volume sampler (CVS) and a Horiba Driver's Aid. The FTP is an emission certification procedure used for light-duty vehicles. It utilizes the Urban Dynamometer Driving Schedule (UDDS), which is 1372 s in duration. The UDDS is divided into two segments, the first having 505 s and the second having 867 s. An FTP is composed of a 505-s cold-transient (bag 1) portion and an 867-s cold-stabilized (bag 2) portion, followed by a 10-minute soak and then a 50-s hot-transient (bag 3) portion. The bagged emissions (THC, CO, NO_x, and CO_2) obtained with the CVS were measured using a Horiba analyzer bench. Vehicles were inspected prior to acceptance into the program. The catalytic converter system in the gasoline vehicles was removed and replaced by a brand new one. The vehicle was run for 1000 km and then tested in the laboratory. The same technician performed all catalytic converter replacement and tune-up calibrations to ensure that the CVS system had acceptable behavior on emissions, fuel economy, and driveability. The gasoline-to-gas conver-

TABLE 4. Mexican Emissions Standards for New and In-Use Gasoline Vehicles Converted to LPG or CNG

	CO (g/km)			THC (g/km)			NO_x (g/km)		
model year	pass cars	LDT[a]	GNC-GLP vehicles	pass cars	LDT	GNC-GLP vehicles	pass cars	LDT	GNC-GLP vehicles
1989	22.0			2.0			2.3		
1990	19.0	22.00	6.0 and before	1.8	2.0	0.4 and before	2	2.3	1.2 and before
1991−1992	7.0		3.0 and later	0.7		0.25−0.3	1.4		0.54−1.0 and later
1992−1993		22.00			2.0			2.3	
1993	2.1			0.3			0.6		
1994									
2000		8.75			0.6			1.4	
2001	2.1	3.11		0.16[b]	0.2		0.25	0.62	

[a] LDT, light-duty trucks (<3857 kg). [b] Reported as NMHC.

TABLE 5. Average Amount of Exhaust Individual Hydrocarbons (and Other Compounds) Using Different Fuels

compound	gasoline (mg/km) NC[a]	gasoline (mg/km) EC[b]	CNG (mg/km)
methane	153.3	69.5	406.7
ethylene	159.3	38.1	1.6
acetylene	225.2	1.9	nd[c]
ethane	29.8	11.6	12.6
propylene	96.9	20.3	nd
propane	7.3	0.9	1.5
isobutylene	47.1	19.5	nd
1-butene	35.4	3.4	nd
1,3-butadiene	85.6	1.5	nd
n-butane	32.0	7.8	2.2
isopentane	174.8	36.3	5.6
n-pentane	81.3	21.0	nd
isoprene	49.8	0.5	nd
2MC5	54.2	19.4	nd
cyclohexane	66.5	13.7	nd
benzene	82.6	33.4	nd
n-heptane	58.2	7.3	nd
2,2,4-trimethylpentane	nd	36.8	1.4
toluene	160.3	46.0	1.4
n-octane	70.5	4.7	nd
ethylbenzene	60.2	6.3	nd
xylenes	266.0	44.9	nd
n-nonane	75.5	1.6	nd
1-methyl 2-ethylbenzene	80.3	10.8	nd
1,2,4-trimethylbenzene	105.9	19.4	nd
formaldehyde	12.1	2.6	1.8
acetaldehyde	5.1	0.9	0.4
SR[d]	4.2	3.0	1.3

[a] NC, no emission control. [b] EC, emission control. [c] nd, not detected. [d] mg of O_3/mg of NMHC.

sion kit is made up essentially of the gas tank, fuel regulator, closed-loop, fuel controller, and catalytic converter designed for CNG use.

Quantitative individual hydrocarbon analysis was performed in three Varian model 3400 gas chromatographs equipped with a flame ionization detector, one for each phase of the FTP procedure. Tedlar bags containing sample exhaust gases collected during the FTP test for each of the three phases were transferred to the chemical speciation laboratory and analyzed using the three chromatographs. Data collection and peak integration were performed on a PE Nelson model 900 station coupled with a computer program to obtain the mass in milligrams per kilometer for exhaust emissions. Over 170 species from C_1 through C_{12} were identified and quantified using this procedure.

Speciated hydrocarbon data were used to estimate the potential of the emissions to form ozone and to predict the impact of fuel changes on air quality. Factors have been published in the literature by Carter (*7*) and are estimates of the ozone-forming reactivity of individual hydrocarbons (*7*). Using this approach, a maximum incremental reactivity (CMIR) value was assigned to individual exhaust constituents. This CMIR represents the predicted impact of the respective constituent on urban atmospheric ozone formation, expressed as grams of ozone per gram of the constituent. Ozone-forming potential for a specific fuel was computed by incorporating the CMIR values for all constituents measured in the exhaust from that fuel. Specific reactivity (SR) for a fuel can be calculated by combining the respective masses of the constituents measured in the exhaust from that fuel, on a per kilometer basis, with the corresponding potential ozone-forming values. Specific reactivity is based on a non-methane hydrocarbons (NMHC) emissions rather than total organic gas emissions (*8*).

Exhaust emission factors were calculated for categories of age and service as tons of pollutant per year. The emission rates measured in our facilities were multiplied by the number of vehicles of a particular category and later by the number of kilometers driven each year. Data on the total vehicular fleet, age distribution by service, and average daily traveled distance were obtained from the published results of the work done by Radian International for the Metropolitan Area of Mexico City (*9*). In this study, Radian used a modified Mobil5 program named M5MCMA-a3, which took into account baseline emissions and deterioration rate.

Fuel economy values were calculated from measurements obtained on the vehicles during chassis dynamometer testing (as opposed to being in-use values). Calculations for fuel economy follow the procedure published in the *Federal Register* (6). 3WCC were all brand new items in the case of CNG tests.

Results and Discussion

Tables 1 and 2 show the average values of regulated exhaust emissions: THC, CO, NO_x, and NMHC for different types of vehicles used in the MAMC. They were tested with both CNG and gasoline. Also fuel economy results are included as kilmeters per liter. For vehicles carburated to CNG, all of them satisfied the environmental standards emissions once they were tuned-up and adjusted using close-loop systems and new 3WCC. Thus far, data in Table 3 indicate that the CNG vehicles exhibit notably lower regulated exhaust emissions, on average, than when gasoline is used and that these values are well within Mexican standards (CO, 7.0; THC, 0.7; and NO_x, 1.4 g/km). In the 1980s and early 1990s, CNG and LPG had substantially lower exhaust emission levels than the gasoline-powered vehicles in the MAMC. The introduction to the market of more advanced vehicles with lower emission levels has created a new situation with respect to the alternatives of gaseous fuels. One has to take into account that the use of catalytic converters was mandatory in the MAMC in 1991 for passenger cars and in 1994 for light-duty trucks. Whereas in the case of private cars, Tier 0 U.S. Standard began in 1993, and Tier 1 will be mandatory in the year 2001 (see Table 4).

TABLE 6. Calculated Emission Factors for Various Vehicle Fleets[a]

vehicle fleet	emission control	CO gasoline	CO CNG	HC gasoline	HC CNG	NO_x gasoline	NO_x CNG	NMHC gasoline	NMHC CNG
passenger	NC	33.7	1.3	3.9	1.0	1.8	1.2	3.7	0.1
cars and taxis	EC	11.7	1.4	0.5	0.5	1.0	0.6	0.4	0.0
LDT	NC	57.8	2.8	5.0	1.0	2.8	0.8	4.8	0.1
	EC	15.8	7.0	1.2	2.6	2.2	0.7	1.0	0.2
HDT	NC	152.2	2.7	7.0	1.3	4.7	2.6	6.8	0.1
	EC	33.5	1.6	1.2	0.6	2.3	1.9	0.9	0.0
microbuses	NC	61.5	1.0	4.6	4.7	4.8	3.6	4.4	0.3
	EC	31.6	2.6	1.3	1.6	1.7	1.1	0.9	0.1

[a] LDT, light-duty truck. HDT, heavy-duty truck. NC, nonexhaust emissions control. EC, emissions control.

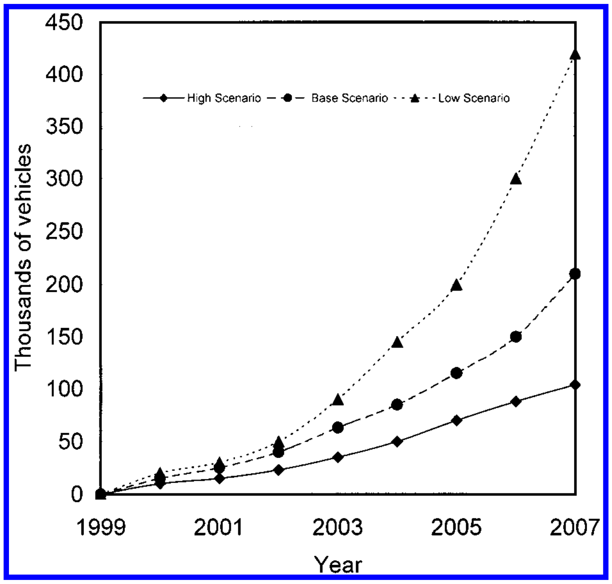

FIGURE 1. Estimation of the number of vehicles converted to CNG by year the 2007 in three scenarios. High scenario, 416 652 additional vehicles (53.8 MBD substituted gasoline); base scenario, 280 326 additional vehicles (35.9 MBD substituted gasoline); low scenario, 104 463 additional vehicles (24.2 MBD substituted gasoline).

Average values of the most common hydrocarbons present in the exhaust emission are shown in Table 5, in which gasoline-powered vehicles with and without emission control are compared to those using CNG. It is clear that the hydrocarbons present in the exhaust emissions in higher concentration are those related directly to the fuel composition. Excluding methane, the biggest contributor of hydrocarbons is low molecular weight olefins, which are known to be highly ozone-forming in the case of vehicles using gasoline (*7*). With the data of individual hydrocarbons obtained from the exhaust emissions in milligrams per kilometer, the ozone-forming potential as a function of gas composition using the CMIR values was calculated. Ozone precursor data are reported in terms of specific reactivity as an average of milligrams of ozone per gram of NMHC. There are no Federal standards for comparison purposes. In addition, the CNG vehicles relative to their gasoline counterparts emit lower levels of ozone-forming constituents. Calculated pollutant emission factors from the experimental data are presented in Table 6. Emissions for gasoline tests were performed without emission control systems and without catalytic converters to compare the impact on vehicles in real conditions. A strategy to decrease vehicle-derived pollutants in the MAMC should take into account the emission rates from various transport modes. About 36 million person-trips are made every day in the MAMC, of which 21.4% are by private cars. Unimodal trips represent about 80% of the total and consist of about 60% by buses, 29% by private cars, and 5% by taxis. Taxis are estimated to carry more than 1 million passengers per day. Vans and microbuses consume about 18% of gasoline. The use of CNG as a transportation fuel is a function not only of the number of units converted but also of the type of vehicle. The approach must be based in the intensity of use and fuel economy of the type of vehicles and their potential population growth in the course of the next years.

In Figure 1, three scenarios for the substitution of gasoline and diesel vehicles fueled by CNG (based on projections made by the Mexican Secretariat of Energy) were estimated (*10*). The low scenario proposes a substitution of 104 163 vehicles by the year 2007 with a distribution by type of vehicles according to the one proposed for the MAMC described in Table 7 (*10*). The same number of vehicles was used in the calculations of the base scenario for the MAMC with an additional quantity of vehicles converted in the rest of the country. In an optimistic scenario (high scenario), 50% additional vehicles substituted by the year 2007 were considered. At present, there are in Mexico 4288 retail gasoline and diesel stations, about 150 LPG stations, and no more than 2 CNG stations. It is estimated that for the year 2007 there will be 150 retail stations in the country. Table 8 provides information concerning the total pollutant emissions by class of vehicles for the MAMC, according to the inventory of 1999; a similar trend is followed in the rest of the country. On the basis of the emission factors obtained in this study, Table 8 shows the total pollutant reduction in ton per year for two scenarios. In the first scenario, total emissions are based on the 1999 emissions. The second scenario is a projection of total pollutant emissions considering the incorporation of 104 163 CNG-powered vehicles. An important reduction in CO, THC, and NMHC emissions is observed. However, the impact on NO_x emissions is less significant.

There are approximately 26 control measures to decrease urban air pollution in Mexico City according to a study made by the World Bank (*11*). The measures can be grouped as

TABLE 7. Estimated Number of CNG-Converted Vehicles in the MAMC for the Years 1999−2007[a]

year	taxis	microbuses	LDT + HDT	buses	police patrols	government vehicles	total
1999	0	0	0	0	183	140	323
2000	540	735	0	142	524	35	1 976
2001	1 620	1 383	6 580	225	799	90	10 697
2002	3 240	2 166	13 554	317	1 084	122	20 483
2003	4 860	3 054	23 268	420	1 378	155	30 084
2004	6 480	3 828	35 949	535	1 542	189	48 523
2005	8 100	4 498	49 370	665	1 710	224	64 567
2006	10 800	5 073	63 563	810	1 740	260	82 246
2007	16 200	6 359	78 564	973	1 769	298	104 163

[a] LDT, light-duty trucks. HDT, heavy-duty trucks.

TABLE 8. Estimated Exhaust Emissions Reduction with the Introduction of CNG-Converted Vehicles[a]

vehicles	emission control	CO (ton/year)	THC (ton/year)	NMHC (ton/year)	NO_x (ton/year)
		Low Scenario			
taxis	EC	57 091	2 196	1 952	5 075
	NC	81 000	9 253	8 892	4 254
microbuses	EC	34 967	1 383	1 029	1 892
	NC	32 818	2 428	2 343	2 435
LDT	EC	47 209	3 645	2 839	6 663
	NC	100 494	8 711	8 363	4 799
HDT	EC	7 467	272	194	513
	NC	85 482	3 932	3 791	2 640
total		446 527	31 819	29 402	28 270
		Base Scenario			
taxis	EC	72 589	2 792	2 492	6 452
	NC	0	0	0	0
	CNG	1 480	554	43	673
microbuses	EC	23 597	934	695	1 277
	NC	0	0	0	0
	CNG	949	579	47	391
LDT	EC	72 687	5 613	4 370	10 259
	NC	43 259	3 750	3 600	2 066
	CNG	12 749	4 825	294	1 321
HDT	EC	21 062	767	547	1 446
	NC	9 205	423	408	284
	CNG	502	205	10	614
total		258 080	20 440	12 506	24 783

[a] NC, nonexhaust emissions control. EC, emissions control. LDT, light-duty trucks. HDT, heavy-duty trucks.

follows: vehicle retrofitting, emission standards and inspection programs, fuel improvements, and alternative fuels. The World Bank study used a cost-effectiveness measure developed by giving different pollutants different weights. The weights were dominated by accepted health considerations, giving lead a high weight, CO a low weight, and PM, SO_x, and NO_x intermediate weights (per emitted ton). In terms of toxic weighted decrease of pollutant, LPG retrofit for gasoline trucks, CNG retrofit for minibuses, and CNG retrofit for gasoline trucks are the three highest ranked (*11*). A strategy for CNG market penetration as an alternative fuel must take into account two types of incentives for the conversion, those of economic issues as well as those of environmental issues. In the first case, the price of CNG as compared to LPG and gasoline must be competitive enough to convince owners that the cost of conversion can be paid back in the course of the useful life of the vehicle. In that sense, the conversion kit for CNG costs between 1000 and 4000 U.S. dollars; so vehicles older than 10 years will not recover rapidly the return of investment because the cost of conversion itself could be greater than the value of the unit. Moreover, vehicles with infrequent daily use also will be in the same situation. Concerning the environmental issues, the target fleet to be converted is the one with vehicles older than 5 years due to the fact that newer vehicles are improved in fuel economy and low emissions. In this sense, in the target fleets we included the model years 1989−1994 used for transportation of goods and people and excluded those of large travel range. Large travel range transport may present difficulties in CNG supply because of the lack of retail gas stations outside MAMC. However, CNG is less readily available than gasoline at retail fuel stations in urban centers and may not be available at all outside urban areas.

The Federal government controls fuel pricing in Mexico. The retail price of motor vehicles is the same at any location in Mexico. It includes the manufacturer price (which is determined according to a reference price based on international price to reflect the opportunity cost of the fuel) and specific and value-added (which is charged on the producer price) taxes. Since the retail price is fixed to control inflation rate and the gas product changes according to market conditions, the specific tax is adjusted each month so that the desired retail price is obtained. Gasoline and CNG consumers pay greater specific taxes than LPG users. Alternative fuel programs should be accompanied by a differential taxation policy that reflects the health impacts and environmental damage associated with different motor vehicle fuels. At least in the beginning, it will probably be necessary to offer financial subsidies to retail fuel stations and consumers, possibly combined with taxes placed on conventional fuels, to overcome the cost disadvantages of alternative fuels. While it is generally agreed that the external (nonmarket) costs of air pollution are enormous, evaluation of these costs in monetary terms is often a problem. Many of the costs of air pollution, such as human mortality, the extinction of plant or animal species, or the damage to objects of cultural and/or historical value, cannot be satisfactorily expressed in monetary terms. The special nature of irreversible damage and the uncertainty surrounding future costs of longer-term problems also complicates the estimation of monetary costs. Government agencies have estimated costs of air pollution taking into consideration, among others, health costs, loss of productivity, and damage to materials. The cost of reduced or minimized pollution control techniques calculated according to 1998 prices is as follows (in U.S. dollars/ton): 9137 for CO, 7930 for THC, and 6280 for NO_x (*12*). It is obvious that the introduction of CNG provides alternatives not only from the point of view of reduction of contaminants but also in terms of necessary economic investment to control pollution.

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