

State of California  
AIR RESOURCES BOARD

EXECUTIVE ORDER D-384-5  
Relating to Exemptions Under Section 27156  
of the Vehicle Code

ENGELHARD CORPORATION  
DPX CATALYZED SOOT FILTER

Pursuant to the authority vested in the Air Resources Board (ARB) by Section 27156 of the Vehicle Code; and

Pursuant to the authority vested in the undersigned by Sections 39515 and 39516 of the Health and Safety Code and Executive Order G-45-9;

IT IS ORDERED AND RESOLVED: That installation of the DPX Catalyzed Soot Filter, manufactured by Engelhard Corporation of 101 Wood Avenue, P.O. Box 770, Iselin, New Jersey 08830-0770, has been found not to reduce the effectiveness of the applicable vehicle pollution control system, and therefore, the DPX Catalyzed Soot Filter is exempt from the prohibitions of Section 27156 of the Vehicle Code for installation on heavy-duty vehicles equipped with the diesel engines listed below.

This exemption is applicable to 1991 through 2000 model-year engines originally certified to meet a particulate matter emission standard of 0.10 grams per brake-horsepower-hour or lower. Use of the DPX Catalyzed Soot Filter requires that the diesel engines must be operated using diesel fuel with a maximum sulfur content of 50 parts per million by weight.

| Engine MY | Engine Make   | Engine Model                        | DPX Part No.                                  |
|-----------|---------------|-------------------------------------|---|
| 1991-2000 | Cummins       | B-Series, ISB (all horsepower)      | 000416088, 000416909,<br>000415808, 000416182 |
| 1993-2000 | Cummins       | M11, C-Series, ISC (all horsepower) | 000416088, 000416909,<br>000415808, 000416182 |
| 1998-2000 | Cummins       | ISM (all horsepower)                | 000416088, 000416909,<br>000415808, 000416182 |
| 1993-2000 | DDC           | Series 50 (all horsepower)          | 000416088, 000416909,<br>000415808, 000416182 |
| 1994-2000 | DDC           | Series 60 (all horsepower)          | 000415808, 000416650                          |
| 1994-2000 | International | 530E (all horsepower)               | 000416088, 000416909,<br>000415808, 000416182 |

This exemption is based on emission tests conducted by Engelhard Corporation with the DPX Catalyzed Soot Filter. Engelhard Corporation submitted the following results:

| No. | Test Engine |               |           | Percent Change in Emissions |     |     |      |
|-----|-------------|---------------|-----------|-----------------------------|-----|-----|------|
|     | MY          | Make          | Model     | THC                         | CO  | NOx | PM   |
| 1   | 1999        | Cummins       | ISB       | -63                         | -87 | 0   | -96  |
| 2   | 1998        | DDC           | Series 60 | -100                        | -96 | -6  | -99  |
| 3   | 1998        | International | 530E      | -100                        | -93 | -10 | -100 |

The test data show that the DPX Catalyzed Soot Filter does not adversely affect the exhaust emissions of the test engines. The same emission impact is expected when the DPX Catalyzed Soot Filter is installed on heavy-duty vehicles equipped with any of the engines listed above.

This Executive Order is valid provided that installation instructions for the DPX Catalyzed Soot Filter do not recommend tuning the vehicle to specifications different from those of the vehicle manufacturer.

Changes made to the design or operating conditions of the DPX Catalyzed Soot Filter, as exempt by the ARB, which adversely affect the performance of the vehicle's pollution control system, shall invalidate this Executive Order.

Marketing of the DPX Catalyzed Soot Filter using identification other than that shown in this Executive Order or for an application other than that listed in this Executive Order shall be prohibited unless prior approval is obtained from the ARB.

This Executive Order shall not apply to any DPX Catalyzed Soot Filter advertised, offered for sale, sold with, or installed on a motor vehicle prior to or concurrent with transfer to an ultimate purchaser.

This Executive Order does not constitute any opinion as to the effect the use of the DPX Catalyzed Soot Filter may have on any warranty either expressed or implied by the vehicle manufacturer.

No claim of any kind, such as "Approved by the Air Resources Board," may be made with respect to the action taken herein in any advertising or other oral or written communication.

In addition to the foregoing, the ARB reserves the right in the future to review this Executive Order and the exemption provided herein to assure that the exempted add-on or modified part continues to meet the standards and procedures of California Code of Regulations, Title 13, Section 2222, et seq.

THIS EXECUTIVE ORDER DOES NOT CONSTITUTE A CERTIFICATION, ACCREDITATION, APPROVAL, OR ANY OTHER TYPE OF ENDORSEMENT BY THE AIR RESOURCES BOARD OF ANY CLAIMS OF THE APPLICANT CONCERNING ANTI-POLLUTION BENEFITS OR ANY ALLEGED BENEFITS OF ENGELHARD CORPORATION'S DPX CATALYZED SOOT FILTER.

Violation of any of the above conditions shall be grounds for revocation of this Executive Order. The Executive Order may be revoked only after a ten-day written notice of intention to revoke the Executive Order, in which period the holder of the Executive Order may request in writing a hearing to contest the proposed revocation. If a hearing is requested, it shall be held within ten days of receipt of the request, and the Executive Order may not be revoked until a determination after a hearing that grounds for revocation exist.

Executed at El Monte, California, this 31<sup>ST</sup> day of May 2000.

Handwritten signature of Allen Brown in black ink, followed by the word "FOR" in capital letters.

R. B. Summerfield, Chief  
Mobile Source Operations Division

State of California  
AIR RESOURCES BOARD

EVALUATION OF ENGELHARD CORPORATION'S  
DPX CATALYZED SOOT FILTER  
FOR EXEMPTION FROM THE PROHIBITIONS OF VEHICLE CODE  
SECTION 27156 IN ACCORDANCE WITH SECTION 2222, TITLE 13 OF THE  
CALIFORNIA CODE OF REGULATIONS

May 2000

by

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(This report has been reviewed and approved for publication by the staff of the California Air Resources Board. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.)

## SUMMARY

Engelhard Corporation of 101 Wood Avenue, P. O. Box 770, Iselin, New Jersey 08830-0770 has applied for an exemption from the prohibitions of Section 27156 of the California Vehicle Code for their DPX Catalyzed Soot Filter. The DPX Catalyzed Soot Filter is designed for installation on heavy-duty vehicles equipped with various model Cummins Engine Company, Inc., Detroit Diesel Corporation, and International Truck and Engine Corporation diesel engines. This exemption is applicable to 1991 through 2000 model-year engines originally certified to meet a particulate matter emission standard of 0.10 grams per brake-horsepower-hour or lower. Use of the DPX Catalyzed Soot Filter requires that the diesel engines must be operated using diesel fuel with a maximum sulfur content of 50 parts per million by weight.

Based on the test data submitted by Engelhard Corporation, the staff concludes that the DPX Catalyzed Soot Filter will not adversely affect the exhaust emissions of the heavy-duty diesel engines for which the exemption is requested.

The staff recommends that Engelhard Corporation be granted an exemption for their DPX Catalyzed Soot Filter as requested and that Executive Order No. D-384-5 be issued.

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I. INTRODUCTION

Engelhard Corporation (Engelhard) of 101 Wood Avenue, P. O. Box 770, Iselin, New Jersey 08830-0770 has applied for an exemption from the prohibitions of Section 27156 of the California Vehicle Code for their DPX Catalyzed Soot Filter. The DPX Catalyzed Soot Filter is designed for installation on heavy-duty vehicles equipped with the following diesel engines:

- (1) 1991-2000 model-year Cummins B-series and ISB, all horsepower
- (2) 1993-2000 model-year Cummins M11, C-series, and ISC, all horsepower
- (3) 1998-2000 model-year Cummins ISM, all horsepower
- (4) 1993-2000 model-year DDC Series 50, all horsepower
- (5) 1994-2000 model-year DDC Series 60, all horsepower
- (6) 1994-2000 model-year International (Navistar) 530E, all horsepower

This exemption is applicable to 1991 through 2000 model-year engines originally certified to meet a particulate matter (PM) emission standard of 0.10 grams per brake-horsepower-hour (g/bhp-hr) or lower. Use of the DPX Catalyzed Soot Filter requires that the diesel engines must be operated using diesel fuel with a maximum sulfur content of 50 parts per million (ppm) by weight. This exemption includes five different DPX filter sizes designed for engines with rated horsepowers between 100 and 600. All of the filters are coated with catalyst formulation MEX-003.

Engelhard has submitted all the required information including emission test data, vehicle operating temperature data, in-use durability information, installation and maintenance procedures, and device identification label for evaluation.

## II. CONCLUSION

Based on evaluation of the test data submitted by Engelhard, the staff concludes that the DPX Catalyzed Soot Filter will not adversely affect the exhaust emissions of the heavy-duty diesel engines for which the exemption is requested.

## III. RECOMMENDATION

The staff recommends that Engelhard be granted an exemption as requested, permitting advertisement, sale, and use of their DPX Catalyzed Soot Filter on the 1991 through 2000 model-year heavy-duty diesel engines listed above.

## IV. DEVICE DESCRIPTION AND OPERATION

Engelhard's DPX Catalyzed Soot Filter is an exhaust emission control device designed primarily to reduce PM emissions from diesel engines. In general, it is installed in place of the original equipment manufacturer (OEM) muffler. The DPX filter consists of a cordierite wall-flow filter substrate coated with precious metal catalysts. The filter substrate is porous and has alternating cells which are plugged, forcing the exhaust gas to flow through the cell wall where the PM in the exhaust gas is captured or trapped. The captured PM is then burned off or oxidized by the catalyst coating, cleaning or regenerating the filter substrate.

The DPX filter contains 100 cells per square inch substrate canned in a 304



stainless steel shell of 17-millimeter wall thickness. The filter is loaded with catalyst formulation MEX-003 and is designed for use with diesel fuel with a maximum sulfur content of 50 ppm by weight. The five DPX filter sizes in the application are:

- (1) 10.5 inch diameter by 12 inch length: part no. 000416088 (100-300 hp)
- (2) 11.25 inch diameter by 12 inch length: part no. 000416909 (200-400 hp)
- (3) 11.25 inch diameter by 14 inch length: part no. 000415808 (200-500 hp)
- (4) 12 inch diameter by 15 inch length: part no. 000416650 (300-600 hp)
- (5) 12 inch major axis and 8 inch minor axis by 15 inch length: part no. 000416182 (100-400 hp)

For the DPX filter to operate properly, it must be designed to correctly match the specific engine and vehicle application. This entails sizing the filter based on engine-out emissions (model-year), exhaust flow rate (engine size and rated horsepower), engine exhaust temperature (vehicle application or duty cycle), manufacturer specified backpressure requirements, and availability of space for the filter. The critical issue in proper filter operation is its regeneration--the exhaust temperatures needed for regeneration must be achieved under various vehicle duty cycles. In general, the exhaust temperatures at which the rate of PM collection equals the rate of PM oxidation must be achieved for at least 40 to 50 percent of the duty cycle to prevent plugging.

The installation location of the DPX filter varies for different vehicle applications, but on the average, the distance between the exhaust manifold or the turbocharger and the filter inlet ranges from three to ten feet and may measure on the extreme from two to 20 feet. For vehicles with dual exhaust system, a DPX filter is installed on each of the exhaust outlets. The installation procedures for the DPX filter are similar to the removal and installation procedures for the muffler. Engelhard recommends that the

DPX filter be cleaned every 12 months by blowing compressed dry air through the filter to remove the lubricant and oil ash. Engelhard will provide the applicable installation instructions and maintenance procedures for the various engine and vehicle applications to the vehicle operator.

V. DEVICE EVALUATION AND DISCUSSION

To demonstrate that the DPX filter would not adversely affect exhaust emissions, Engelhard tested its filter on three different engines. Engelhard provided the following results:

| Test Engine |               |            | Test Fuel | Test Cycle | Emissions: Baseline/Modified |           |           |             |
|-------------|---------------|------------|-----------|------------|------------------------------|-----------|-----------|-------------|
| MY          | Make          | Model      | Sulfur    |            | THC                          | CO        | NOx       | PM          |
| 1999        | Cummins       | ISB*       | 3 ppm     | FTP**      | 0.30/0.11                    | 1.5/0.2   | 3.7/3.7   | 0.094/0.004 |
| 1998        | DDC           | Series 60^ | 15 ppm    | CSHVR^^    | 0.26/0.0#                    | 6.81/0.29 | 34.5/32.4 | 0.211/0.003 |
| 1998        | International | 530E~      | 15 ppm    | CSHVR^^    | 0.48/0.0#                    | 2.25/0.15 | 18.1/16.3 | 0.186/0.0#  |

Note: \* 5.9 liter, 250 horsepower      \*\* Emissions in grams per brake-horsepower-hour  
 ^ 12.7 liter, 430 horsepower      ^^ Emissions in grams per mile  
 ~ 8.7 liter, 275 horsepower      # Emissions were under the detectable limit of 0.000

Test No. 1

The Cummins ISB engine was tested on an engine dynamometer using the heavy-duty diesel transient federal test procedure as set forth in Title 40, Part 86 of the Code of Federal Regulations. One baseline emission test was conducted with the engine in the OEM configuration, and one modified emission test was conducted with the DPX filter. The test fuel had a sulfur content of 3 ppm by weight.

### Test No. 2

Five grocery trucks equipped with the DDC Series 60 engines were tested on a mobile chassis dynamometer operated by the West Virginia University (WVU) using the transient City-Suburban Heavy Vehicle Route (CSHVR). The CSHVR represents distance-based (city and highway) drive routes (speed ranges from 0 to 45 miles per hour) and is approximately 6.7 miles long. The baseline and modified emission results reported are averages of emissions from the five test vehicles. Each vehicle test included a minimum of three CSHVR test runs where the vehicle underwent a ten-minute warm-up before each test run (no cold-start run). It should be noted that two different sets of five test vehicles were used for the baseline and modified emission tests. The ten test engines and vehicles were determined to be nominally identical to each other. To facilitate collection of sufficient PM for measurement for the modified tests, each test run consisted of a double-length, or 13.4-mile, CSHVR drive cycle. The test fuel had a sulfur content of 15 ppm by weight.

### Test No. 3

Two school buses equipped with the International 530E engines were also tested on the mobile chassis dynamometer using the CSHVR test cycle. The baseline and modified emission results reported are averages of emissions from the two test vehicles. Each vehicle test included a minimum of three CSHVR test runs where the vehicle underwent a ten-minute warm-up before each test run (no cold-start run). The same two vehicles were tested for the baseline and modified emission tests. The two test engines and vehicles were determined to be nominally identical to each other. To facilitate collection of sufficient PM for measurement for the modified tests, each test run consisted of a double-length, or 13.4-mile, CSHVR drive cycle. The test fuel had a sulfur content of 15 ppm by weight.

## Emission Evaluation

PM removal from the exhaust stream is fixed by the physical characteristics of the filter medium and is relatively unaffected by engine operating conditions. The engines for which the exemption is requested have been certified to PM emission standards ranging from 0.05 to 0.10 g/bhp-hr. To demonstrate compliance with the emission requirements, Engelhard tested three engines, one from each manufacturer. All of the test engines were originally certified to meet the 0.10 g/bhp-hr PM emission standard, representing worst case in terms of engine-out PM emissions. The emission data showed that within the 3 and 15 ppm fuel sulfur content range, there was no adverse impact on total hydrocarbons (THC), carbon monoxide (CO), oxides of nitrogen (NO<sub>x</sub>), or PM emissions.

However, Engelhard has requested the exemption to include the use of a DPX filter on engines operated using diesel fuel with a maximum sulfur content of 50 ppm. Earlier studies have indicated that there is a direct relationship between PM emissions and fuel sulfur level. In catalyzed particulate filters such as the DPX filter, sulfur in the exhaust is oxidized by the catalyst to form sulfates which are measured as PM on the filter. As a result, higher sulfur content fuel will generate more sulfates and will require higher temperatures for filter generation. However, Engelhard has indicated that the DPX filter with the MEX-003 catalyst formulation has been designed specifically for use with diesel fuel containing 50 ppm or less sulfur. To support that within the 50 ppm fuel sulfur content, there would be no adverse emission impact, Engelhard provided the following test data:

| Test Engine |         |           | Test Fuel |            | Emissions: Baseline/Modified |         |          |             |
|-------------|---------|-----------|-----------|------------|------------------------------|---------|----------|-------------|
| MY          | Make    | Model     | Sulfur    | Test Cycle | THC                          | CO      | NOx      | PM          |
| 1999        | Cummins | ISB*      | 3 ppm     | FTP**      | 0.30/0.11                    | 1.5/0.2 | 3.7/3.7  | 0.094/0.004 |
|             |         |           | 15 ppm    | FTP**      | ^/0.12                       | ^/0.3   | ^/3.7    | ^/0.002     |
|             |         |           | 20 ppm    | FTP**      | ^/0.10                       | ^/0.3   | ^/3.7    | ^/0.005     |
| 1992        | Cummins | B-Series~ | 50 ppm    | MLTB~~     | 3.06/0.49                    | 3.0/0.4 | 10.7/9.9 | 0.557/0.046 |

Note: \* 5.9 liter, 250 horsepower  
 \*\* Emissions in grams per brake-horsepower-hour  
 ^ Baseline emissions were not available.  
 ~ 5.9 liter, 145 horsepower  
 ~~ Emissions in grams per kilometer;  
 The emissions were measured over the Millbrook London Transport Bus Cycle and are averages of two test runs. Two different vehicles were tested for baseline and modified emissions.

Testing on the Cummins ISB engine showed that with the increase in fuel sulfur content from 3 ppm to 15 and 20 ppm, there was little change in the modified THC, CO, NOx, and PM emissions. The changes in PM emissions may be attributed to test-to-test variability. Testing on the 1992 model-year Cummins B-series engine showed that even with the 50 ppm sulfur content fuel, there was no adverse impact on THC, CO, NOx, or PM emissions. The supporting data indicate that use of the DPX filter on engines operated using diesel fuel with a maximum sulfur content of 50 ppm does not cause any negative effect on exhaust emissions. The same emission impact is expected when the DPX filter is installed on all of the engines included in the exemption.

#### DPX Filter Regeneration

Once the PM is captured in the filter element, there must be catalyst "light-off" to burn off or oxidize the PM, regenerating the filter. The condition for catalyst "light-off" or filter regeneration varies with vehicle operating conditions (engine speed and load) and engine exhaust temperatures. Engelhard has indicated that to get sufficient

regeneration of the DPX filter (MEX-003 formulation for use with diesel fuel containing 50 ppm or less sulfur), the average temperature of the exhaust gas entering the filter must be at least 250 degrees Celsius ( $^{\circ}$  C). The average exhaust temperature required for regeneration may be lower for an engine and vehicle application with a higher peak operating temperature. For an application where the average exhaust temperature is below this threshold for a prolonged period of time, there may not be enough PM oxidation, and the filter may become plugged. This will lead to excessively high backpressure and may cause damage to the turbocharger and/or the engine. Such unfavorable temperature conditions may be encountered in a large engine operating under low load and/or in an engine operated under a duty cycle that results in low exhaust temperatures.

To demonstrate that the temperature condition for sufficient regeneration would be met for the engines for which the exemption is requested, Engelhard measured the exhaust gas temperatures of two engines during on-road vehicle operations that represent typical heavy-duty vehicle duty cycles. Engelhard provided the following results:

| Test Engine |      |           |          |                      | Application            | Exhaust Temperature ( $^{\circ}$ C) |         | % Time                            |
|-------------|------|-----------|----------|----------------------|------------------------|-------------------------------------|---------|-----------------------------------|
| MY          | Make | Model     | Size (L) | HP                   |                        | Minimum                             | Maximum | Temperature Over 250 $^{\circ}$ C |
| 1998        | DDC  | Series 60 | 12.7     | 430                  | Delivery Truck*        | 150                                 | 400     | 56                                |
| **          | DDC  | Series 50 | 8.5      | 250-350 <sup>^</sup> | City Bus <sup>^^</sup> | 200                                 | 425     | 73                                |

- Note:
- + All of the engines were tested with DPX filter, formulation MEX-003.
  - # The temperatures are stabilized operating temperatures. They were extracted from real-time temperature versus time graphs and are only estimates.
  - \* Temperatures were measured over a six-hour drive period.
  - \*\* Model-year information was not available.
  - <sup>^</sup> Horsepower information was not available and is estimated based on certification information.
  - <sup>^^</sup> Temperatures were measured over a five-hour drive period.

The temperature data showed that for the two vehicles, the operating exhaust temperatures were above the 250° C threshold for over 50 percent of the duty cycles. With respect to exhaust temperatures, the city bus represents one of the worst case conditions due to its frequent stop-and-go duty cycle, and under such a condition, Engelhard showed that the exhaust temperature criterion for regeneration is met.

To further illustrate that the DPX filter would operate properly on-road, Engelhard cited test programs in which numerous units are currently or have been operating without failure. Engelhard provided the following information to address the long-term operability of the DPX filter formulated for use with diesel fuel containing 50 ppm or less sulfur:

| Test Program               | No. of Units | Duration of Operation | Miles of Operation |
|----------------------------|--------------|-----------------------|--------------------|
| ARCO Tanker Trucks         | 5            | 5 months              | *                  |
| LA Sanitation Trucks       | 5            | 1 year                | *                  |
| Paris/Renault              | 700          | *                     | 94,000             |
| Ralphs Grocery Trucks      | 5            | 3 months              | *                  |
| San Diego School Buses     | 5            | 8 months              | 20,000             |
| Sweden/UK Buses and Trucks | *            | 1-2 years             | *                  |

Note: \* Data were not available.

The displacement and horsepower rating of the engines for which the exemption is requested range from 5.9 to 14.0 liters and 195 to 575 horsepower, respectively. The staff concludes that the test engines above are representative of the engines included in the exemption application and that similar emission and temperature results will be achieved for the remaining engines and vehicle applications. Based on the findings above, the staff concludes that Engelhard's DPX Catalyzed Soot

Filter will not have any adverse impact on the exhaust emissions of the engines included in the exemption.