State of California
AIR RESOURCES BOARD

PROPOSED AMENDMENTS TO THE SPECIFICATIONS FOR LPG USED IN MOTOR VEHICLES

(Staff Report and Initial Statement of Reasons)

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October 1998

State of California
AIR RESOURCES BOARD

Staff Report: Initial Statement of Reasons For Proposed Rulemaking

Public Hearing to Consider

PROPOSED AMENDMENTS TO THE
SPECIFICATIONS FOR LIQUEFIED PETROLEUM GAS
USED IN MOTOR VEHICLES

To be considered by the Air Resources Board on December 10-11, 1998, at:

Air Resources Board
Board Hearing Room
Lower Level
2020 L Street
Sacramento, California

Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Acknowledgments

The Air Resources Board staff thanks the organizations and their employees who participated on the LPG Task Group and the companies and agencies that funded the test program. Also, we thank The Adept Group for its management of the test program and the Ford Motor Company for donating the truck used for emission tests.

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SUMMARY AND RECOMMENDATION

This report is the Initial Statement of Reasons for proposed amendments to section 2292.6, title 13, California Code of Regulations. That section sets specifications for liquefied petroleum gas (LPG) sold for motor vehicle use. Section 2291 prohibits the sale or supply of LPG that is intended for use in motor vehicles in California if the LPG does not comply with section 2292.6. The specifications ensure that the fuel received by LPG vehicles in use is similar to the LPG that is specified for certifying new vehicles and engines to their emission standards.

Previous reports regarding the standards in section 2292.6 were published by the Air Resources Board (ARB) staff in 1992[1], 1994[2], and 1997[3].

This chapter summarizes information presented in the later chapters. Also, it presents the ARB staff's recommendation for changes to the maximum limits on the propene content and on the combined contents of butanes, butenes, and heavier hydrocarbons. The proposal is in response to the Board's instruction at a hearing in 1997 to recommend final specifications for motor vehicle LPG to take effect in 1999.

A. LPG Regulations

In 1992, the Board adopted specifications for motor vehicle LPG. The specifications include a maximum limit on the propene content at five percent by volume. However, out of concern that the supply of complying LPG might be unreliable, the Board made the 5 volume percent propene limit effective on January 1, 1995, and set an interim propene limit at 10 volume percent. In 1994 and again in 1997, the Board granted petitions from the 5 volume percent propene limit because of supply concerns. In 1997, the Board extended the effective date of the 5 volume percent propene limit until January 1, 1999.

In making the second delay, the Board stated its intent to grant no further delays. It instructed the staff to seek an alternative to the specifications in section 2292.6 that would provide satisfactory emission control, provide good performance in LPG engines, and be likely to be met by the LPG that is in the market. The Board stated its willingness to consider such an alternative; but if none is proposed, the originally adopted LPG specifications, including the 5 volume percent propene limit, will take effect in 1999.

Less than 10 percent of the propane marketed in California is used in motor vehicles. The remainder is sold for use in fueling home and recreational vehicle heaters and stoves and outdoor grills among other uses.

There are no other legally enforceable specifications on LPG for vehicles in the United States. However, LPG that is used in vehicles is the fuel commonly known as "propane", which meets the voluntary industry standard for "commercial propane", which allows up to 50 percent propene content.

B. Task Group and Test Program

To assist us in seeking an alternative specification for motor vehicle LPG, the staff assembled a task group consisting of representatives from refiners, engine makers, automakers, propane (the common form of LPG) marketers, and government agencies. The task group produced a test protocol for conducting emission tests, engine performance tests, and engine durability tests on LPGs of various propene contents and butane contents. The tests were designed to investigate the suitability of higher propene and butane contents for LPG engines with current technology. The tests provided an important addition to what had been scant information on the emission effects of the propene and butane contents of LPG. The program also addressed the performance issues raised by engine manufacturers and automakers about commercial LPG that does not meet the 5.0 volume percent limit on propene.

C. Emission Results from the Test Program

Emission tests were performed on fuels selected by the Task Group. They were a base fuel representing HD-5 (5.0 percent propene or less and 2.5 percent butane or less) and five test fuels with various higher values of propene and butane. Table A describes the six fuels. All the fuels were tested in a Cummins B5.9 medium heavy-duty LPG engine and in a Ford F150 truck with a 5.4 liter bi fuel (gasoline/LPG) engine.

Table A. ARB/Task Group Test Fuels

Fuel	Propene, vol%	Butane, vol%*	Octane # **
Base^	3.6	2.1	102.3
1	9.8	5.0	101.2
2	14.6	5.0	100.2
3	10.0	10.0	100.6
4	3.8	20.0	100.6
5	21.3	1.6	---

* Mean of all measurements
** (R+M)/2
^ ARB certification fuel (meets HD-5 specification)

For the Cummins engine tests, increasing the propene and butane contents of the LPG blends appeared to decrease hydrocarbon emissions but increased oxides of nitrogen (NOx) and carbon monoxide (CO) emissions and the ozone-forming potential (OFP) of emissions. However, for fuel 1 (10 percent propene), after considering allowances* for the potential effects of testing error and the variability of engine emission performance, only the NOx emissions increase was determined to be real. For fuel 1, the apparent increases in CO and OFP over the base fuel were attributed to error or test variability. The NOx increase was about 9 percent, or 3 percent higher than the LPG Task Group's allowance for test variation. The other fuels with propene contents greater than 10 percent had greater impacts on NOx emissions.

For the Ford truck data, fuel 1 passed the test protocol criteria* for equivalency. That is, the 10 percent propene and 5 percent butane fuel was deemed to have emissions equivalent to the base fuel (5 percent propene).

The test data for both engines indicate that, using the Task Force's criteria for emission increases small enough to be attributed to testing error and variability in the engine, fuel 1 (10 percent propene, 5 percent butane) gave the best performance compared to the base fuel.

D. Other Emission Tests

The Western Propane Gas Association (WPGA) published a study[4] of emissions from three light- and medium-duty LPG vehicles that were converted from gasoline operation. WPGA tested various propene and butane contents, over greater ranges than in the ARB/task force program. Emission trends were generally consistent with those seen in the Cummins engine in the 1998 test program.

ARCO, with others, has published three studies[5, 6, 7] of the effects of LPG butane contents much larger than what the staff is proposing. The data indicate that for some LPG vehicles, emissions of hydrocarbons, CO, and OFP may increase slightly and NOx may decrease slightly if the butane content of vehicle LPG increases by the amount allowed by the proposal.

E. Performance and Durability Testing

Engine performance and combustion tests are to begin shortly on the Cummins engine for both the base fuel and test fuel 1. The tests will compare how the engine operates on the test fuel and on the base fuel for various internal temperatures, pressures, voltages, knock, and power. The tests will determine if the engine continues to operate within the manufacturer's design limits while using the test fuel. The results should be available to the Board before the hearing on the staff's proposal.

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* To account for the expected error associated with testing, the Task Group developed an "emission allowance" for each pollutant. As a result, a test fuel was judged not equivalent to the base fuel if its average emissions exceeded the base fuel emissions by an amount greater than the emission allowance.

Detroit Diesel Company has found acceptable performance in the Series 50 engine with LPG containing 10 percent propene.

Durability testing of test fuel 1 is also scheduled for the near future, but is not expected to be completed before the hearing. ARB staff and the task group does not expect that problems attributable to the fuel will occur in durability testing if none are apparent in the performance testing. In-use vehicles have been using LPG with up to 10 volume percent for the past four years with no reported pattern of problems.

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F. Discussion

The moderate increase in NOx for LPG with 10 volume percent propene versus LPG with 5 percent propene (shown in the Cummins engine and WPGA tests) must be considered in the context of the cleanliness of LPG vehicle emissions compared to emissions from gasoline and diesel vehicles. The emissions from gasoline vehicles have greater OFP and much greater toxic contents than do emissions from LPG vehicles. Also, LPG-fueled engines produce virtually no particulate matter (PM) compared to diesel engines.

Based on the results of the test program and other available data, staff is proposing that the 10 volume percent interim propene limit be made permanent and that new butane limits be set. This would retain the status quo for the propene limit, so actual current emissions would not increase. The principle reason for proposing the 10 volume percent propene limit is to assure availability of LPG for use in vehicles. The preservation of complying LPG could prevent a possible reversion by vehicle owners to gasoline or diesel vehicles and prevent a handicap to developing the future market for LPG vehicles and engines. That market development could avoid OFP and toxic emissions from conventional-fueled vehicles that will be much larger than the effects in the LPG vehicles.

G. Effects of the Proposal

For the proposed limits of 10 volume percent propene and 5 volume percent butane, the potential changes to the on-road vehicle emissions inventory in the state are:

NMHC (reactivity-adjusted): 0.01 tpd   NOx: 0.03 tpd   CO: 0.15 tpd

These numbers reflect the amount of motor vehicle LPG that will be sold that nominally already contains 5 percent propene, but they do not reflect any avoidance of diesel particulate matter emissions should future vehicle owners choose LPG vehicles over new diesel vehicles.

The staff's proposal will not have any impact on State Implementation Plan (SIP) measures because these fuel specifications are not a SIP strategy.

There will be no new costs associated with the proposed limits. They may prevent a decline in the availability of LPG vehicle fuel and may thus prevent an increase in price to users. Further, the proposed changes do not affect the certification fuel standards, nor how engine manufacturers comply with engine certification standards.

H. Recommendation

The staff is recommending that the propene limit in section 2292.6 CCR, title 13, be amended to 10.0 percent by volume and that the limit on butanes, butenes, and heavier hydrocarbons be amended to 5.0 percent by volume, both effective January 1, 1999. To prevent the extra butane-and-heavier content from being all heavier than butane, we also recommend a new limit of 0.5 percent by volume on the butene, pentane-and-heavier content. The proposed amendments are shown in Appendix 1. They are proposed to preserve and enhance the current supply of complying fuel to owners of LPG vehicles while assuring adequate emissions performance.

I.

INTRODUCTION

This report is the Initial Statement of Reasons for a proposed amendment to section 2292.6, title 13, California Code of Regulations. That section limits several properties of liquefied petroleum gas (LPG) sold for motor vehicle use. Section 2291 prohibits the sale or supply of LPG that is intended for use in motor vehicles in California if the LPG does not comply with the limits in section 2292.6.

Previous reports regarding the standards in section 2292.6 were published by the Air Resources Board (ARB) staff in 1992[1], 1994[2], and 1997[3].

In 1992, the Board adopted specifications for motor vehicle LPG. The Board's specifications include a maximum limit on the propene content at five percent by volume (HD-5) and a maximum limit on the combined contents of butanes, butenes, and heavier hydrocarbons (collectively, "C4+") at 2.5 volume percent*. However, out of concern that the supply of complying LPG might not be reliable, the Board made the 5 volume percent limit on propene effective January 1, 1995, and set an interim propene limit at 10 volume percent. The specifications were not adopted to reduce emissions but to ensure that the in-use LPG is similar to the LPG used to certify LPG vehicles.

In 1994, WPGA petitioned the Board to continue the interim propene limit because of its concern about a reliable supply under a 5 volume percent limit. In response, the Board continued the interim 10 volume percent limit until January 1, 1997.

After a second petition from WPGA, the Board in 1997 continued the interim limit again, until January 1, 1999. In making the second delay of the 5.0 volume percent limit, the Board stated its intent to grant no further delays. It instructed the staff to seek an alternative to the specifications in section 2292.6 that would provide satisfactory emission control, provide good performance in LPG engines, and be more likely to be met by the LPG that is in the market. The Board stated its willingness to consider such an alternative; but it also stated that if no alternative is proposed, the originally adopted LPG specifications, including the 5 volume percent propene limit, will take effect in 1999.

*An option to the C4 limit is a maximum temperature limit of -37 °F for volatility residue evaporated at 95 percent.

II.

BACKGROUND

A. LPG as Vehicle Fuel

"LPG" (liquefied petroleum gas) refers to a mixture of light hydrocarbons, predominantly propane, that is pressurized into a liquid for use as a fuel. LPG has uses similar to those of natural gas. LPG sold at retail is called "propane" and usually meets the industrial specification for "commercial propane". Commercial propane is used in space heating (e.g., in rural buildings and recreational vehicles) and portable appliances (e.g., barbeques). Less than 10 percent of the propane marketed is used in motor vehicles. There is a more restrictive industry voluntary specification, "HD-5", which contains 5 percent or less propene, intended for engine fuel. These specifications are voluntary guidelines for producers and suppliers.

The Board's specification for LPG for use in vehicles is very similar to HD-5, differing only in the minimum propane content. It is the only required specification for LPG. The United States Environmental Protection Agency does not have any specifications for LPG. Table II-1 shows the compositional elements of the commercial and ARB specifications.

Table II-1. Specifications for LPG

Constituent	**Commercial Propane**	**Propane HD-5**	**ARB** current	1999
Propane	"predominantly propane"	> 90%	> 85%	> 85%
C_4+ (butane & heavier)	< 2.5%	< 2.5%	< 2.5%	< 2.5%
Olefins (e.g., propene)	(no limit)	< 5.0%	< 10%	< 5.0%

The staff reported in 1997[3] that there are about 45,000 on-road LPG vehicles in California, almost all conversions dedicated to LPG. Most are light-duty trucks. Table III-2 shows from the same report the estimated emissions in the state from those vehicles operating on LPG and as if they operated on gasoline. Because of their small number, emissions from LPG vehicles are a relatively small fraction of the on-road vehicle inventory. There may be emissions of a similar amount from off-road vehicles, mostly forklifts and similar utility vehicles.

Table II-2. Estimated Emissions from 45,000 LPG Vehicles
(and total on-road inventory in California)
(tons/day)

	NMHC	NOx	CO
LPG	0.5*	2.4	20
Gasoline operation**	1.4	1.9	19
(on-road inventory)**	(1,200)	(1,500)	(9,000)

* reactivity-adjusted to gasoline basis
** from annual-average planning inventory for 1995

B. How LPG is Produced and Marketed

Production. LPG is produced by oil refineries and by gas plants in oil and gas fields. In refineries, it is a by-product of processes that produce gasoline. At gas plants, LPG is separated from crude oil and from natural gas (methane and ethane).

Some refineries have substantial amounts of propene in their LPG. The propene content depends on whether or not the refinery has a fluidized catalytic cracker (FCC), which creates olefins (such as propene) in its by-product gas, and whether or not the refinery separates those olefins to feed to processes that make high-octane gasoline blending materials. Without such a process, a refiner has no in-house use for propene. Unless the price and demand for low-propene LPG rise enough, the refiner will probably blend the propene-rich FCC gas into its LPG.

LPG from gas plants has almost no propene if the LPG comes only from production fields. However, some gas plants receive gas by-products from refineries. LPG from such gas plants can contain substantial propene.

Table II-3 shows, by propene content, the available data on the amounts of LPG produced in California in 1995/1996. The data were received in response to a 1996 survey by the staff of refiners and gas plants. Table II-3 shown that the majority of the LPG produced (60 percent) has a propene content of 10 percent or less. The remaining propane has a propene content of up to 50 percent.

Although the amount produced of LPG with less than five percent propene is more than adequate to satisfy the vehicular demand, the economics of marketing preclude segregating that LPG just for use in vehicles.

Table II-3. Results of 1996 Survey of Producers, by Producer Type

	Refiners	Gas Plant Operators	Total
Number surveyed	13	7	20
Number of responses	13	5	18
Propene Content	Annual production (million gallons)*		
<5% propene**	150	20	170
5% to 10% propene**	50	25	75
other (>10% propene)	145	0	145
Total (rounded)	345	45	390

* Volumes shown are commercial propane.
** currently legal for vehicles

Marketing. Most LPG that is sold at retail is handled in one of three ways:

- A marketer picks up the fuel by tank truck from a supplier's loading rack and delivers it in bulk to the customer's storage tank.
- A marketer picks up the fuel and transfers it into his own storage tank, to which the customer brings his LPG vessel or vehicle for filling.
- A marketer picks up the fuel and stores it in his own tank, from which he later fills a tank truck that is dispatched to various customers' sites.

Most LPG is delivered from the marketers' own storage tanks. At most storage sites, a marketer has only one tank/dispensing system for LPG.

C. Original Adoption of LPG Specifications

In March 1992, the Board adopted specifications for LPG used in motor vehicles. These included specifications for certification fuel for certifying new LPG vehicles and specifications for commercial (in-use) LPG for vehicles, in section 2292.6, Title 13, CCR. The commercial specifications (which are the sole subject of the current proposal) define the fuel that is to be used by motor vehicles in normal operation in California. They ensure that in-use fuel is similar to the fuels used to certify new vehicles and engines, and they assure the vehicle and engine manufacturers about the quality of the LPG that their vehicles will receive in use.

The Board adopted a specification very similar to the industry voluntary standard specification for LPG for engines, HD-5. For the Board’s purposes, the five-percent limit in HD-5 on the propene content serves to limit the reactivity of exhaust emissions since propene is more reactive in the atmosphere than is propane, the main component of LPG. However, because of concern about the ability of commercial propane dealers to deliver HD-5 consistently to vehicle owners, the Board adopted an interim propene limit of 10 percent until January 1, 1995, and has twice granted extensions of the interim limit (as discussed below).

D. Petitions from Western Propane Gas Association

The Board has twice amended section 2292.6, continuing the 10-percent propene limit for two years each time. The Board's actions have been in response to petitions by the Western Propane Gas Association, the trade association of dealers in commercial propane.

"Commercial propane" is defined by industry standards to be "predominantly propane" but can be up to half propene. It can have a maximum of 2.5 percent butanes, butenes, and heavier hydrocarbons (collectively, "C4+"). LPG meeting the Board's specification for vehicular LPG is a subset of commercial propane. A five percent propene limit excludes as vehicle fuel much of the LPG that is available to the propane dealers from refineries. Furthermore, several refiners who sell propane that often meets HD-5 do not guarantee that standard to the dealers. Thus, while there is ample HD-5 in California to meet the small vehicular demand, it is not reliably available to many propane dealers.

It would be technically possible for refiners with high-propene LPG blends to reduce the propene contents. However, that has not occurred because the demand for HD-5 is too small to warrant the necessary processing, storage, and delivery systems. Vehicle use of propane is less than 10 percent of the total propane market. And, while propane dealers could install tankage to handle HD-5 as a specialty product, it is too small a part of their overall business to warrant the expense. In summary, vehicular LPG that is delivered through the existing LPG marketing system is commercial propane, a product that often does not consistently meet the 5 percent propene limit.

The Board has twice delayed enforcing the five-percent propene limit out of concern that it could reduce the attractiveness of LPG as a workable alternative fuel. LPG results in exhaust that is lower in reactivity than gasoline exhaust and that is free of diesel particulate matter. However, those properties will be of practical value only if LPG for vehicles is sufficiently available for dealers to offer a reliable supply of complying fuel to prospective LPG vehicle owners.

E. Issues Raised about Engine Performance on LPG Not Meeting HD-5

The LPG Task Group test program was prompted by a lack of emission data for recent OEM LPG engines and by concerns over engine performance problems that some have suggested as resulting from higher propene levels in LPG. These include concerns such as lower octane, air/fuel ratio changes and fuel injector gumming.

III.

OVERVIEW AND RESULTS OF LPG TEST PROGRAMS

A. LPG Task Group

In early 1997, the staff invited propane dealers, refiners, engine manufacturers, automakers, public interest groups, and government agencies to participate in an LPG Task Group. Appendix 2 lists the participating organizations. The Task Group was formed to address technical issues in developing new specifications for vehicular LPG that would be less restrictive than HD-5. The first meeting occurred on February 11, 1997. The Task Group continued meeting as needed through 1997 and 1998 to assist the staff in obtaining data on the effects of the propene and C4+ contents on emissions, engine performance, and engine durability. The major efforts in this regard were designing, funding, and overseeing a test program that measured emissions from several LPGs with various propene and butane contents. The Task Group is also overseeing tests of the engine-performance aspects of a fuel meeting the proposed new specification.

B. Test Program by the LPG Task Group

The tests were conducted according to a protocol developed by the Task Group. The protocol is appended as Appendix 3. The following paragraphs outline the test program.

The test program included emission tests on five fuels of varying propene and butane contents (with the balance being propane, in all cases). The compositions of the five test fuels and the base fuel (LPG for vehicle certification) are shown in Table III-1. Because more emissions tests were done than originally anticipated, additional batches of base fuel and test fuel 2 were made to complete the emissions tests for the Cummins B5.9 LPG engine. Also, for the Ford F-150 emissions test, a new batch of test fuel 1 was made for the last emissions test on that fuel. Appendix 4 shows laboratory analytical results of the fuel properties.

The emission tests were conducted on a Cummins B5.9 light heavy-duty engine and a Ford F-150 LPG/gasoline dual-fuel light-duty truck. The measured pollutants are THC or NMHC (depending on the engine), NOx, CO and non-methane organic gases (NMOG) . The ozone-forming potential was calculated from the NMOG data. Table III-2 shows the number of observations per fuel.

Table III-1. ARB/Task Group Test Fuels

Fuel	Propene, vol%*	Butane, vol%*	Octane # **
Base^	3.6	2.1	102.6
1	9.8	5.0	101.2
2	14.6	5.0	100.2
3	10.0	10.0	100.6
4	3.8	20.0	100.6
5	21.3	1.6	---

* Mean of measurements by two labs
** (R+M)/2
^ ARB certification fuel (meets HD-5 specification)

Table III-2. Number of Tests

	Cummins*	Ford F-150
Base	9 (3)*	6
1	3 (2)	3
2	5 (1)	2
3	2 (1)	3
4	2 (1)	3
5	2 (1)	3

* Numbers in ( ) are for NMOG and OFP

Performance testing on the Cummins engine had not begun when this report was written. However, the LPG Task Group agreed to evaluate test fuel 1 and the base fuel so that data may be available before the staff's proposal will be heard. A second test fuel may also eventually be tested. The performance testing will measure various temperatures, pressures, and voltages in the engine and the power and torque. The observations on test fuel 1 will be compared to the observations on the base fuel and compared to Cummins' proprietary tolerances.

Durability testing is to be done on test fuel 1 but had not begun as of mid-October. The Task Group chose the Cummins engine because its higher octane requirement and design may make it more sensitive than the Ford engine to changes in fuel composition. The durability testing will consist of 500 hours of continuous operation. This test is not as extensive as what is done for new-product testing; it is a screening test for obvious changes that would indicate unsatisfactory results in a more demanding test. Durability testing will not be complete by the hearing in December. However, the staff and task group members do not anticipate that any significant problems will surface during durability testing that will not be evident from performance testing.

C. Analysis of Emission Data from the LPG Task Group Tests

Cummins B5.9 LPG Engine. The top half of Table III-3 shows for the Cummins engine tests the average emissions from the base fuel and from each of the test fuels. The bottom half of the table shows the same results as percent changes relative to the base fuel average. Emissions increased slightly for NOx from the beginning to the end of the test program. The emissions drift effect (as fit by a linear model) was statistically significant above a 90 percent confidence level but did not change the results significantly. The adjusted NOx emissions are shown in the table. No linear drift was seen for the other pollutants. The analysis and a graphical representation of the data for NOx is in Appendix 5. Each test fuel's emissions exceeded the base fuel emissions for at least one pollutant. Because of random error, this is not unexpected even if the test and base fuels are truly equal.

To see if the apparent emissions increases for a given pollutant are due to more than just random errors in testing, the test protocol developed by the task group calls for comparing the average emissions on a test fuel to the base fuel average plus an allowance, "δ", for potential random error. With this approach, the apparent increase in emissions from a test fuel is deemed probably real if it exceeds 2δ x base fuel emissions, where δ is set for each pollutant for each engine. If the apparent increase is less than 2δ times the base fuel emissions, then it is unclear if the apparent increase in emissions is due to fuel differences, and the test fuel is deemed equivalent to the base fuel. Appendix 6 gives the derivation of δ.

Table III-3. Average Results for Cummins Engine

Fuel	Propene	Butane	NMHC	THC	CO	NOx*		NMOG	OFP
			Actual Emissions, grams/bhp-hr						
Base	3.6	2.1	.814	.848	.385	2.91	(2.91)	.750	1.07
1	9.8	5.0	.670	.702	.407	3.18	(3.19)	.689	1.14
2	14.6	5.0	.636	.670	.489	3.26	(3.24)	.849	1.34
3	10.0	10.0	.815	.856	.618	3.23	(3.23)	.832	1.36
4	3.8	20.0	.736	.782	.816	3.03	(3.02)	.775	1.24
5	21.3	1.6	.594	.623	.324	3.63	(3.56)	.518	1.07
			Changes Relative to Base Fuel						
1	9.8	5.0	-18%	-17%	**6%**	**9%**	**(9%)**	-8%	**6%**
2	14.6	5.0	-22%	-21%	**27%**	**12%**	**(11%)**	**13%**	**25%**
3	10.0	10.0	**0.2%**	**0.9%**	**60%**	**11%**	**(11%)**	**11%**	**27%**
4	3.8	20.0	-10%	-8%	**112%**	**4%**	**(3%)**	**3%**	**15%**
5	21.3	1.6	-27%	27%	-16%	**25%**	**(22%)**	-31%	-.6%

* Numbers in ( ) are adjusted for emissions drift effects.

Table III-4 shows the average emissions from each test fuel *relative* to the maximum allowed by the criterion for equivalence. (The values of "δ" for the Cummins engine tests are those derived from the test data.) A value in the table less than zero indicates passing the criterion for the pollutant, and a positive value indicates failing.

In the Cummins engine tests, no fuel passes all the test protocol criteria. However, fuel 1 (10 percent propene, 5 percent butane) fails only on NOx, by an amount equal to only three percent of the base fuel emissions. The δ for NOx (3%) is much lower than for the other pollutants. If a higher value of δ (5%) were used, fuel 1 would pass on NOx despite the 9 percent increase in NOx over the base fuel.

Table III-4.   Emissions Increase above Task Group Criteria for Cummins Engine
(average emissions - (1+ 2δ) x base-fuel emissions)/base fuel emissions

(percent of base fuel emissions)

Fuel	Propene	Butane	NMHC	THC	CO	NOx*	NMOG	OFP
1	9.8	5.0	-42	-41	-33	**3.2**	-28	-7.6
2	14.6	5.0	-46	-45	-11	**5.9**	-7	**11**
3	10.0	10.0	-24	-23	**22**	**5.1**	-9.1	**13**
4	3.8	20.0	-34	-32	**74**	-2	-17	**1**
5	21.3	1.6	-51	-51	-54	**19**	-51	-15
δ values derived from test data:			12%	12%	19%	3%	10%	7%

* Not adjusted for emissions drift.

Ford F-150 Bi-Fuel Pickup Table III-5 shows for the Ford truck tests the average emissions from the base fuel and from each of the test fuels. As with the Cummins engine test results, many of the differences compared to the base fuel are increases. Again, to see if the increases above the baseline were due to just random test variability, the test protocol calls for comparing the average emissions on a test fuel to the base fuel average plus an allowance for potential random error. In this case the allowance is based on externally derived values of “δ” rather than (as in the preceding analysis) from the test data. The test-derived values of “δ” have been rejected because they are so large (12% to 25%) as to make even a substantially “dirtier” test fuel likely to pass all the criteria versus the base fuel.   Because of the high variability seen in these tests it is difficult to separate the effect of the small changes in fuel properties from other variable effects (No linear drift effects were evident). Nonetheless, Table III-6 shows the emission changes relative to the “pass” criteria developed by the task group, with negative values indicating “pass”.

Table III-5. Average Results for Ford Truck

Fuel	Propene	Butane	THC	CO	NOx	NMOG*		OFP
			Actual Emissions, grams/mile					
Base	3.6	2.1	.055	2.03	.040	.036	(.036)	.048
1	9.8	5.0	.050	2.04	.037	.035	(.037)	.050
2	14.6	5.0	.057	2.08	.043	.038	(.041)	.068
3	10.0	10.0	.052	1.58	.051	.035	(.035)	.054
4	3.8	20.0	.070	2.77	.040	.047	(.046)	.067
5	21.3	1.6	.042	2.14	.049	.033	(.029)	.060
			Percent Changes Relative to Base Fuel					
1	9.8	5.0	-8.7%	-0.7%	-5.9%	-4.5%	(-4.5%)	**3.0%**
2	14.6	5.0	**4.0%**	**2.3%**	**8.4%**	**6.3%**	**(14%)**	**40%**
3	10.0	10.0	-5.3%	-22%	**28%**	-3.5%	(-3.5)	**13%**
4	3.8	20.0	**27%**	**37%**	**1.7%**	**31%**	**(28%)**	**38%**
5	21.3	1.6	-24%	-5.4%	**24%**	-8.2%	(-19%)	**24%**

* Numbers in ( ) are adjusted for emissions drift effects.

Table III-6. Emissions Increase above Task Group Criteria for Ford F-150
(average emissions - (1+ 2δ) x base-fuel emissions)/base fuel emissions

(percent of base fuel average)

Fuel	Propene	Butane	THC	CO	NOx	NMOG*	OFP
1	9.8	5.0	-23	-15	-40	-22	-15
2	14.6	5.0	-10	-14	-26	-12	**22**
3	10.0	10.0	-19	-38	-6	-22	-5
4	3.8	20.0	**13**	**21**	-32	**13**	**20**
5	21.3	1.6	-38	-11	-10	-26	**6**
δ values derived from external test data			7%	8%	17%	9%	9%

* Not adjusted for emissions drift.

According to the table, fuels 1 and 3 meet the equivalency criteria as set by the task group before the testing.

D. Other Reported Emission Tests

WPGA Test Program[4]. There is only one recent published study reporting emissions from LPG vehicles versus the propene content of the LPG. It was sponsored by the WPGA in support of its 1996 petition to delay the five-percent propene limit.

Three 1995 light-duty vehicles were converted to dual-fuel (LPG and gasoline) operation and then tested on Indolene (federal certification gasoline) and on seven LPGs, including a base fuel with five percent propene and 2.5 percent butane (HD-5). The propene contents of the six test LPGs ranged from 5 to 20 percent, and the butane contents ranged from 2.5 to 40 percent. The vehicles were also tested on Indolene (federal certification gasoline). Table III-7 shows the vehicles and fuels. More information is in reference 3.

Table III-7. Fuels and Vehicles Tested by WPGA

Vehicles	LPGs			
		% Propane	% Propene	% Butanes
1. '95 Dodge Caravan	1.	92.5	5	2.5
2. '95 Chev. C1500	2.	87.5	10	2.5
3. '95 Chev. K2500	3.	77.5	20	2.5
	4.	67.5	30	2.5
	5.	75	5	20
	6.	55	5	40
	7.	50	10	40

Since the butane contents above 2.5 percent were too high to be of interest with respect to the LPG Task Group fuel 1, the pertinent WPGA results are for the effect of increasing the propene content for the four test fuels with a butane content of 2.5 percent. Figures 1 to 4 show them graphically.

Emissions of NMHC, NOx, and OFP were all lower on both the 5 percent and 10 percent propene test fuels than on the gasoline (except for NOx from the C1500 van). Generally, NMHC emissions declined with increasing propene in LPG. This is consistent with the result in the LPG Task Group study, including test fuel 1. NOx tended to increase with propene, again consistent with the LPG Task Group study in general, although not for fuel 1 in the Ford truck data (which appears inconsistent with the other NOx data on the Ford). The WPGA results do not show a CO effect of propene, which again is consistent with the LPG Task Group study, including the results for test fuel 1. Finally, OFP increases moderately with propene, as in the LPG Task Group results.

WPGA Emissions Test Results

Figure III-1

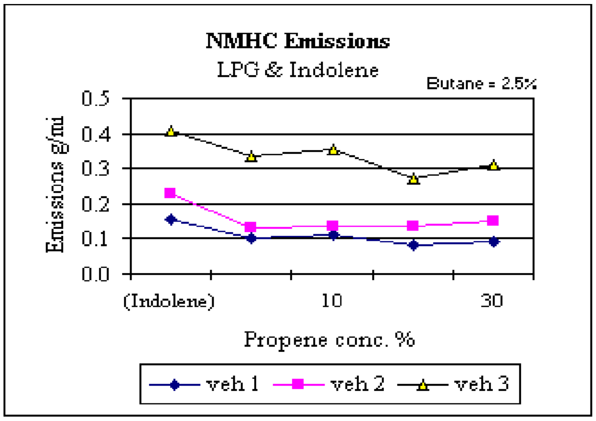


Figure III-2

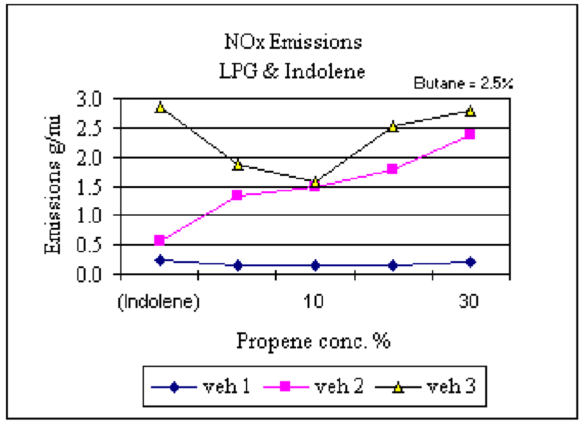


Figure III-3

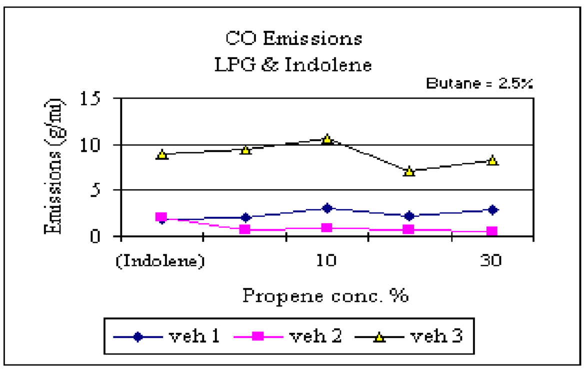
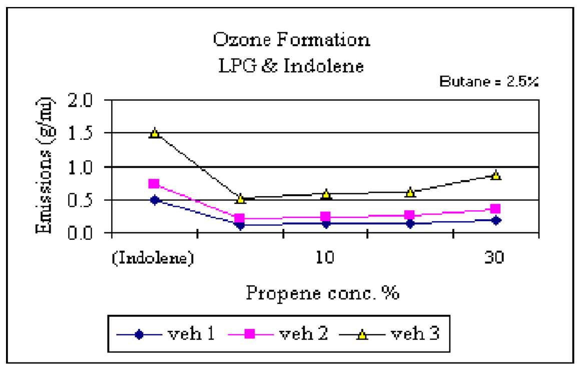


Figure III-4



. <u>ARCO Test Programs</u> [5,6,7] ARCO, with several co-investigators, has published three studies of emissions versus the butane content of LPG. The first two were laboratory studies. One study used a passenger car meeting the TLEV standards on gasoline, which was converted to LPG. It was tested on propane/butane mixtures varying from pure propane to pure butane.

The second study used a 1990 model car converted to LPG and propane/butane mixtures from pure propane to 50 percent butane. The third study was an in-use vehicle study. Three medium-duty, LPG-converted transit vehicles with 1993 engines were tested for emissions during the course of operation on three fuels with butane contents of 0, 20 percent, and 80 percent (balance propane).

The following table summarizes results reported by the study authors. The laboratory studies (Pontiac and Oldsmobile) mostly corroborate the WPGA results. They show a decrease in NOx with increasing butane content and increases in the other pollutants. The in-use study (MDVs) does not show the effects seen in the WPGA or LPG Task Group studies, except for a possible increase in ozone forming potential with increased butane content.

Table III-8. Effect of Increasing Butane Content
(results reported by ARCO et al.)

	1994 Pontiac* (max. butane 100%)	**1990 Oldsmobile*** (max. butane 50%)	**1993 MDVs** (max. butane 80%)
THC	increase	increase	no effect**
NMOG	increase	no effect	---
CO	increase	increase	no effect**
NOx	decrease	maybe decrease	no effect**
OFP	increase	maybe increase	maybe increase

* Statistical significance is not discussed by the study authors, but the effects noted are generally of substantial size over the full ranges of the butane content.

** no statistically significant effect

E. Other Reported Performance Work

Detroit Diesel has reported[8] testing LPG with 9.8 percent propene and 2.3 percent butane in a Detroit Diesel Series 50 engine for cold-start cranking and idle stability, peak torque and horsepower, and knock sensitivity. The test fuel was compared to an HD-5 LPG. Operation on the 9.8 percent propene fuel was indistinguishable from operation on the HD-5, except for greater knock sensitivity at 1500 rpm (but not other rpms). The knock sensitivity, measured as the maximum air-charge temperature that did not produce knock, was well within the design value and not expected to be encountered in normal use.

F. Estimated Effect on Individual Vehicle Emissions

In comparing emissions from vehicles, staff used available data to estimate the emissions effects of using a 10 percent propene and 5 percent butane fuel to the ARB certification fuel. This includes data from LPG Task Group study, ARCO test data, and WPGA test data. The studies conducted by ARCO on very high butane contents provide information only relative to increased butane.

Table III-9 summarizes information from these sources about the potential effects of propene and butane content on emissions. (The analysis regarding the WPGA data are in Appendix 7.)

Table III-9. Estimates of Emission Effects in LPG Vehicles -- 10% Propene, 5% Butane vs. 4% Propene, 2.0% Butane
(percent change)

Data Source	NMHC or THC	NOx	CO	Ozone-Forming Potential
Cummins Engine Test	-18%	9%	6%	6%
Ford F-150 Test	-9%	-6%	1%	3%
WPGA study*	0	9%	2%	15%
ARCO LDV tests (butane effect, only)	small increase	small decrease	small increase	small increase
ARCO MDV tests (butane effect, only)	0	0	0	very small increase

* per ARB staff's regression analysis

IV.

PROPOSAL AND RATIONALE

This chapter describes the proposed amendments to the specifications for motor vehicle LPG and the staff's rationale.

A. Proposal

The staff is proposing that the propene limit in the motor vehicle LPG specification be retained permanently at 10 percent by volume. Without this action, the propene limit will decline to 5 percent in January 1999.

The staff is also proposing that the allowable limit on the butane-and-heavier content of motor vehicle LPG be increased to 5.0 percent by volume, from the current value of 2.5 percent. To prevent the extra butane-and-heavier components from being substantially non-butane material, we also are recommending that the combined content of butenes, pentanes, and heaver species be limited to 0.5 percent by volume.

B. Rationale

Supply. There is no evidence that the situation on the supply of LPG meeting the 5 percent propene limit has improved since 1997, when the Board last delayed that limit. As described in the January 1997 staff report, there is enough LPG with about 5 percent or less propene to fuel all the LPG vehicles. However, there is no practical way for the LPG marketing industry to segregate this high-quality LPG from the rest of the commercial LPG and direct it to vehicles. This problem is experienced mostly in northern California, where much of the LPG sold at wholesale has a propene content greater than 5 percent. LPG vehicle owners could find the supply of complying fuel unreliable if the propene limit declines to 5 percent. Also, while about 40 percent of the LPG marketed today has, on average, 5 percent or less propene, if the 5 percent propene limit was enforced this would further restrict supply as some would occasionally exceed 5 percent and could not be marketed as vehicle grade LPG.

If the LPG supply is unreliable, owners of existing LPG vehicles, which are mostly conversions, might re-convert them to gasoline. Or, in selecting new vehicles, current and prospective LPG vehicle owners may opt instead for gasoline or diesel vehicles. The result would be more reactive organic gas emissions and more diesel particulate matter than will be emitted if LPG remains a practical vehicle fuel.

Emissions. With respect to emissions, making permanent the 10 volume percent interim propene limit will not result in any changes in emissions from the current situation. The small increase in NOx emissions resulting from the in-use fuel having a higher propene content than the certification fuel would continue. However, the effect on the on-road inventory will be small. Also, the apparent effect on the inventories may be misleading because there is no way to quantify the extra future emissions that may occur if people choose not to buy LPG vehicles in lieu of new diesel or gasoline vehicles.

The test data indicate only slight emission effects for the proposed increase in the limit on butane and heavier components. Therefore, for the same kinds of reasons as discussed with respect to the propene limit, the staff believes it is appropriate to broaden the potential supply of complying LPG by raising slightly the limit on butane. Because the proposed changes have a small effect on emissions, vehicles are expected to meet the emissions standards to which they are certified when using the in-use fuel.

Performance. Engine manufacturers have stated a concern about the potential effect of a lower octane number in LPG if the propene content is greater than allowed by the 5 percent limit. However, among the test fuels in the LPG Task Group study (which spanned a range of composition much greater than the changes the staff is proposing), the range of measured octane numbers was only 1.5, and all fuels had (R+M)/2 over 100. (For comparison, the octane number of premium gasoline is 92.) The effect of the staff's proposal will be a reduction of up to one octane number, which is well less than the uncertainty in octane measurement and is also probably smaller than the variation in the octane requirement of most engines due to changes in load, ambient temperature, age, and altitude. Therefore, octane should not be a significant concern with respect to the proposal. Also, there have been no reports of performance problems with current motor vehicle LPG, which in California is now allowed to have 10 percent propene and which is not regulated at all in other areas where the propene content can vary up to 50 percent. The staff expects the ongoing performance testing to confirm this conclusion.

Also, Detroit Diesel Company has found acceptable performance in the Series 50 engine with LPG containing 10 percent propene.

V.

EFFECTS OF THE PROPOSAL

A. Economic Effects

The proposed amendment would not create a new regulation; nor would it impose a new cost on any party. The staff has identified the following economic effects that could result from the proposed amendment.*

Consumers of Vehicular LPG. The proposed amendment would enable consumers to avoid the potential adverse effects of a reduced supply of vehicular LPG, especially in northern California and the San Joaquin Valley. The avoided potential economic effects could include price increases for LPG meeting the 5 percent propene limit and a need to reduce the use of LPG vehicles.

Most of the LPG-fueled on-road motor vehicles in the state are in commercial fleets. In the event of a price increase (if the proposed amendment is not adopted), the vehicle owners could reduce their use of LPG by converting LPG vehicles to run on gasoline again, by replacing them with new gasoline or diesel vehicles, or by increasing the use of non-LPG vehicles already owned.

The staff has not identified any adverse economic impacts on consumers of vehicular LPG that would result from adopting the proposed amendment.

Producers and Marketers of Vehicular LPG. For producers and marketers of vehicular LPG that currently has a propene content between five and ten percent, the proposed amendment

* California Government Code section 11346.3(a) requires that in proposing to adopt or amend administrative regulations, state agencies shall assess the potential for adverse economic impacts on California business enterprises and individuals. The assessment shall include the impact of the proposed or amended regulation on the ability of California businesses to compete with businesses in other states. In addition, section 11346.3(b) requires state agencies to assess the potential impact of their regulations on the creation or elimination of jobs in California, the creation of new businesses or their elimination, and the expansion of businesses in California.

would prevent (or delay) the costs associated with the immediate need to find other markets for this product, install segregated distribution facilities, or reduce the propene content of the LPG.

Since the supply of complying LPG would at least initially be less if the propene limit were to decline to 5 percent, without the amendment the price of complying LPG might rise. Producers of LPG having a propene content of five percent or less would have to forego the revenue increase associated with higher prices for vehicular LPG. Thus the proposal could delay an increase in revenues that producers of complying LPG could experience in connection with a price increase.

If there were an increase in suppliers' prices for vehicular LPG, its effect on marketers of complying LPG would depend on the marketers' ability to pass the increases on to consumers. Such an ability could depend on the ability to segregate vehicular LPG as a separate product. However, the staff is not aware of any LPG producers or marketers who have altered their facilities or operations to reduce the propene content of their LPG, or to allow segregation of vehicular LPG, in preparation for the implementation of the five-percent propene limit on January 1, 1999.

The proposed amendment would not affect employment or the number or competitiveness of businesses in California.

B. Environmental Effects

Relative to current emissions (under the Board's LPG specifications as enforced since their inception), the proposed propene limit would have no effect. The proposed butane limit would allow small increases in emissions from existing LPG vehicles, according to the various test data discussed in this report.

Relative to what emissions will be if the adopted five-percent propene limit takes effect and the 2.5 percent butane limit remains, the emission effects of staff's proposal would have negligible air quality effects because emissions from LPG vehicles are a very small fraction--~0.05 percent--of on-road vehicle emissions. Applying the results in table III-9 to the (at most) 45,000-vehicle LPG fleet inventories in Table II-2 yields these estimates of the worst case emissions reductions that might not occur in the state in 1999 if the proposal is adopted:

NMHC (reactivity-adjusted): 0.04 tpd   NOx: 0.1 tpd   CO: 0.5 tpd

The reactivity of fugitive emissions from marketing LPG for vehicles would increase (relative to the 5 percent limit) due to the increased propene content of that fuel. However, since there would not be a net increase in the propene content of the overall supply of LPG (commercial propane) for all uses, there would be an offsetting decrease in the OFP of marketing emissions of LPG used for non-vehicular purposes.

However, about 70 percent of the LPG available for vehicular use is in areas where the LPGs in commerce have propene contents of 5 percent or less, even under the current 10 percent limit. There is no reason to expect the propene contents of this vehicular LPG will change if the staff's proposal is adopted. When this factor is accounted for, the probable emission reductions that will not occur are reduced to:

NMHC (reactivity-adjusted): 0.01 tpd   NOx: 0.03 tpd   CO: 0.15 tpd

There could be similar emissions effects up to about the same magnitude from non-road vehicles that use LPG, although there are no emission-rate or vehicle-population data by which to reliably estimate such effects.

The data on toxic pollutant emissions from the various studies do not show any basis for predicting any change in toxic pollutants from the proposed amendment. Since the emissions of the most potent exhaust toxic pollutants--benzene and 1,3-butadiene--from LPG vehicles are very low in comparison to emissions from gasoline vehicles, any change would correspond to an extremely small effect.

If the proposed amendment is not adopted, LPG with a propene content between five and ten percent, which is now burned in vehicles, may be used in other combustion devices. If such fuel displaces LPG with a lower propene content, the reactivity of emissions from those devices would probably increase somewhat.

The moderate increases (foregoing of decreases) in emissions of NOx and OFP just discussed must be considered in light of the cleanliness of LPG vehicle emissions compared to gasoline vehicle emissions (in OFP and toxic emissions) and compared to diesel emissions (diesel PM and NOx). If the continued availability of complying LPG due to the proposal prompts the sale of even a few new LPG engines or vehicles in lieu of new gasoline or diesel vehicles, the net effect of the proposal could be a decrease in future emissions. If existing LPG use in vehicles would be displaced by gasoline (in re-conversions to gasoline prompted by a supply problem under the 5 percent propene limit), current exhaust, evaporative, and gasoline marketing emissions would increase. Finally, larger LPG engines could be replaced with diesel engines, which emit significant amounts of exhaust particulate matter.

None of the above emission effects would affect the State Implementation Plan. No other significant environmental impacts have been identified.

References

1. Air Resource Board; Proposed Specifications for Alternative Fuels for Motor Vehicles, October 28, 1991.

2. Air Resources Board; Proposed New Specifications for Diesel Fuel ... and Proposed Amendments to the Commercial Motor Vehicle Liquefied Petroleum Gas Regulations, August 5, 1994.

3. Air Resources Board; Proposed Amendment to the Limit on the Propene Content of Liquefied Petroleum Gas Intended for Use in Motor Vehicles, January 1997.

4. Erin Higinbotham and Wendy Clark, Automotive Testing Laboratories; William Platz, Western Propane Gas Association; Effects of Selected LPG Fuel Components on Speciated Exhaust Emissions, WPGA Project 304, 1996.

5. Michael E. Payne and Jack S. Segal, ARCO Products Co.; Matthew S. Newkirk and Lawrence R. Smith, Southwest Research Institute; "Use of Butane as an Alternative Fuel-Emissions from a Conversion Vehicle Using Various Blends", SAE Technical Paper Series 952496, October 16, 1995.

6. Michael E. Payne and Jack S. Segal, ARCO Products Co.; Matthew S. Newkirk and Lawrence R. Smith, Southwest Research Institute; "Reactivity and Exhaust Emissions from an EHC-Equipped LPG Conversion Vehicle Operating on Butane/Propane Fuel Blends", SAE 961991.

7. Ana Rodriguez-Forker et al., ARCO; George M. Sverdrup et al., Battelle; Al Pierce, OCTA; Thomas D. Durbin, UCR-CERT; "Fleet Test Using Butane and Propane Mixtures", SAE 982444, 1998.

8. Terry Bistue and Roger Parry, Detroit Diesel Co.; "Detroit Diesel Series 50 LPG Development, Fuel Variability Test"