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Draft Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources

Chapter 5

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Chapter 5

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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Chapter 5: Vehicle Technological Feasibility

5.1 Feasibility of Cold Exhaust Emission Standards for Vehicles

5.1.1 NMHC Emissions Control Technologies on Tier 2 Gasoline-Fueled Vehicles

Emission control technology has evolved rapidly since the passage of the CAA Amendments of 1990. Emission standards applicable to 1990 model year vehicles required roughly 90 percent reduction in exhaust non-methane hydrocarbon (NMHC) emissions compared to uncontrolled emission levels. The Tier 2 program and before that, the NLEV program, contain stringent standards for light-duty vehicles that have further resulted in additional NMHC reductions. Tier 2 vehicles currently in production show overall reductions in NMHC of more than 98 percent compared to uncontrolled emissions levels. These emission standards for NMHC are measured under the EPA Federal Test Procedure (FTP), which measures exhaust emissions from vehicles operating only in the ambient temperature range of 68˚ F to 86˚ F.

Table 5.1-1 below lists specific types of NMHC emission controls that EPA projected in the Tier 2 technological feasibility assessment could be used in order to meet the final Tier 2 standards. It is important to point out that all of the following technologies have not necessarily been needed to meet the Tier 2 standards. The choices and combinations of technologies have depended on several factors, such as current engine-out emission levels, effectiveness of existing emission control systems, and individual manufacturer preferences. In some cases, no additional hardware from the NLEV level of hardware was needed. Instead, many manufacturers focused their efforts in the software and calibration controls to achieve stringent emission levels.

Table 5.1-1. Tier 2 Projected Emission Control Hardware and Technologies

Emission Control Technologies	
Fast Light-off Exhaust Oxygen Sensors	Secondary Air Injection into Exhaust
Retarded Spark Timing at Start-up	Heat Optimized/Insulated Exhaust Pipe
More Precise Fuel Control	Close-coupled Catalyst
Individual Cylinder Control	Improved Catalyst Washcoats/Substrates
Manifold with Low Thermal Capacity	Increased Catalyst Volume and Loading
Air Assisted Fuel Injection	Engine Modifications
Faster Microprocessor	Universal Exhaust Oxygen Sensor

A number of technological advances and breakthroughs have allowed these significant emission reductions to occur without the need for expensive emission control equipment. For example, the California Air Resources Board (ARB) originally projected that many vehicles would require electrically-heated catalysts to meet their LEV I program requirements. Today, with even more stringent standards than LEV I, no manufacturer needs to use these devices to comply with program requirements. Similarly, the Tier 2 and LEV II programs, currently being phased-in, have projected that some additional emission control hardware and techniques may be required. However, initial indications from the Tier 2 vehicles already certified indicate that increases in hardware content have been kept to a minimum, likely to minimize cost.

The Tier 2 program requires reductions in all regulated pollutants, but the largest reductions are required for NOx emissions. To achieve these NOx reductions, significant improvements in catalyst technologies have been employed, largely in improved catalyst substrates and washcoats containing the precious metals. In fact, some manufacturers have even been able to reduce precious metal loadings as compared to previous generation catalysts because of the new substrate and washcoat improvements developed in response to Tier 2. These catalyst technologies have generally also resulted in better emission performance of all regulated pollutants, largely because of improved catalyst light-off times.

The Tier 2 program also includes new tighter non-methane organic gases (NMOG) standards. Unlike tight NOx controls, manufacturers had significant experience in NMOG controls, and therefore NMHC controls, primarily from the stringent NMOG standards under the NLEV and LEV I programs. In fact, the NMOG standards for a Tier 2 Bin5 package are the same as the passenger car (PC) and light-duty truck (LDT1) as those established under the NLEV program. The largest challenge manufacturers have encountered under the Tier 2 program is possibly the program's weight neutral standards for all vehicles up to 8500 lbs. gross vehicle weight rating (GVWR) and medium-duty passenger vehicles (MDPV) up to 10,000 lbs. GVWR. These heavier vehicles may be where new hardware will more likely be required to meet Tier 2 weight neutral standards as they fully phase in to Tier 2.

Some of the most significant technological advances that have facilitated low NMHC emission levels have occurred in calibration and software based controls. These controls have been carefully designed to both minimize exhaust emissions before exhaust aftertreatment readiness and accelerate the usage of the aftertreatment earlier in the operation of the engine. Additionally, fuel metering controls during the critical period prior to aftertreatment readiness is more precise than previous systems, largely due to advances in software controls. While some improvements also have been made to base engine designs, which have resulted in lower overall operating engine-out emissions, controls aimed at minimizing emissions during the critical period before exhaust aftertreatment readiness have been done almost exclusively with software based controls. Even with base engine and exhaust hardware improvements, calibration and software controls of the emission control hardware remain the most important and powerful emission control technique used by manufacturers. Calibrations and software controls will continue to become more refined and sophisticated as manufacturers learn new ways to better utilize existing hardware, particularly in the remaining Tier 2 phase-in vehicle models.

Today, these emission control strategies are utilized at 75˚ F to meet stringent Tier 2 and LEV II NMOG standards. The potential exists for these same software and calibration controls to be utilized at 20˚ F and all other cold start temperatures to control NMHC emissions. Most of these controls are feasible and available today in Tier 2 and LEV II vehicles. With the implementation of these controls at the colder start temperatures, significant reductions in NMHC emissions (and therefore air toxics) can be realized. The following sections provide details on these software and calibration control strategies, supporting certification results, and feasibility studies utilizing these existing emission control opportunities.

5.1.1.1 Calibration and Software Control Technologies

Tier 2 vehicles are equipped with very sophisticated emissions control systems. Table 5.1-1 above lists some of the technologies manufacturers have successfully used to meet stringent Tier 2 emission standards. In addition to hardware technologies, manufacturers have developed calibration and software control strategies to meet Tier 2 emission standards that also can be effectively used at 20˚ F to achieve significant reductions in NMHC and other emissions. We expect manufacturers will expand the use of these same emission control strategies already in place on Tier 2 vehicles at 75˚ F to control NMHC emissions at 20˚ F. The following descriptions provide an overview of the calibration and software technologies capable of reducing exhaust emissions at 20˚ F.

5.1.1.1.1 Idle Speed and Air Flow Control

Idle speed and air flow control have been utilized very successfully as a method to both reduce emissions before the catalyst aftertreatment is considered active and to accelerate the activity of the catalyst. Elevated idle speeds immediately following the start of a vehicle, particularly in park and neutral, will result in more stable combustion resulting from the improved air and fuel mixture motion. This is largely due to the higher air velocity entering the combustion chamber which generally results in a more homogeneous mixture, and therefore, a more fully combustible air-fuel mixture. The higher engine speed may also increase heat created from piston to cylinder wall friction, further assisting in transforming fuel droplets to burnable mixtures. The higher engine speeds cause additional combustion events, further assisting in the rapid heating of the combustion chamber. The higher combustion stability can generally result in the ability to run leaner air-fuel ratios, which reduces the percentage of unburned fuel that would be exhausted from the engine.

Air flow through the engine, which is exhausted after combustion, provides the heat required for the catalyst to become active. Increased air flow through the engine, mainly through elevated idle speeds, provides the catalyst with supplemental heat. Additionally, this extra exhaust heat is carried to the catalyst at higher exhaust flow velocities, further shortening the amount of time the catalyst is inactive. The higher combustion stability from the increased air flow provides the catalyst with a preferable mixture composed of less lost fuel in the form of hydrocarbons, which can actually quench a catalyst and slow its warming. The ability to run leaner mixtures can provide the catalyst with the necessary oxygen for the catalyst to begin oxidation of NMHC and carbon monoxide (CO).

Elevated air flow used off idle can also produce significant emission benefits. This elevated air flow is achieved by allowing extra air flow primarily when the throttle is closed but also during the transient period when the throttle is in the process of closing. This momentary air flow increase has been referred to as "dashpot" effect. It typically has been used only for short durations following a throttle closing to help provide additional air flow, and usually only during the first few minutes of cold start engine operation. Elevated air flow has also been used to provide slightly more closed throttle engine torque to overcome additional loads only encountered following a cold start. This reduces risk of idle undershoots and stalling.

5.1.1.1.2 Spark Control

Spark control has evolved with modern electronic controls to a highly precise tool to carefully control when the combustion event is initiated in a spark ignition engine. Retarding the spark delivery immediately after the start has been highly effective at reducing exhaust emissions. Retarding the spark, particularly after a cold start, generally reduces engine-out emissions. This is generally believed to be a result of the longer period of time that the fuel is under compression and absorbing combustion chamber heat. This assists in more complete combustion when the fuel is finally spark-ignited. It also is believed that the retarded spark timing results in lower cylinder peak pressures during the combustion of the air-fuel mixture, reducing the opportunity for hydrocarbons to migrate to crevices and further helping lower engine-out hydrocarbon emissions.

Retarded timing also has been used very effectively to accelerate the early usage of the catalyst by providing supplemental heat, which reduces the time for the catalyst to begin oxidation. The retarded timing results in peak combustion of the air-fuel mixture occurring later in the engine operating cycle, leading to significant thermal energy being transferred into the exhaust. This thermal energy very effectively provides a boost to the catalyst warm-up, particularly at colder temperatures and for large mass catalyst systems or catalyst systems that are further from the engine than desirable.

The effectiveness of retarded timing can be enhanced significantly when used in conjunction with elevated idle speeds and/or air flow control. The simultaneous use of the two features generally is much more effective than either feature used independently, and the resulting emission reductions can be much higher than sum of each feature measured independently. Additionally, utilizing elevated idle speeds while retarding the timing can offset any engine vacuum level concerns encountered when only retarding timing is used.

5.1.1.1.3 Secondary Air Injection Control

Many Tier 2 vehicles produced today contain secondary air injection systems to comply with stringent Tier 2 and LEV II standards. These systems reduce vehicle emissions by injecting ambient air into the rich engine exhaust upstream of the catalyst for a short period of time immediately after a start. This reduces emissions in two ways. First, the oxygen in the ambient air being pumped into the exhaust assists in oxidizing HC and CO prior to reaching the catalyst. Second, this oxidation can result in the generation of highly desirable, large amounts of heat that help bring the catalyst to effective temperatures much sooner. As the catalyst reaches effective temperature, the secondary air can continue to provide needed oxygen for oxidation in the catalyst until the total system is ready to go “closed loop,” at which time the secondary air injection is ceased.

The secondary air injection technology for controlling emissions is not a new technology. For many years, manufacturers used secondary air injection systems that ran continuously from a mechanical belt-driven pump to oxidize HC and CO emissions produced from a rich exhaust mixture. With the advent of the three way catalyst (TWC), manufacturers began to use engine control modules (ECM) to activate electric air pumps to reduce start emissions only at 75˚ F, typically on vehicle packages with specific emission challenges. For example, vehicles that have large mass catalysts or catalyst systems located relatively far from the engine have utilized secondary injection to assist catalyst light-off. Further, many Tier 2 and LEV II packages certified to the cleanest emission levels utilize secondary air injection to achieve these results. Some Tier 2 packages that appear to have relatively high engine-out emissions, possibly due to engine design limitations, also have implemented secondary injection to allow compliance with Tier 2 emission standards.

Many manufacturers that have equipped some of their Tier 2 vehicles with secondary air injection systems do not appear to consistently utilize this emission control strategy across start temperature ranges outside of the currently regulated cold start temperature (75˚ F for Tier 2 and 50˚ F for LEV II). However, many vehicle models common to Europe and the U.S. that are equipped with secondary air injection do appear to be using this technology at 20˚ F on models sold in the U.S., based on our analysis of the certification data. This is attributable to common emission control technologies with the European market vehicles, where manufacturers are already required to meet a 20˚ F NMHC standard.

The activation of the secondary air system is a feasible and effective emission control technology for 20˚ F as well as all other interim start temperatures. The use of secondary air injection technology at 20˚ F is well proven as an emission control technology, as observed in the European vehicles. Certain design criteria must be taken into account for the system to operate robustly at these colder temperatures, but there appears to be no technological challenge that would prevent these vehicles already equipped with secondary air injection from activating this emission control technology at 20˚ F.

Some manufacturers, who do not use secondary air injection systems at 20˚ F but do include the systems on some of their U.S.-only models, have expressed concerns with freezing water in the system. We have investigated this concern with the manufacturers of the secondary air injection components and found this to be a system design issue that has been addressed by guidelines on the location and plumbing of the individual secondary air injection components.[1]

5.1.1.1.4 Cold Fuel Enrichment

Gasoline-fueled spark ignition engines generally require rich air-fuel mixtures (i.e., a larger amount of fuel for a given amount of air) for some amount of time immediately following a cold start. Under normal operating conditions, the amount of required enrichment always increases as start temperature decreases. This is largely because low in-cylinder temperatures for some period of time following the cold start lead to a lower percentage of liquid fuel vaporizing to a burnable mixture. The level of enrichment and its duration following the start will vary with many factors, including base engine hardware design and fuel properties. Fuel property interactions with engine combustion chamber dynamics are quite complex and can vary with fuel composition, but typical gasoline fuel available in the U.S. during the cold weather (e.g., 20˚ F) is properly formulated for robust cold start operation.

The level of enrichment should be calibrated to closely match the “winter” grade fuel properties that the overwhelming majority of vehicles will be experiencing during the colder start conditions. Winter grade fuel is formulated to have a higher Reid vapor pressure (RVP), specifically to allow the fuel to vaporize at lower cold start temperatures and minimize the need for additional enrichment. Any fuel enrichment beyond the minimum required level results in proportional increases in cold start emissions, primarily NMHC and CO. Additionally, over-fueling can hamper earlier use of the exhaust aftertreatment by quenching the catalyst with the unburned fuel, effectively cooling the catalyst. This retards the warm-up rate of the catalyst and also reduces the availability of any excess oxygen that would be used by the catalyst to oxidize the NMHC and CO.

The amount of required enrichment also can be reduced when used in conjunction with the previously mentioned elevated idle speed emission control technology. As stated earlier, elevated idle speeds will result in a more homogeneous mixture which supports more stable combustion. The improvements in the mixture will allow the enrichment levels to be reduced accordingly.

5.1.1.1.5 Closed Loop Delay

"Closed loop" operation refers to operation that allows the exhaust oxygen sensor to feed back to the engine control module and control the air-fuel mixture to an exhaust stoichiometric ratio. Following start-up of a modern gasoline fueled engine, operation in closed loop is delayed for some amount of time based on a combination of engine and oxygen sensor readiness criteria. As stated in the previous section, gasoline-fueled engines require rich air-fuel mixtures for some amount of time immediately following a start. The amount of time requiring the rich operation and, therefore, the delay of exhaust stoichiometric operation, will vary with the gasoline engine's ability to operate smoothly at these air-fuel ratios.

The delay also will be determined by the exhaust oxygen sensor's ability to properly function. Modern exhaust oxygen sensors, including both conventional switching and universal linear sensors, contain heating elements to allow them to maintain proper operating sensor temperatures and also to be used sooner following a cold start. These internal heating elements require careful control to prevent any potential thermal shock from water or fuel in the exhaust stream. The water is generated from the combustion process but also can be present in the exhaust pipe from condensation of water, particularly during certain ambient temperature and humidity operating conditions. Generally, cold starts at 20˚ F only require a short delay to allow the initial heating of the exhaust manifold to vaporize any combustion water. This period is followed by an electronically controlled and monitored heating of the sensor. Exhaust oxygen sensors have been designed to have significant protection from water and are typically fully operational well before the engine is prepared to use their information.

Generally, within approximately one minute of 20˚ F cold start operation, combustion chamber temperatures are at levels that vaporize sufficient amounts of the gasoline fuel to command exhaust stoichiometric operation of the engine. Also within that minute, exhaust oxygen sensors should have sufficient time to reach operating temperature with any thermal issues mitigated, allowing closed loop stoichiometric operation. As stated earlier, operating a gasoline-fueled engine at stoichimetry provides the exhaust aftertreatment with oxygen required for oxidation of HC and CO. Therefore, the amount of time requiring enrichment should be minimized and closed loop operation of the emission control system should be able to occur as soon as physically possible.

5.1.1.1.6 Transient Fuel Control

The control of the air-fuel ratio during transient maneuvers (i.e., operator-induced throttle movement) has dramatically improved with modern hardware and software controls. This is largely due to the improved accuracy of both the measurement sensors and the fuel delivery devices, but also refined software modeling of both air flow and physical fuel characteristics. Tier 2 vehicles have highly accurate sensors that measure changes in air flow to predict and deliver the appropriate amount of metered fuel. Additionally, the software that interprets these sensor signals has evolved to predict transient behaviors with much higher accuracy than ever before. Many of these improvements were necessitated by increases in emission stringency in the recent Tier 2 and LEV II programs, which were much less tolerant of transient errors that were acceptable in past emission control systems.

With the recent widespread penetration of electronic throttle controls (ETC), partially in response to the stringent Tier 2 and LEV II 75˚ F standards, manufacturers have been able to further reduce variability of transient errors. ETC applications remove the direct mechanical connection from the accelerator pedal to the engine. Instead, the pedal is simply a sensor that reports pedal movement to the ECM. The ECM interprets the pedal movement and provides a corresponding controlled movement of the engine throttle.

Transient air-fuel errors can be minimized through advanced approaches to ETC usage. This is possible because the electronic controls can better synchronize the introduction of the transient maneuver and closely match required air and fuel amounts. The controls can be designed and programmed to prevent most of the transient errors experienced with older cable-driven mechanical systems. The older mechanical systems resulted in reactionary response to throttle movements, making it significantly more difficult to deliver precise dynamic air-fuel control. Since the ETC systems control the actual movement of the throttle, they have the ability to essentially eliminate transient errors by preceding the throttle movement with appropriate fuel metering amounts. This is particularly important at colder temperatures (i.e., 20˚ F cold start) where transient errors can be exaggerated when the engine is operating rich of stoichiometry.

5.1.1.1.7 Fuel Volatility Recognition

Improved modeling of the effect of fuel properties on engine and emission performance has eliminated the need for a new sensor. For instance, some manufacturers have successfully designed software models that can determine the percentage of ethanol in the fuel on which the vehicle is operating. These “virtual sensor” models take into account information from sources such as existing sensors and use historical data for the determinations. The models use this information to adjust many outputs including fuel metering and spark ignition control.

Currently, manufacturers have active software features that are designed to recognize and recover from a lean condition that can be a precursor to an engine stall. These features use different input criteria to identify and actively change the air-fuel ratio when an excessively lean condition may be occurring. These features may look at control parameters such as engine speed (RPM), engine manifold absolute pressure (MAP), engine mass air flow (MAF), and even engine misfire-related information to determine if a fuel metering change should occur.

The approaches described above exemplify possible software-based control designs that can achieve the desired emission and engine performance characteristics. Manufacturers have extensive experience designing and implementing software features to identify and react to specific fuel parameters that are deemed important to engine operation. The ability to recognize fuel volatility and actively adjust the fuel metering accordingly would allow the gasoline-fueled engine to operate at the lean limit, reducing engine-out emissions, particularly NMHC and CO. Much like the “virtual sensor” model described above for ethanol content, this model would take existing sensor information and other information available from the ECM and determine the fuel volatility characteristics at any given cold start temperature. The modern engine controllers have the ability to maintain significant historical data that can help predict fuel properties. The items of importance for fuel volatility may include ambient temperature exposure of fuel, amount of time since previous start, and other related items.

5.1.1.1.8 Fuel Injection Timing

Fuel injection timing control is another emission control technology that has evolved as a result of increased computing power of the engine. Depending on the engine design and the thermal characteristics of the intake port design, significant opportunity may exist for optimizing fuel preparation prior to combustion.

Generally, there are two fuel injection timing approaches used to optimize fuel preparation: closed valve injection and open valve injection. Closed valve injection is the traditional method of injecting fuel into the cylinder head intake port. As the name states, the intake valve is closed during the injection time period. This approach allows the fuel to have residence time in the intake port prior to ingestion into the cylinder. Usually, the fuel injector is targeted to spray the fuel on the back of the closed intake valve in order to allow the fuel to absorb any heat conducted through the valve from the combustion events occurring inside the cylinder chamber. The heat absorbed by the fuel potentially allows more of the fuel to vaporize either in the port or in the chamber, resulting in higher percentage of vaporized fuel that can be combusted. If the higher percentage of vaporized fuel burns, less liquid fuel will be exhausted, effectively reducing the engine-out NMHC levels.

Open valve injection involves carefully coordinating the fuel injection timing in order to inject fuel while the intake valve is in some state of opening. This approach attempts to take advantage of the incoming air velocity as the air is drawn through the port and also the intake air pressure depression. The mixture motion and depression can help vaporize the fuel and assist in better mixing of the air and fuel prior to combustion, resulting in improved fuel burn. This approach is dependent on many aspects, including injector spray design, injector targeting, intake valve timing, and intake valve lift. Open valve timing may be used initially after engine start followed by a closed valve approach, described previously, once the intake valve is heated. Many similar approaches are detailed in past Society of Automotive Engineers (SAE) papers[2].

5.1.1.1.9 Spark Delivery Control

With the increases in the computing power of the engine controller, opportunities have been created for new spark delivery related emission control features. Separate from the retarded timing benefits described previously, there are other potential controls that may help reduce engine-out emissions. Many new engines contain individual cylinder ignition coils. With these individual coils comes the opportunity for individual cylinder-based spark control features designed to promote more complete combustion. Additionally, some new engines have dual spark plugs (i.e., two plugs for each cylinder). These dual spark plug systems may have opportunities for new concepts targeted at emission reductions, particularly following cold start operation.

Spark energy, the amount of energy delivered to the spark plug that is used to ignite the air-fuel mixture, can be carefully controlled by modifying the dwell time delivered to the ignition coil. The dwell time is the amount of time that the ignition coil is allowed to be charged with electrical energy. An increase in dwell time will generally result in an increase in spark energy delivered to the spark plug. Higher spark energy typically results in a higher burn rate particularly in air-fuel mixtures that are not optimized, which is typical of mixtures at start-up.

Other new concepts may include such ideas as multiple spark events on a single engine cycle. The concept of delivering redundant spark events has been used in the past, primarily for engine performance. While we do not currently know if redundant spark events are beneficial in reducing emissions, it could be explored for emissions control. Similarly, dual spark plug engines or engines with individual cylinder ignition coils can explore other spark delivery related concepts that may prove to be effective emission control tools.

5.1.1.1.10 Universal Oxygen Sensor

As listed in Table 5.1-1 above, universal oxygen sensors were projected to be an emission control hardware that could be used to meet Tier 2 vehicle standards. Several manufacturers did in fact decide to replace their conventional switching oxygen sensors with these universal oxygen sensors. Universal oxygen sensors have certain benefits over conventional switching sensors that should prove substantially beneficial at 20° F. While these sensors require a similar delay to reach operating temperature following a start, universal oxygen sensors can accurately control the air-fuel ratio during rich operating conditions prior to commanded closed loop operation. Conventional switching sensors cannot indicate the actual air-fuel ratio during rich conditions, therefore preventing them from being used as a control sensor during critical rich operation. Additionally, universal oxygen sensors can be used to more accurately recover from air-fuel transient errors during the warm-up due to their ability to measure the magnitude of the error.

5.1.1.2 Tier 2 Engine and Exhaust Control Technologies

The Tier 2 technological feasibility assessment described several engine and exhaust hardware control technologies that could be used to meet stringent Tier 2 emission standards. [3] These technologies continue to be very effective emission control strategies to meet Tier 2 standards. We believe that manufacturers will use these same Tier 2 technologies in order to meet the proposed 20˚ F NMHC standard. We do not expect that manufacturers will need to utilize additional emission control hardware. However, if a manufacturer chose to do so, most of these same Tier 2 technologies can also be used to meet the proposed 20˚ F NMHC standard.

5.1.2 Data Supporting Cold NMHC Standard Technical Feasibility

Data to support the feasibility of complying with a 20˚ F NMHC standard are presented in the following two sections. The first section includes evidence from recent model year certification emissions data submitted to EPA. Certification data are required to include cold temperature carbon monoxide emissions data, and some manufacturers have also included associated cold temperature total hydrocarbon emissions data. The second section provides evidence from a feasibility evaluation program recently undertaken by EPA. This program examined the effects of making only calibration modifications to vehicles with 20˚ F NMHC levels that were significantly higher than the industry average.

When considering the supporting data, it should be noted that manufacturers generally design vehicles to incorporate a compliance margin in their exhaust emissions controls systems to account for operational variability. Specifically, they will design controls to meet emissions targets below the standard when using catalytic converters thermally aged to the full useful life. By ensuring that emission targets are met when testing on artificially aged converters, manufacturers reduce the probability that in-use vehicles will exceed the relevant standard throughout the useful life of the vehicles.

However, the data presented in the following sections do not explicitly incorporate a compliance margin since the cold temperature NMHC data, at the time they were submitted to the EPA, were not subject to EPA standards. The data represent the cold NMHC emissions as tested, and only suggest that a significant number of vehicles are within reach of today’s proposed standards

5.1.2.1 Certification Emission Level

Manufacturers are required to report carbon monoxide (CO) exhaust emissions test results for compliance with cold temperature CO standards (i.e., the 20˚ F FTP test) for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. Many manufacturers have included total hydrocarbon (THC) cold temperature exhaust emission data that are collected along with cold CO data. In addition, several of these manufacturers also reported test results for both the THC emission data and the matching NMHC emission data. Based on these data from manufacturers who have included both THC and NMHC cold temperature data, non-methane hydrocarbons (NMHCs) account for approximately 95% of total hydrocarbon emissions at cold temperatures. Therefore, a review of the more abundant THC data provides a reasonable means of assessing manufacturers’ cold NMHC emissions performance.

EPA analyzed 2004, 2005, and 2006 model year full useful life certification data for vehicles certified to nationwide Tier 2 standards, NLEV program standards, and the California program standards. Lists were compiled from certification data submissions that reported unrounded cold THC results and for which an associated FTP full useful life deterioration factor (DF) was available. The DF is incorporated into the emissions result to estimate emissions at the full useful life of the vehicle. The DF was applied to the unrounded test result, and that result was rounded to one decimal point. This calculation was then compared to the cold temperature NMHC standards of 0.3 g/mi for LDV/LLDTs, and 0.5 g/mi for HLDT/MDPVs.

Table 5.1-2 shows the number of car lines for which the resulting calculation for total hydrocarbons was at or below the 0.3 g/mi NMHC standard for LDV/LLDTs, and at or below the 0.5 g/mi NMHC standard for HLDT/MDPVs. Again, these data only reflect an analysis of those car lines for which manufacturers voluntarily provide cold THC data.

Tables 5.1-3, 5.1-4, and 5.1-5 show, by model year, the total hydrocarbon emission levels (calculated according to the method described above) for LDV/LLDTs at or below 0.3 g/mi, and HLDT/MDPVs at or below 0.5 g/mi. For each manufacturer, the data were grouped according to car lines with the same calculated cold THC emission result. Where a range is shown for the emission level, tests on multiple configurations within the car line yielded a range of results.

Table 5.1-2. Number of car lines with one or more engine families whose certification data for total hydrocarbons was at or below the proposed cold NMHC standards

Year	LDV/LLDTs	HLDT/MDPVs	Total Car Lines
2004	41	13	54
2005	42	16	58
2006	44	22	68

As the tables suggest, there are already a significant number of vehicle configurations, across a wide range of vehicle types and manufacturers, within reach of the proposed cold temperature NMHC standards. Though the number of LDV/LLDT configurations at or near the proposed cold NMHC standards significantly outnumber the heavier HLDT/MDPVs, EPA is proposing a later phase-in for HLDT/MDPVs due to the unique challenges related to these heavier vehicles, as discussed in Section VI of the Preamble. The number of configurations approaching the proposed standard increases for both LDV/LLDTs and HLDT/MDPVs from 2004 to 2006, as vehicles have adopted more stringent emission controls to meet the Tier 2 standards.

This analysis does not necessarily imply that manufacturers could have certified these vehicles to meet the proposed cold NMHC standards. But the data do support the feasibility of meeting such standard levels. This analysis is conservative given that actual NMHC emissions would be slightly less than that of the total hydrocarbon emissions, and not all of the vehicles included here were certified to the more stringent Tier 2 standards. That is, some vehicles in the certification data are interim non-Tier 2 vehicles. We would expect hydrocarbon levels to be somewhat lower as these vehicles fully phase-in to Tier 2.

Table 5.1-3. 2004 model year vehicles with certification data for total hydrocarbons at or below the proposed cold NMHC standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
ACURA	1.7EL, TL	0.1
ACURA	MDX 4WD	0.2
ACURA	RSX	0.3
AUDI	A4 QUATTRO	0.3
BMW	325I SPORT WAGON, 330CI CONVERT.	0.1
BMW	X3	0.2
CADILLAC	CTS	0.2
CHEVROLET	CORVETTE	0.2
HONDA	ACCORD	0.1 - 0.3
HONDA	CIVIC	0.1 - 0.2
HONDA	CIVIC HYBRID, INSIGHT	0 - 0.1
HONDA	CR-V 4WD, ELEMENT 4WD, S2000	0.2
HONDA	ODYSSEY 2WD	0.3
HONDA	PILOT 4WD	0.2 - 0.3
HYUNDAI	XD-5DR	0.3
MAZDA	MAZDA 3	0.2 - 0.3
MAZDA	MAZDA 6, MAZDA 6 SPORT WAGON, MPV	0.3
MERCEDES-BENZ	C240 (WAGON), C-CLASS SEDAN/WAGON, S-CLASS	0.3
MERCEDES-BENZ	E320 4MATIC (WAGON), S500 (GUARD)	0.2
MITSUBISHI	GALANT	0.1 - 0.2
MITSUBISHI	LANCER SPORTBACK	0.3
NISSAN	ALTIMA	0.3
NISSAN	SENTRA	0.2 - 0.3
SATURN	VUE AWD	0.2
TOYOTA	CAMRY	0.3
TOYOTA	PRIUS, RAV4 4WD	0.2
VOLKSWAGEN	JETTA, JETTA WAGON, BEETLE CONVERT.	0.2
VOLVO	V70	0.2 - 0.3
HLDT/MDPVs		
BENTLEY	CONTINENTAL GT	0.3
BMW	X5	0.3
CHEVROLET	ASTRO AWD(C) CONV	0.5
CHEVROLET	K15 SLV HYBRID 4WD	0.4
GMC	K1500 SIERRA AWD	0.4
HIREUS	RR01	0.3
MERCEDES-BENZ	G500, ML350	0.4
PORSCHE	CAYENNE, CAYENNE S	0.3
ROLLS-ROYCE	PHANTOM	0.3
VOLKSWAGEN	TOUAREG	0.4
VOLVO	XC 90	0.3, 0.5

Table 5.1-4. 2005 model year vehicles with certification data for total hydrocarbons at or below the proposed cold NMHC standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
ACURA	1.7EL, MDX 4WD	0.1
ACURA	RL, RSX	0.2
AUDI	A4 QUATTRO	0.3
BMW	325I SPORT WAGON, 330CI CONVERTIBLE	0.1
BMW	X3	0.2
BUICK	LACROSSE/ALLURE	0.3
CADILLAC	CTS	0.2
HONDA	ACCORD	0.1 - 0.2
HONDA	ACCORD HYBRID	0.2
HONDA	CIVIC	0.1 - 0.2
HONDA	CIVIC HYBRID	0 - 0.1
HONDA	CR-V 4WD, ODYSSEY 2WD, S2000	0.2
HYUNDAI	JM(2WD)	0.3
HYUNDAI	JM(4WD)	0.2
HYUNDAI	XD-5DR	0.3
MAZDA	MAZDA 3	0.2 - 0.3
MAZDA	MPV	0.2
MERCEDES-BENZ	C240 (WAGON), C32 AMG, E320 4MATIC (WAGON), S55 AMG	0.3
MERCEDES-BENZ	C320	0.2
MERCEDES-BENZ	S430 4MATIC	0.1
MITSUBISHI	GALANT	0.2 - 0.3
MITSUBISHI	LANCER, LANCER SPORTBACK	0.3
NISSAN	SENTRA	0.2
SATURN	RELAY AWD	0.3
SATURN	VUE AWD	0.2
TOYOTA	CAMRY, SCION XB	0.3
TOYOTA	PRIUS, RAV4 4WD	0.2
VOLKSWAGEN	JETTA, JETTA WAGON, BEETLE CONVERT., V70	0.2
HLDT/MDPVs		
BENTLEY	CONTINENTAL GT	0.3
BMW	X5	0.3
CHEVROLET	ASTRO AWD(C) CONV, C2500 SLVRADO 2WD, K1500 SUB'N 4WD	0.5
CHEVROLET	K15SLV HYBRID 4WD	0.4
GMC	G3500 SAVANA(P), K1500 SIERRA AWD	0.4
LAND ROVER LTD	LR3	0.4
LEXUS	GX 470	0.4
MERCEDES-BENZ	G500, ML350	0.4
MERCEDES-BENZ	G55 AMG	0.2
PORSCHE	CAYENNE	0.3
ROLLS-ROYCE	PHANTOM	0.3
TOYOTA	TOYOTA TUNDRA 4WD	0.5
VOLVO	XC 90	0.3

Table 5.1-5. 2006 model year vehicles with certification data for total hydrocarbons at or below the proposed cold NMHC standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
ACURA	MDX 4WD	0.1
ACURA	RL, RSX	0.2
AUDI	A4 QUATTRO	0.3
BUICK	LACROSSE/ALLURE	0.3
CADILLAC	CTS	0.3
CHEVROLET	COBALT, IMPALA	0.3
CHRYSLER	TOWN & COUNTRY 2WD	0.3
HONDA	ACCORD	0.1 - 0.2
HONDA	CIVIC, CR-V 4WD, ODYSSEY 2WD	0.2
HONDA	CIVIC HYBRID	0.1
HONDA	INSIGHT	0 - 0.1
HONDA	S2000	0.3
HYUNDAI	JM(2WD), XD-4DR/5DR	0.3
HYUNDAI	JM(4WD)	0.2
LEXUS	GS 300 4WD, RX 400H 4WD	0.3
MAZDA	MAZDA 3, MAZDA 5, MPV	0.2
MAZDA	MAZDA 6, MAZDA 6 SPORT WAGON	0.3
MERCEDES-BENZ	B200 TURBO, S350	0.2
MERCEDES-BENZ	S430 4MATIC	0.1
MERCEDES-BENZ	S55 AMG	0.3
MITSUBISHI	GALANT	0.2 - 0.3
MITSUBISHI	LANCER, LANCER SPORTBACK	0.3
NISSAN	ALTIMA, SENTRA	0.3
SATURN	RELAY AWD	0.3
SATURN	VUE AWD	0.2
SUZUKI	FORENZA WAGON	0
TOYOTA	CAMRY, CAMRY SOLARA, YARIS	0.3
VOLKSWAGEN	JETTA WAGON	0.2
VOLKSWAGEN	PASSAT WAGON	0.3
VOLVO	V70	0.2
HLDT/MDPVs		
CADILLAC	FUNERAL COACH/HEARS, SRX AWD	0.5
CHEVROLET	C2500 SLVRADO 2WD	0.5
CHEVROLET	K15SLV HYBRID 4WD	0.3
DODGE	DAKOTA PICKUP 4WD, RAM 1500 PICKUP 2WD	0.5
GMC	ENVOY XUV 4WD, G1525 SAVANA CONV	0.5
GMC	K15 YUKON XL AWD	0.3
HONDA	RIDGELINE 4WD	0.2
JEEP	GRAND CHEROKEE 4WD	0.4
LAND ROVER LTD	LR3	0.5
LEXUS	GX 470	0.4
LEXUS	LX 470	0.5
MERCEDES-BENZ	R500	0.2

PORSCHE	CAYENNE, CAYENNE S	0.3
PORSCHE	CAYENNE TURBO KIT	0.5
ROLLS-ROYCE	PHANTOM	0.3
TOYOTA	TOYOTA TUNDRA 4WD	0.5
VOLKSWAGEN	PHAETON	0.5
VOLVO	XC 90	0.3

5.1.2.2 EPA Test Program

To determine the feasibility of meeting the proposed NMHC standard with only changes to the calibration, EPA performed a test program involving a Tier 2 vehicle that was deemed very challenging. The vehicle selection criteria for a feasibility study include several key aspects. First, the vehicle needs to currently produce 20° F NMHC levels that are significantly higher than the industry average. Second, since vehicle weight was determined to be a potential disadvantage, a heavier GVWR vehicle is preferable for feasibility testing. Finally, the technological approach chosen by the manufacturer to meet stringent 75° F Tier 2 standards was also considered. Specifications for the test vehicle are included in Table 5.1-6.

Table 5.1-6. EPA Test Vehicle Specifications

Vehicle	Engine Family	Powertrain	GVWR	Emission Class	Mileage
2004 Chevrolet Trailblazer	4GMXT04.2185	4.2L I6 4-speed auto 2-WD	5550 lbs.	Tier 2 Bin 5	36,500

The vehicle was tested at 20° F following EPA cold FTP test procedures established in 40 CFR 86.230-94. In addition to regulated pollutant measurements, additional measurements included NMHC, oxides of nitrogen (NOx), and particulate matter (PM). NMOG analysis also produced measurements of 13 carbonyls. PM measurement was performed following 40 CFR 86.110-94 procedures. A detailed diagram of the emission and PM sampling system can be seen in the docket.[A] The road load force target coefficient settings, contained in Table 5.1-7, are 10% higher than the vehicle's 75° F target coefficients as established procedure in EPA guidance letter CD-93-01.[B]

Table 5.1-7. EPA 20° F Cold Test Vehicle Settings

Vehicle	Test Weight	20° F Target Coefficients
2004 Chevrolet Trailblazer	**5000 lbs.**	**A=38.97** **B=1.2526** **C=.02769**

[A] "Cold Chamber Sampling System Diagram," PDF file from test lab.

[B] Available at www.epa.gov/otaq/cert/dearmfr/dearmfr.htm.

5.1.2.2.1 2004 Chevrolet Trailblazer Feasibility

As indicated earlier, the selection criteria of the vehicle candidate for the feasibility study were designed to meet several key goals. The 2004 Chevrolet Trailblazer was chosen as a candidate because it met the desired criteria. First, it is certified as a Tier 2 Bin 5 package, which represents what can be considered the "typical" or average 75˚ F emission level once Tier 2 phase-in is complete. This is because the Bin 5 emission standards represent the required EPA fleet average for NOx and therefore the hardware used on the Trailblazer to comply with Bin 5 standards represents what we might expect from many manufacturers and vehicle lines. Second, while it was certified to the expected average Tier 2 emission levels, its NMHC emission performance at 20˚ F was substantially worse than the industry averages. Finally, due to its GVWR, it represents vehicles that are very close to 6000 lbs. GVWR. Different Trailblazer models fall above and below 6000 lbs. GVWR, but do not have any discernable differences in the emission control hardware.

The Trailblazer engine control system is representative of typical Tier 2 systems. The system includes an electronic engine control module (ECM), individual cylinder fuel injectors, individual cylinder ignition coils, heated exhaust gas oxygen sensors (HEGO) before and after the catalyst, electronic throttle control, variable valve timing and several other necessary supporting sensors. The aftertreatment hardware consists of a single, under-floor catalyst and a secondary air injection system.

The secondary air injection system is composed of an electric air pump and an electric solenoid valve. The air pump is located under the vehicle's driver-side floor board where it is mounted to a frame bracket. The electric solenoid valve is mounted to the engine cylinder head directly above the exhaust manifold on the passenger side of the vehicle. Clean air is drawn by the air pump from the air cleaner assembly in the engine compartment through a pipe, then it is pumped back to the electric solenoid valve through a second pipe. The two pipes used to transport the air are fairly long, due primarily to the air pump location.

The secondary air injection system on the Trailblazer appears to operate on cold starts above 40˚ F only. The system operates for approximately 20 to 45 seconds after the start, depending on start-up coolant temperature, and is deactivated when the emission control system goes into closed loop operation. Some manufacturers have indicated that operation of the secondary air injection system is not currently performed at and below freezing cold start temperatures due to potential water freezing in the system which would prevent proper system operation. This is, however, not universal across all manufacturers, since several manufacturers do, in fact, operate their secondary air injection system at 20˚ F cold start temperatures and above. They have addressed the issue of water collecting and freezing by design aspects primarily concentrated around system plumbing and location of the components. On some European vehicle models, these manufacturers effectively use the secondary air injection systems to comply with a 20˚ F NMHC standard in Europe.[4]

A key element of the feasibility test program was to imitate emission control system behaviors observed at the currently regulated start temperatures of 75˚ F and 50˚ F (California-only requirement). In the case of the Trailblazer, while not all behaviors could be demonstrated, several of the most important behaviors were replicated. First, the operation of the secondary air injection system was determined to be a requirement. Second, elevated idle speeds, similar to what the Trailblazer currently uses after the start at the regulated start temperatures, were also required.

The activation of the secondary air injection was accomplished through circuit overrides of the air pump and solenoid valve control circuits, completely external to the ECM. The air pump and the solenoid valve are each powered by a relay normally only controlled by the ECM output signals. The two relays were forced on to activate the secondary air injection system during the desired period following the cold start. Several delay periods from the start of the engine until the secondary air system was activated were tested to measure benefits of earlier introduction of the air injection. The secondary air was always run until ECM induced closed loop operation (approximately 60 seconds after the start). At the completion of the desired period of operation, control of the relays was returned to the ECM.

The elevated idle speed was performed by allowing a manually controlled vacuum leak into the intake manifold during the first 30 to 60 seconds following engine start. The controlled vacuum leak targeted 1550 to1600 RPM idle speed in park/neutral, mimicking the same desired idle speed the ECM commands at 50˚ F cold starts. Typically, idle speeds increase with drops in start temperature, but the observed desired idle speeds in the Trailblazer were lower at 20˚ F (1350 RPM) than at the warmer 50˚ F starts (1550 RPM). Ideally, utilizing the electronically controlled throttle to achieve a target idle speed would have been the best method, but control of the electronic throttle was not available. Manufacturers today control to a desired idle speed through control of electronic throttle or other air bleed devices.

Table 5.1-8 below contains the weighted test total (3 bags) emission results of the different test configurations attempted on the Trailblazer. Test #7 and #8 also included defroster operation starting at 130 seconds into the test and remaining on for the rest of the test. Since the methods used to control cold start NMHC emissions were used only in the first minute of operation, prior to defroster activation, the NMHC and PM emission results with defroster operation remain representative of emission control opportunities. It is important to note the consistent reductions in NMHC with early activation of the secondary air injection system as seen in the test sequence from test #3 through test #6, but also in the defroster tests. The tests with defroster operation were included to assess any emission impacts of defroster-on, which is being proposed in a fuel economy rule.[C]

While NOx emissions are not part of the controls investigation, the NOx levels appeared to increase with the NMHC control methods. After some modal investigation, it was determined that the NOx increases were occurring after the NMHC controls had performed the majority of their benefits. The NOx emissions were brought back almost to the baseline levels by shortening the elevated idle speed and air bleed time. This can be observed in the results of test #6 and #7. In fact, test #6 produced the largest NMHC reduction with essentially the same NOx levels as the baseline tests. Manufacturers would be able to better synchronize their controls through their ECM to control NMHC and NOx emissions simultaneously, as compared to this test program’s limitations.

[C] Fuel Economy Final Rule XX Defroster Operation Requirement for Cold FTP.

CO and PM measurements also indicate significant reductions when NMHC controls are activated. CO, the only currently regulated pollutant at 20˚ F, demonstrated consistent reductions over baseline levels with each of the control combinations. PM generally also indicated reductions; however, it is less obvious when reported as test total results. Since the emissions are recorded over the three-phase test with each phase composed of an individual bag measurement, PM reductions can be better evaluated in Table 5.1-9, which contains the emission results for only the first phase (bag 1) of the three-phase emission test.

Table 5.1-8. Trailblazer Test Configuration and 20˚ F FTP Weighted Test Total Results

Test Number	Air Injection	Elevated Idle & air bleed time	NMHC g/mi	CO g/mi	NOx g/mi	PM g/mi	Fuel Economy mi/gallon
Proposed Standard ≤ 6000 lbs GVWR			**.3**				
Proposed Standard > 6000 lbs GVWR			**.5**				
1-baseline	none	none	1.08	7.8	.05	.024	13.82
2-baseline	none	none	1.03	9.5	.04	.015	13.64
3-controls	5 s delay	60 s	.59	5.2	.15	.025	13.87
4-controls	2 s delay	60 s	.42	5.5	.19	.013	13.56
5-controls	1 s delay	60 s	.35	5.2	.17	.014	13.71
6-controls	0 s delay	30 s	**.29**	5.1	.06	.013	13.64
7-defrost on	1 s delay	30 s	.38	6.9	.08	.012	13.17
8-defrost on	0 s delay	45 s	.32	6.4	.13	.013	13.25

As can be seen in Table 5.1-8, control test #6 provided a NMHC level that would have allowed the Trailblazer to comply with the proposed standard for the ≤ 6000 lbs GVWR class (i.e., 0.3g/mi). While this vehicle was tested as the lower GVWR class at 5000 lbs test weight, the Trailblazer also is sold as an over 6000 lbs. GVWR model that would have been tested at 5500 lbs. We believe that if tested at the higher weight, the emission results likely would not have increased much, reflecting a large margin (.2 g/mi) for this vehicle when certified to the heavier class. We recognize that manufacturers will need to account for a compliance margin, but we believe this vehicle can achieve a comfortable compliance margin for the more stringent standard (i.e., 0.3g/mi) with some additional minor calibration changes.

While emissions results for the 20˚ F cold CO test are reported as a weighted three-bag average, bag one (the first 505 seconds of the test) provides a better indication of emission reductions achieved with controls. Since almost all of the emissions at 20˚ F are emitted in the first few minutes of operation and all control changes were attempted only during the first minute of operation, Table 5.1-9 presents only the bag 1 emission results. This table highlights the emission reductions from the control changes by not diluting the improvements over the second and third phase (bag 2 and 3) of the emission test.

As observed below in Table 5.1-9, the level of reductions in emissions with the different control changes are more obvious as measured in the first phase of the test. NMHC, CO and PM reductions can be clearly seen from the results. NMHC and CO reductions occur with all the control attempts but achieve the best results with control test #6 and #8, in which secondary air injection was activated immediately upon engine cranking. PM reductions also follow similar behavior as NMHC but appear to be very sensitive to delayed secondary air injection.

Table 5.1-9. Trailblazer Test Configuration and 20° F FTP Phase 1 Only Results

Test Number	Air Injection	Elevated Idle & air bleed time	NMHC g/mi	CO g/mi	NOx g/mi	PM g/mi	Fuel Economy mi/gallon
1-baseline	none	none	5.18	27.3	.22	.055	11.55
2-baseline	none	none	4.92	31.7	.16	.040	11.47
3-controls	5 s delay	60 s	2.81	18.6	.72	.043	11.29
4-controls	2 s delay	60 s	1.96	15.0	.85	.033	11.30
5-controls	1 s delay	60 s	1.63	13.6	.81	.026	11.40
6-controls	0 s delay	30 s	1.34	13.3	.29	.022	11.45
7-defrost on	1 s delay	30 s	1.75	14.8	.35	.010	11.23
8-defrost on	0 s delay	45 s	1.47	13.2	.61	.022	11.27

While the emissions reductions were fairly substantial with the best control combination in test #6, we believe that even greater emission reductions can be achieved with more precise use of the secondary air system and additional control measures described earlier in the calibration and controls technology section. The ability to more precisely provide the ideal air-fuel mixture for the secondary air injection system likely would have resulted in faster catalyst light-off and subsequently even greater reductions in emissions, especially NMHC. Additionally, retarded timing was not tested due to the limited capability to modify engine operation. Typically this would further compound the rate of heating the catalyst, particularly on secondary air injection systems, and thus, would be expected as an additional opportunity to reduce NMHC.

5.1.2.2.2 Additional Tier 2 Vehicle Feasibility

We are entertaining expanding the feasibility testing to additional Tier 2 vehicles utilizing the technologies described earlier in the calibration and controls technology section. Any additional studies are contingent on our ability to access and modify these emission control technologies in the time window of this rulemaking.

5.2 Feasibility of Evaporative Emissions Standards for Vehicles

The proposed standards for evaporative emissions, which are equivalent to the California LEV II standards, are technologically feasible now. As discussed in Section VI of the preamble for today's proposed rulemaking, the California LEV II program contains numerically more stringent evaporative emissions standards compared to existing EPA Tier 2 standards, but because of differences in testing requirements, some manufacturers view the programs as similar in stringency. See Section VI.B.2.c of today's proposed rule for further discussion of such test differences (e.g., test temperatures and fuel volatilities). Thus, some manufacturers have indicated that they will produce 50-state evaporative systems that meet both sets of standards (manufacturers sent letters indicating this to EPA in 2000).[5, 6, 7] In addition, a review of recent model year certification results indicates that essentially all manufacturers certify 50-state evaporative emission systems.[8] Therefore, harmonizing with California's LEV-II evaporative emission standards would streamline certification and be an "anti-backsliding" measure – that is, it would prevent future backsliding as manufacturers pursue cost reductions. It also would codify the approach manufacturers have already indicated they are taking for 50-state evaporative systems.

References for Chapter 5

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[1] Memo to docket "Discussions Regarding Secondary Air System Usage at 20˚ F with European Automotive Manufacturers and Suppliers of Secondary Air Systems," December 2005.

[2] Meyer, Robert and John B. Heywood, "Liquid Fuel Transport Mechanisms into the Cylinder of a Firing Port-Injected SI Engine During Start-up," SAE 970865, 1997.

[3] For a more detailed description of these technologies see the Tier 2 final rule at 65 FR 6698-6822, February 10,2000, and Regulatory Impact Analysis Chapter IV: Technical Feasibility.

[4] Memo to docket "Discussions Regarding Secondary Air System Usage at 20˚ F with European Automotive Manufacturers and Suppliers of Secondary Air Systems," December 2005.

[5] DaimlerChrysler, Letter from Reginald R. Modlin to Margo Oge of U.S. EPA, May 30, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.

[6] Ford, Letter from Kelly M. Brown to Margo Oge of U.S. EPA, May 26, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.

[7] General Motors, Letter from Samuel A. Leonard to Margo Oge of U.S. EPA, May 30, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.

[8] U.S. EPA, Evaporative Emission Certification Results for Model Years 2004 to 2006, Memorandum to Docket EPA-HQ-OAR-2005-0036 from Bryan Manning, February 9, 2006.