Stationary Reciprocating Internal Combustion Engines
Technical Support Document
for NOx SIP Call

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Doug Grano/Bill Neuffer
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Introduction

Large[1] stationary reciprocating internal combustion engines (IC engines) are primarily used in pipeline transmission service and some are used in field storage pumping operations. Gas turbines are also used in these operations. On a capacity basis the IC engines and turbines in pipeline transmission service are about evenly divided.[2,3] The uncontrolled emission rate from IC engines is about ten times greater than the uncontrolled emission rate for gas turbines.[4] That is, uncontrolled NOx emissions from large IC engines are greater than 3.0 lbs/mmBtu while uncontrolled NOx emissions from gas turbines are about 0.3 lbs/mmBtu.

In the NOx SIP call, EPA determined that NOx emissions from large gas turbines (and large boilers) can be decreased by highly cost-effective controls to an average emission rate of 0.15-0.17 lbs/mmBtu[5]. As part of the NOx SIP call rulemaking, EPA stated that highly cost-effective controls[6] are available to reduce emissions from large IC engines by 90% from uncontrolled levels (i.e., to about 0.3 lbs/mmBtu)[7]. The DC Circuit Court in a March 3, 2000

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[1]Large, as defined in the NOx SIP call (63 FR 57356, October 27, 1998), means an IC engine which emitted, on average, greater than 1.0 ton of NOx/day during the 1995 ozone season.

[2]Alternative Control Techniques (ACT) document, "NO_x Emissions from Stationary Reciprocating Internal Combustion Engines," (ACT document for IC engines) EPA-453/R-93-032, July 1993, page 3-15. The ACT documents were required by section 183(c) of the Clean Air Act Amendments of 1990 and subject to public review prior to publication.

[3]"Retrofit NOx Control Technologies for Natural Gas Prime Movers," Gas Research Institute, March 1994, GRI-94/0329, page 2-4, (1994 GRI report).

[4]See, for example, data from EPA's AP-42, Emission Factors document, Table 3.2-1, 10/96.

[5]See NOx SIP call final rule and support material (63 FR 57356, October 27, 1998).

[6]"Highly cost-effective controls" are defined in the NOx SIP call as controls which are less than $2000/ton of ozone season NOx reduction in 1990 dollars (63 FR 57356, October 27, 1998).

[7]The discussion below uses "grams/brake horsepower-hour" or g/bhp-hr rather than lbs/mmBtu since the former is the convention for the industry. The uncontrolled estimate of 3.0 lbs/mmBtu (from AP-42, October 1996) corresponds to about 11.3 g/bhp-hr. The 1993 ACT document for IC engines estimates average uncontrolled emissions at 5.13 lb/mmBtu or 16.8 g/bhp-hr.

decision ruled that EPA had not provided adequate notice and opportunity to comment on the IC engines control level EPA used to determine the State NOx budgets for the final rule. In the February 22, 2002 proposed rulemaking, EPA proposed that highly cost-effective controls are available to reduce emissions from large IC engines by 82-91% (see 9-5-00 TSD).

In the October 27, 1998 final NOx SIP call rule, EPA identified about 300 large IC engines. Subsequently, EPA received information from commenters seeking to make changes to the emissions inventory. The EPA made corrections and now includes 180 IC engines in its final NOx SIP call budget[8]. The vast majority are natural gas-fired engines.

An August 2000 report by the Pechan-Avanti Group estimates the control costs and NO_x emission reductions for large IC engines affected under the NOx SIP Call. The report provides information about the universe of potentially affected IC engines, control cost modeling methods, scenario analyses, and caveats and uncertainties associated with this analysis.[9] For the control range of 82-93%, the report estimates the average cost effectiveness to be $520-549 per ton.[10] A September 2000 report by EC/R also contains estimates of the control costs and NO_x emission reductions for large IC engines. The EC/R report estimates the average cost effectiveness for IC engines 2,000-8,000 hp to be $420-840 per ton.[11]

Large IC Engines Except Natural Gas-Fired Lean-Burn

[8]Federal Register of March 2, 2000 (65 FR 11222).

[9]"NOx Emissions Control Costs for Stationary Reciprocating Internal Combustion Engines in the NOx SIP Call States" prepared by Pechan-Avanti Group for EPA, August 11, 2000 (Pechan IC engines report).

[10] Annual (capital and operating) costs in 1990 $ per ozone season tons reduced. For SCR and NSCR, the annual operating costs are for the ozone season only. LEC controls are assumed to operate year-round, thus, year-round operating costs are included. For comparison to other recent EPA rulemakings, the costs can be escalated to 1997 $ using a factor of 1.21, resulting in $629-664/ton.

[11]"Stationary Reciprocating Internal Combustion Engines: Updated Information on NOx Emissions and Control Techniques," EC/R Incorporated, September 1, 2000.

In the initial 1998 NOx SIP call budget calculation, EPA divided IC engines into 4 categories and assigned a 90 percent emissions decrease, on average, to each category. This reflected non-selective catalytic reduction (NSCR) for rich-burn engines and selective catalytic reduction (SCR) for diesel and dual-fuel engines. For all large IC engines, except natural gas-fired variable load lean-burn engines (see discussion below), EPA continues to believe that 90% control is achievable through NSCR or SCR and is highly cost-effective. This is demonstrated, for example, in the 1993 ACT document for IC engines and in the 9-1-00 EC/R report which updates information on NOx emissions and control techniques for IC engines.[12] In addition, the following sources provide supporting information (see docket A-96-56):

* "NOx Reduction Technology for Natural Gas Industry Prime Movers,"Acurex Corporation for Gas Research Institute, August 1990.

* "Retrofit NOx Control Technologies for Natural Gas Prime Movers," section 4, Gas Research Institute, March 1994, GRI-94/0329.

* "Assessment of Control Technologies for Reducing Nitrogen Oxide Emissions from Non-Utility Point Sources and Major Area Sources," Final Ozone Transport Assessment Group (OTAG) Policy Paper, July 1996; Chapter 5, Appendix C, to the OTAG Final Report, http://www.epa.gov/ttn/rto/otag/index.html.

* "Emission Control Technology for Stationary Internal Combustion Engines," Status Report, Manufacturers of Emission Controls Association, July 1997.

* "California Environmental Protection Agency/Air Resources Board - Determination of Reasonably Available Control Technology and Best Available Retrofit Control Technology for Stationary Spark- Ignited Internal Combustion Engines," November 2001

* CAPCOA/ARB - "Determination of Reasonably Available Control Technology and Best Available Retrofit Control Technology for Stationary Internal Combustion Engines - Draft," December 3, 1997

Natural Gas-Fired Rich-Burn Engines

Non-selective catalytic reduction (NSCR) provides the largest NO_x percent reduction of all the highly cost effective technologies considered in the ACT document as it is capable of providing a 90 to

[12] "Stationary Reciprocating Internal Combustion Engines: Updated Information on NOx Emissions and Control Techniques," EC/R Incorporated, September 1, 2000 (EC/R report on IC engines).

98 percent reduction in NO_x emissions.[13] The EC/R report on IC engines states that 95 percent control is generally achievable through the use of NSCR on rich-burn IC engines.[14] The time required from cost proposal to field installation of NSCR is less than 11 months.[15]

Diesel and Dual Fuel Engines

For diesel and dual fuel engines, SCR provides the largest NO_x reduction of all highly cost effective technologies considered in the 1993 ACT document. It is reported to provide an 80-90 percent reduction in NO_x emissions.[16] More recent reports state that NO_x emissions can be reduced by 90% or more by SCR.[17, 18, 19] Therefore, EPA estimates NOx reductions for these engines at 90% on average. The EPA estimates the diesel/dual fuel IC engines are a very small part of the large IC engines population in the NO_x SIP call. There are only 5 large diesel IC engines identified in the SIP call jurisdictions, some of which may be capable of dual fuel operation.

Natural Gas-Fired Lean-Burn IC Engines

Uncontrolled Emission Rate

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[13]ACT document for IC engines, Tables 2-2 and 2-12.

[14]EC/R report on IC engines, section 4.3.4.

[15]Telephone records by Bill Neuffer, EPA, dated 5-19-00 and 5-24-00; conversations with a regulatory agency representative, an operator of the control equipment and an equipment vendor.

[16]ACT document for IC engines, Tables 2-8, 2-14 and 2-15.

[17]"Emission Control Technology for Stationary Internal Combustion Engines," Status Report by Manufacturers of Emission Controls Association, July 1997, page 7 (1997 MECA report).

[18]"CAPCOA/ARB - Draft - Determination of Reasonably Available Control Technology and Best Available Retrofit Control Technology for Stationary Internal Combustion Engines," December 3, 1997, page 29.

[19]EC/R report on IC engines, section 4.2.4.

The EPA examined data on large natural gas fired lean burn engines obtained from the pipeline industry, collected by the Agency, and contained in the ACT document. These include data from large natural gas fired lean burn engines covered by the SIP call. The EPA believes the data supports the16.8 g/bhp-hr value proposed on February 22, 2002, as described below.

One of the data sets that supports the 16.8 g/hp-hr level is additional data developed by pipeline industry members that is based on a survey of LEC retrofit installation in SIP call States. In a November 20, 2000 letter from Tennessee Gas Pipeline & Transcontinental Gas Pipe Line to the Ozone Transport Commission, survey data presented in Attachment A of the letter include both pre-LEC and post-LEC data for 86 engines in NOx SIP call States. Most of the engines are 2000 hp or greater. Table 1 of the letter summarizes the data and states that the average uncontrolled NOx emissions level for these 86 engines is 16.8 g/bhp-hr. The range of uncontrolled values is 7.0-25.8 g/bhp-hr. Considering only those engines greater than or equal to 2,000 hp, there are 66 engines with an average uncontrolled emissions rate of 18.2 g/hp-hr (see table below).

From Attachment A (engines > or = 2,000 hp):

Location	Engine	Uncontrolled(g/bhp-hr)
AL-Station 110	C-B V-250-16 (2)	23.9
MD -Station 190	Clark TCV-10;16	14.2, 12.2
NJ - Station 505	I-R 412 KVS (8)	21.8
NY- Station 237	Clark TCV-10	9.0
NY -Station 241	Clark TLA-10(2 engines at)	7.0
NY- Station 224	I-R KVS 412(4)	16.0
NY - Station 237	I-R KVS-412 (2)	16.0
PA- Station 219	C-B GMV-10(2)	16.0
PA - Station 307	Clark TCV-10	9.0
PA- Station 307	I-R KVS-412 (4)	16.0
PA - Station 219	C-B V-250-16	11.0
PA- Station 200	Clark TLA-6 (4)	14.5
PA -Station 200	Clark TCV-10(2)	9.0
PA- Station 200	Clark TCV-16	12.0
PA- Station 515	C-B GMWC-10(3)	25.8
PA - Station 535	I-R 36 KVS	18.6
PA - Station 520	I-R 412 KVS (5)	22.4
PA- Station 535	I-R 512 KVS (3)	17.8-2; 17.2
PA- Station 515	C-B V-250-10 (2)	23.3
PA- Station 195	C-B V-250-12 (2)	18.1
TN - Station 87	C-B V-250-16	11.0
TN -Station 2101	I-R KVS-412	16.0
TN- Station 2101	C-B V-250-8	18.0
VA - Station 180	Clark TCV-10 (3)	12.0

VA - Station 185	I-R 412 KVS (10)	22.4

Attachment B to the same 11-20-00 letter summarizes pre-LEC and post-LEC data for 20 engines.(see table below). Fourteen of the 20 engines are 2,000 hp or greater. The letter states that the average uncontrolled NOx emissions for the 20 engines is 14.1 g/bhp-hr and the range of uncontrolled values is 7.0-18.0 g/bhp-hr. Considering only the engines from this data set greater than or equal to 2,000 hp, the average uncontrolled emissions for these engines is also14.1 g/hp-hr.

From Attachment B (engines > or = 2,000 hp):

Station	Engine	Uncontrolled(g/hp-hr)
NY- Station 237	Clark TCV-12	9.0
NY- Station 241	Clark TLA-10 (2 engines)	7.0
NY- Station 237	I-R KVS-412	16.0
NY- Station 224	"	16.0
NY- Station 237	"	16.0
NY- Station 224	"	16.0
PA- Station 307	" (4 engines)	16.0
PA- Station 219	C-B V-250-16	11.0
TN- Station 87	C-B V-250-16	18.0
TN- Station 2101	C-B V-250-8	18.0

Consolidated Natural Gas Service Company, a major pipeline company, also sent a letter, dated 11/22/00 to the Ozone Transport Commission (OTC) concerning the OTC's development of a set of model NOx rules. The attachment to Dominion's 11-22-00 letter to OTC, contains uncontrolled and RACT emission rates for 62 engines retrofit with LEC (see Table 1). The average uncontrolled emission rate taken into consideration all 62 engines from this data set is 17.6 g/bhp-hr. Considering the average emissions for each of the 18 models gives 17.2 g/bhp-hr. Although these engines are "major" sources since they are subject to RACT, it is not clear if all are "large" engines with respect to the NOx SIP call.

Table 1. Uncontrolled Emissions - Dominion's 11-22-00 Letter

Number of Engines	Engine Model	Uncontrolled NOx emissions (g/hp-hr)
2	Ajax DPC-600	15.5
5	Clark HBA-5T	23
6	Clark HLA-8	27
5	Clark TLA-6	16
3	Clark TLA-6	16
2	Clark TLA-6	16
5	Clark TLA-6	16
2	Clark TCV-10	16
3	Clark TLA-10	16
4	Clark TCV-10	16
2	Cooper 14W330	13
5	Cooper GMVC-6	11
3	IR 36 KVS-FT	20
1	IR 48 KVS-ET	20
3	IR 103 KVG-ML	16
3	IR 104 KVG-LL	16
3	IR 512 KVS-FT	16
5	IR 512 KVS-ET	20
Total: 62 engines		Average: 17.6

EPA collected additional test data to better determine controlled and uncontrolled emission levels from the current population of large engines in the NOx SIP call area. The data were placed in the docket and the uncontrolled emission rate data are summarized in Table 2. The average uncontrolled NOx level from this set of 42 test values is 16.7 g/bhp-hr, nearly identical to the proposed level of 16.8 g/bhp-hr.

Table 2. Uncontrolled Emissions - Additional Test Data - SIP Call Area

Engine Model	Uncontrolled NOx emissions (g/hp-hr)	Location	Reference
CB GMW	20.6	GA Transco Station 120	5-22-02 fax from EPA Region 4
CB GMW	20.1 (avg. 6 tests)	TX Transco Station 40	6-3-02 e-mail from TNRCC
CB GMW-6TF	17.4	KY Texas Gas	4-10-02 e-mail from Jon Trout
CB GMW-8	14.5	TN Tenneco Station 87	6-2-02 e-mail from EPA Region 4
CB V-250	18.3	PA Transco Station 195	6-28-02 e-mail from State of PA
CB V-250	23.3	PA Transco Station 515	6-28-02 e-mail from State of PA
CB 8V-250	16.9	TN MW Station 2101	6-2-02 e-mail from EPA Region 4
CB 16V-250	18.3	TN Tenneco Station 87	6-2-02 e-mail from EPA Region 4
CB 16V-250	23.9	AL Tenneco Station 110	5-22-02 e-mail from EPA Region 4
CB GMWA	13.6	KY Tenn. Gas Jefferson Co.	4/10/02 email from Jon Trout
CB GMWA-8	16.0	TX Vidor	6-3-02 e-mail from TNRCC
CB GMWA-8	20.9	TN Coastal Cottage Grove	1-5-01 letter Coastal to State of TN
CB GMWC	25.8	PA Transco Station 515	6-28-02 e-mail from State of PA
CB GMWC-10	32.4	TN Tenneco Station 87	6-2-02 e-mail from EPA Region 4 and 2-21-95 letter from Tenneco to TN

CB GMVA	18.2	CA Mobil Rincon	EC/R 9-00 report, p.30
CB W330	12.5	NY Tenn. Gas Station 241	5-29-02 e-mail from EPA Region 2
Clark HLA	27	PA Dominion South Bend	6-28-02 e-mail from State of PA
Clark HBA-8T	8.4 (avg of 7 tests)	MD Transco Station 190	1995 test data sent by Maryland - 9/02
Clark TCV-10 TCV-16	8.4 11.3	Transco Station 200	6-28-02 e-mail from State of PA
Clark TCV-12	13	NY Station 237	5-29-02 e-mail from EPA Region 2 (OEM estimate)
Clark TCVC-20	10.1	TN ANR Cottage Grove	6-2-02 e-mail from EPA Region 4
Clark TCVD-16	12.8 13.0	TN Coastal Cottage Grove	6-1-02 e-mail from EPA Region 4 and 10-5-00 letter Coastal to TN
Clark TLA	9.6		10-92 Acurex report to GRI
Clark TLA	13	NY Tenneco Syracuse	5-29-02 fax from EPA Region 2
Clark TLA	9.8	MI Consumers Energy Oversiel	6-7-02 e-mail from State of Michigan
Clark TLA	13.4 13.1 16.1 15.7	NY Algonquin Stony Point (4 engines)	5-24-02 fax from EPA Region 2
Clark TLA	13.3 11.5 15.0	MD Transco Station 190 (3 engines)	Information sent by Maryland - 8/02
IR KVS-412	8.1		10-92 Acurex report for GRI
IR KVS	24.4	PA Transco Station 520	6-5-91 letter from Transco

IR KVS	25	NY Tenneco Clymer Station	5-29-02 fax from EPA Region 2
IR KVS	25	NY Tenneco Clifton Springs	5-29-02 fax from EPA Region 2
IR KVS	24.8 (1 test result for 2 engines)	TN Tenneco Station 2101	6-02-02 e-mail from EPA Region 4 and 2-21-95 letter from Tenneco to TN
IR KVS	19.4	TX Vidor Station	6-3-02 e-mail from TNRCC
IR KVR	8.2	TX Motiva	6-3-02 e-mail from TNRCC
IR KVT-512	21.4	TN Tenneco Station 2101	6-02-02 e-mail from EPA Region 4 and 2-21-95 letter from Tenneco to TN
	16.7 Average		

Uncontrolled emissions data are also reported in chapter 3 of the EC/R report,[20] as summarized below. The data show a wide range of values, due in part to the inclusion of some engines considered by the EC/R report as being controlled.

> A 1994 Gas Research Institute (GRI) report indicated separate emission levels for 2 stroke (12.5 g/bhp-hr) and 4 stroke-engines (13.2 g/bhp-hr). Test results for 2 stroke engines range from 2-29 g/bhp-hr. For 4-stroke engines, results range from 1-25 g/bhp-hr. The report noted that the higher end 25-29 g/bhp-hr was representative of the older uncontrolled engines (these are the engines most likely affected by the SIP Call). Engines equipped with turbochargers and intercoolers as original design features typically emit 7-15 g/bhp-hr. The lower end of the range often reflects the newer lean burn engines which achieve 1-2 g/bhp-hr. Thus, the average emission levels presented in this GRI report were calculated including some engines considered controlled for purposes of the EC/R report.
>
> In the AP-42 (10/96) document, uncontrolled emissions are reported for 2-stroke engines at 10.9 g/bhp-hr and for 4-stroke at 11.8 g/bhp-hr. This report uses many of the same test data references as 1994 GRI report. The EC/R report states that it appears likely the uncontrolled data include test reports from newer lean-burn engines that would be considered controlled.

[20]"Stationary Reciprocating Internal Combustion Engines: Updated Information on NOx Emissions and Control Techniques," EC/R Incorporated, September 1, 2000 (EC/R report on IC engines).

In the AP-42 (1997 draft revision) document, uncontrolled emissions for 2 stroke are 12.2 g/bhp-hr and 15.0 g/bhp-hr for 4-stroke. This is based on 38 tests for 2-stroke and 18 tests for 4-stroke. The EC/R report notes that some lean burn engines in this database are actually controlled emissions by LEC technology.

A 1996 GRI report includes data on six 2 stroke engines representing 5 models. Each engine was tested 2-5 times. The 2-stroke engine averages ranged from 4.9 - 20.8 g/bhp-hr and the 4-stroke engine averages ranged from 7.0 g/bhp-hr - 22.0 g/bhp-hr. The test data were more concentrated towards the lower end of each range.

A 1998 GRI report includes data from a Cooper Z-330 engine that had not been retrofitted with Clean Burn to be up to 24 g/bhp-hr.[21] Emissions from 2 other models were reported to range from 6-13 g/bhp-hr and 11.5 for another model.

Uncontrolled 1995 test data from a PG&E site for 2 Cooper Bessemer W-330 models is reported to be 18.9 and 16.7 g/bhp-hr. (EC/R reference 9, page3-14, letter and attachments from Carol Burke, PG&E to W. Neuffer - 2/3/00.)

Test data from So Cal Gas is reported for 2 Ingersoll Rand 412KVS models to be 21.4 and 17.0 g/bhp-hr. (Reference page 3-4, EC/R report.)

A 1990 GRI report stated uncontrolled emissions for lean and rich burn to range from 7-26 g/bhp-hr.

A 1992 paper prepared by Cooper for Society of Petroleum Engineers states that, prior to regulation, for both lean and rich burn engines, NOx emissions range from 10-20 g/bhp-hr.

A 1997 Manufacturer of Emission Control Association report states that typical NOx emissions for engines that operate slightly lean of stoichiometric is 18 g/bhp-hr.

A 1994 Oil and Gas Journal article on natural gas compressor station engines indicates that typically emissions are 15 g/bhp-hr, for both lean and rich burn engines.

During a visit to a So Cal Gas plant, a representative of the plant stated that for a DeLaval HVA16C engine, uncontrolled emissions were 28 g/bhp-hr prior to installing LEC.

Product literature from Ajax Superior Division of Cooper Energy indicates uncontrolled

[21]"NOx Control for Two-Cycle Pipeline Reciprocating Engines" prepared by Arthur D. Little, Inc. for GRI, December 1998, figure 1-1.

emissions from an Ajax 2-stroke lean-burn engine (110 -720 bhp) range from 3.0-9.5 g/bhp-hr and from a Superior 4-stroke lean-burn engine (825-2650 bhp) range from 15.0 - 22.1 g/bhp-hr.

As described in the ACT document, uncontrolled emission levels were provided to EPA by several engine manufacturers. These emission levels were tabulated and averaged for engines with similar power ratings. Most manufacturers provided emission data only for current production engines, but some included older engine lines as well. For lean burn engines, the average ranges from 7.9-18.6 g/hp-hr. The 7.9 g/hp-hr represents the smallest engine category and is considerably lower than all the other lean burn engines size categories. As can be seen from the data below, there is considerable agreement in the value for the larger engines, with a average range of 16.5-18.6. This is significant because the SIP call specifically addresses large engines.

From Table 4-1 - ACT Document

Lean burn engines (g/bhp-hr)[22]

Size (HP)	No. of engines in data base	Highest	Lowest	Average
0-400	7	17.5	3.0	7.9
401-1,000	17	27.0	` 15.5	18.6
1,001-2,000	43	27.0	14.0	17.8
2,001-4,000	30	27.0	10.0	17.2
4,001+	25	17.5	10.0	16.5

There are several reasons to use the ACT document data:

*Using the applicable ACT document rather than AP-42 is consistent with our treatment of other non-EGU source categories, including glass, process heaters, iron & steel, and other industrial source categories in the NOx SIP call rulemaking.

*The ACT document provides a comprehensive look at the IC engine class and has the advantage of using a consistent data set for uncontrolled emissions, costs, and controls.

*If we used AP-42 uncontrolled numbers, it would be logical to use the AP-42 controlled numbers. However, the AP-42 controlled data set is limited in terms of technologies considered, costs, and expected decreases in emissions.

[22]From Table 4-1 - ACT Document.

*The ACT document uses a large data set from which to draw conclusions.

*ACT test data are available in several horsepower size categories; this is important since EPA chose to not calculate emission reductions from the smaller IC engines. The 16.8 g/bhp-hr appears to be more representative of larger engines, which are the engines affected by the NOx SIP call.

EPA also examined the available data separately for 2- and 4-stroke engines. As shown in Table 3, the test data for the large IC engines in the SIP call area indicate uncontrolled levels of 16.4 and 18.9, respectively, for the 2- and 4-stroke engines. Using information from the pipeline industry that about 85% of the engines in the SIP Call area are 2-stroke, the weighted average of the 16.4 and 18.9 values is 16.8, identical to EPA's proposed value.[23] EPA believes these data support the 16.8 value proposed by EPA.

Table 3. Uncontrolled Emissions - 2-Stroke; 4-Stroke

Data Source	2-Stroke Average Emission Rate (# engine tested)	4-Stroke Average Emission Rate (# engine tested)
Attachment A	15.7 g/hp-hr (28)	19.7 g/hp-hr (37)
Attachment B	11.7 " (6)	16.0 " (8)
Dominion	17.6 " (44)	18.0 " (18)
Additional Tests	16.1 " (35)	20.1 " (9)
Totals	16.4 " (114)	18.9 " (76)

In addition, EPA reviewed the data used to update AP-42. In order to focus on the type of engines addressed in the NOx SIP call, EPA examined test data from those engines greater than 2,000 HP operating at greater than 90% load. As a result, the average emission rate is: 12.2 grams. Further, if we remove 2 extremely low values–which probably represent reduced engine emissions due to turbocharging [2.2 and 6.3 grams]–the average is 14.9 grams. The group of large engines in this database represents only 2 engine models and 8 tests; both models are 4-stroke engines. The data are summarized below (NO_x emissions in this database were given in ppm NO_2 @ x% oxygen; values were converted to ppm NO_2 @ 15% oxygen and then converted to g/hp-hr by dividing by 70).

[23]For large lean-burn IC engines in the NOx SIP Call states, 2-stroke engines represent 83% of the total large engines and 85% of the total large engine horsepower. (From INGAA's April 22, 2002 comments, pages 2 and 10.)

The engines considered were:

29.33x -	Cooper Bessemer LSV-16 - 4,200 HP	- 13.1 g/hp-hr
29.34x -	" " " "	- 12.2 g/hp-hr
29.35x -	" " " "	- 6.3 g/hp-hr
29.36x -	" " " "	- 2.2 g/hp-hr
29.37x -	" " " "	- 9.6 g/hp-hr
29.38x -	" " " "	- 11.2 g/hp-hr
29.40x -	Ingersoll-Rand KVS - 412 - 2,000 HP	- 20.8 g/hp-hr
29.41x -	" " " " - 2,000 HP	- 22.3 g/hp-hr

The data in the 7-00 AP-42 update do not differentiate between uncontrolled lean-burn engines and engines that may be turbocharged. Thus, the average "uncontrolled" emissions reported may include some engines with lower NOx emissions due to the turbocharging. See footnotes "(a)" to Tables 3.2-1 and 3.2-2 in the 7-00 AP-42 document identifying this concern. It is important to note that essentially all modern engines above 300kW are turbocharged to achieve higher power densities (Energy Nexus Group, Inc, p16, Feb.2002). The effect of turbocharging is to increase the air/fuel ratio, which will lower the NOx emissions. Thus, the AP-42 data (2002 document) appear to reflect a newer engine population with a lower average emission rate which may not be representative of the older SIP call population.

In summary, based on the ACT data, the data contained in the industry letters to OTC, and data EPA recently collected, there is considerable agreement/support with the 16.8 g/bhp-hr uncontrolled emission rate value EPA proposed.

Selective Catalytic Reduction

Information received by EPA from the natural gas transmission industry after publication of the NOx SIP Call final rule in 1998 indicate that most, if not all, large natural gas-fired lean-burn IC engines in the SIP Call region are in natural gas distribution and storage service and that these engines experience frequently changing load conditions. According to the industry, these conditions make application of SCR infeasible. The industry also stated that low emission combustion (LEC) technology is a proven technology for natural gas-fired lean-burn engines, while SCR is not.[24]

Regarding variable load operations, EPA's ACT document states that little data exist with which to evaluate application of SCR for the lean burn, variable load operations. More recent information indicates that application of SCR on variable load engines experienced problems in earlier applications but that vendors of SCR systems believe they have corrected the earlier problems with a

[24]For example, November 30, 1998 letter from Lisa Beal, INGAA, to docket A-98-12 (docket # III-D-53) and February 16, 1999 memo from Lisa Beal, INGAA, to Tom Helms, EPA.

new generation of the SCR technology.[25] However, SCR still remains to be widely demonstrated in the United States on lean burn IC engines in variable load operation. With the understanding that these large IC engines are in variable load operations, EPA believes there is an insufficient basis currently to conclude that SCR is an appropriate technology for the large variable load lean-burn engines. Therefore, EPA no longer believes that SCR is a highly cost-effective control technology for the natural gas- fired lean-burn IC engines.

Emission Rate with Low Emission Combustion (LEC) Technology

The industry and EPA agree that low emission combustion (LEC) technology is a proven technology for natural gas-fired lean-burn engines.[26] The ACT for IC engines and other documents also indicate that LEC technology is appropriate for lean-burn engines, continuous or variable load, and is highly cost effective. The EPA proposed that application of LEC would achieve NO_x emission levels in the range of 1.5-3.0 g/bhp-hr. This is an 82-91 percent reduction from the average uncontrolled emission levels reported in the ACT document and discussed above. IC engine manufacturers will typically guarantee the LEC performance to be 3.0 g/bhp-hr or less.[27]

1. Data on large IC engines with LEC technology

In 2002 EPA collected additional data on emission rates of lean burn engines that have been retrofitted with LEC. These engines had been identified as being retrofitted with LEC in Interstate Natural Gas Association of America's (INGAA) April 22, 2002 comments on the proposed Phase 2 SIP Call. Also, earlier emission test results had been obtained for several engines retrofitted with LEC including 7 Clark TLA-6 (2,000 HP) engines at Southern Cal Gas's Newberry Springs Station. Three emission tests were performed on each of the 7 engines. The 3-test averages range from 0.8 - 1.7 g/bhp-hr. Also, a Cooper Bessemer GMV-6 located at Kittanning, New York was retrofitted with LEC and tested by GRI. The 3 emission test results were 1.4, 1.8 and 2.5 g/bhp-hr (average - 1.9 g/bhp-hr). Also, emission test data were obtained from several state agencies. The results for all these engines are summarized in Table 4.

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[25]EC/R report on IC engines, section 4.2.

[26]For example, December 1, 1998 letter from INGAA to EPA docket, February 16, 1999 memo from INGAA to Tom Helms, EPA, and April 26, 2002 comment letter from Kinder Morgan (Natural Gas Pipeline Company of America).

[27]From Copper-Bessemer, a reasonable level of performance expected to be achieved by LEC retrofits is 3 g/hp-hr. According to another major vendor (Dresser- Rand/Clark), LEC has no problem meeting the 3.0 g/hp-hr level even for Worthington engines. See docket at XII-E-14 and XII-E-15.

Table 4. Large IC Engines Tested with Retrofit LEC Controls

Engine Model	Number of engines tested	Test Results (g/bhp-hr)	% of total units in the SIP Call Area
Clark BA-8T	3	1.3, 3.1, 3.2	1
Clark HLA	6	1.7, 1.9,2.4, 2.5,2.7, 2.8 (Avg - 2.3)	5
Clark TLA	20	0.4- 4.0 (others - 0.5(2) 0.8. 0.9(2), 1.0, 1.1, 1.2, 1.3(2), 1.4 (2), 1.7,1.9, 2.3, 2.4(2), 2.9) Avg - 1.5	1
Clark TCV	6	1.4-3.6(others - 2.5, 3.0, 3.3,3.5) Avg- 2.9	18
Cooper-Bessemer(C-B) GMW	2	0.7, 4.3	17
C-B V-250	8	1.6 - 3.4(2) (others - 2.6, 2.8; 3.0, 3.2, 3.3) Avg - 2.9	12
C-B GMWA	1	0.6	8
C-B GMWC	3	3.1(3 engines tested)	6
C-B GMVA	2	0.5 ,3.3 Avg - 1.9	2
C-B 12V-275	2	1.3, 3.1	0
C-B 8Q155L	1	1.9	0
C-B GMV	1	1.9	0
C-B W-330	1	0.5	1
Ingersoll-Rand(I-R) KVG	4	Avg - 2.0	1
I-R KVR	2	1.4, 2.1	1

I-R KVS	13	0.4, 1.1, 1.2, 1.3, 2.3, 2.5, 2.6, 2.8, 3.0, 3.0, 3.3, 3.6, 3.7	7
Totals	75	0.4 - 4.3	80

Models without test data - C-B LSV - 6%; Worthington MLV - 3%; Clark TCVC - 3%; C-B Z-330 - 2%; C-B GMVH - 2%; Nordberg FSE - 1%; I-R KVB - 1%; Worthington - 1%; C-B GMWH - 1%; C-B GMWS - 1% Total - 21%[28]

The data in Table 4 show that 56 of 75 engines with LEC retrofits have NOx emission test levels that are at or below 3.0 g/hp-hr. Nineteen of 75 engines (25 %) have emission test results greater than 3.0 g/hp-hr with the maximum being 4.3 g/hp-hr. The next highest was 4.0 g/hp-hr. The average emission level achieved by these 75 engines is 2.2 g/hp-hr.

The data in Table 5 below use the same data as in Table 4, except the data are limited to large engines in the NOx SIP call area. The data show that 40 of the 56 tests have NOx emission levels at or below 3.0 g/bhp-hr. The LEC technology retrofit on these large engines achieved, on average, an emission rate of 2.3 g/bhp-hr.

The set of data for large engines in the SIP Call area cover 80% of the engine models in the NOx SIP call area. However, emission rates for some of the engine models for which test data are not available are likely to be higher than the 2.3 average value. For example, Worthington and Nordberg engines are known to be difficult to retrofit. One vendor reported achieving a level of 6 g/bhp-hr for certain Worthington engines.[29] A Worthington UTC 165 in New York reduced NOx emissions to 4.4 g/hp-hr. A pipeline company commented that they operate 6 Worthington engines and that 4.0 g/bhp-hr is their targeted emission reduction level, based on vendor projections.[30] Thus, it appears that a 4.0 to 6.0 g/bhp-hr level is achievable on these difficult to retrofit Worthington engines. At this time, EPA believes that 5.0 g/bhp-hr is a reasonable emission rate, on average, for engines known to be difficult to retrofit. Although not all of the 21% of engine models for which test data are not available are likely to be difficult to retrofit, EPA believes it is reasonable to treat these engines as one group and to conservatively assume that this group of engines would achieve a 5.0 level, on average.

[28]The total percentage (models with and without test data; 80 and 21) do not add to 100 due to rounding convention.

[29]"Stationary Reciprocating Internal Combustion Engines: Updated Information on NOx Emissions and Control Techniques," EC/R Incorporated, September 1, 2000, page 4-5.

[30] Docket number XII-D-24

Table 5. Large IC Engines in SIP Call Area Tested with Retrofit LEC Controls

Engine Model	Number of engines tested	Test results (g/hp-hr)
Clark BA-8T	3	1.3, 3.1, 3.2
Clark HLA	6	1.7, 1.9, 2.4, 2.5,2.7, 2.8
Clark TCV	5	1.7; 3.0,3.3, 3.5, 3.6
Clark TLA	13	0.4, 0.5, 0.5, 1.1, 1.3, 1.3, 1.4, 1.9, 2.3, 2.4, 2.4, 2.9, 4.0
C-B 12V-275	2	1.3, 3.1
C-B GMV	1	1.9
C-B GMW	2	0.7, 4.3
C-B GMWA	1	0.6
C-B GMWC	1	3.1
C-B V-250	8	1.6, 2.6, 2.8, 3.0, 3.2, 3.3, 3.4, 3.4
C-B W-330	1	0.5
Cooper Quad 8Q155L	1	1.9
I-R KVS	12	1.1, 1.2, 1.3, 2.3, 2.5, 2.6 2.8, 3.0, 3.0, 3.3, 3.6, 3.7
Totals	56	0.4 - 4.0 (Avg - 2.3)

The data in Tables 4 & 5 were disaggregated below for 2- and 4-stroke engines (Tables 6-9 below). In Tables 6 and 7, data for the large IC engines with LEC retrofit indicate controlled levels of 2.2 g/bhp-hr for both 2- and 4-stroke engines. Test data for the large IC engines with LEC retrofit in the SIP call area indicate controlled levels of 2.3 and 2.5, respectively, for the 2- and 4-stroke engines (Tables 8 and 9). Assuming 85% of the engines in the SIP Call area are 2-stroke,[31] the weighted

[31]For large lean-burn IC engines in the NOx SIP Call states, 2-stroke engines represent 83% of the total large engines and 85% of the total large engine horsepower. (From INGAA's April 22, 2002 comments, pages 2 and 10.)

average of the 2.3 and 2.5 values is 2.3. Thus, based on the available data, the emission factor is the same whether considering 2- and 4-stroke engines together or separately.

Table 6. Large IC Engines Tested with Retrofit LEC Controls -- 2 stroke

Engine Model	Number of engines tested	Test Results (g/bhp-hr)	% of total units in the SIP Call Area
Clark BA-8T	3	1.3, 3.1, 3.2 (Avg - 2.5)	1
Clark HLA	6	1.7, 1.9, 2.4, 2.5, 2.7, 2.8 (Avg-2.3)	5
Clark TCV	6	1.4-3.6 (other tests - 3.0, 3.3,3.5, 2.5) Avg- 2.9	18
Clark TLA	20	0.4- 4.0 (others - 0.9, 0.8, 0.9, 1.0, 1.2, 1.7, 0.5,0.5,1.4, 1.9, 2.3,2.4,2.4,1.4,1.3,1.1, 1.3, 2.9) Avg - 1.5	1
Cooper-Bessemer (C-B) 8Q155L	1	1.9	0
C-B 12V-275	2	1.3, 3.1 (Avg -2.2)	
C-B GMV	1	1.9	0
C-B GMVA	2	0.5, 3.3 Avg - 1.9	2
CB GMW	2	0.7, 4.3; AVG - 2.5	17
C-B GMWA	1	0.6	8
C-B GMWC	3	3.1 (3 engines tested)	6
C-B V-250	8	1.6 - 3.4 (other -2.8; 3.4, 3.3,3.0,2.6,3.2) Avg - 2.9	12
C-B W-330	1	0.5	1
Total	56 engines	Avg - 2.2	

Table 7 – Large IC Engines Tested with Retrofit LEC Controls -- 4 stroke

Ingersoll Rand (I-R) KVG	4	Avg - 2.0	1
I-R KVR	2	1.4 - 2.1(Avg - 1.8)	1
I-R KVS	13	0.4, 1.1, 1.2, 1.3, 2.3, 2.5, 2.6, 2.8, 3.0, 3.0, 3.3, 3.6, 3.7; Avg - 2.4	7
Total	19	Avg- 2.2	

Table 8 - Large IC Engines in SIP Call Area Tested with Retrofit LEC Controls -- 2 stroke

Engine Model	Number of engines tested	Test results (g/hp-hr)
C-B 12V-275	2	1.3, 3.1 (Avg - 2.2)
C-B GMV	1	1.9
C-B GMW	2	0.7, 4.3 (Avg- 2.50
C-B GMWA	1	0.6
C-B GMWC	1	3.1
C-B V-250	8	1.6,2.6,2.8,3.0,3.2,3.3, 3.4, 3.4 (Avg - 2.9)
C-B W-330	1	0.5
Cooper Quad 8Q155L	1	1.9
Clark BA-8T	3	1.3, 3.1, 3.2 (Avg - 2.5)
Clark HLA	6	1.7, 1.9, 2.4, 2.5,2.7, 2.8 (Avg - 2.3)

Clark TCV	5	1.7; 3.0,3.3, 3.5, 3.6 (Avg- 3.0)
Clark TLA	13	0.4, 0.5, 0.5, 1.1, 1.3, 1.3, 1.4, 1.9, 2.3, 2.4, 2.4, 2.9, 4.0 (Avg- 1.7)
Total	44 engines	Avg- 2.3

Table 9 - Large IC Engines in SIP Call Area Tested with Retrofit LEC Controls -- 4 stroke

I-R KVS	12	1.1, 1.2, 1.3, 2.3,2.5, 2.6 2.8, 3.0, 3.0 .3.3, 3.6, 3.7 (Avg - 2.5)

As shown in Table 10, the maximum NOx emission level for the 13 engines with an HPFI retrofit was 2.4 g/hp-hr. The average was 1.1 g/hp-hr. High-pressure fuel injection (HPFI) uses high pressure fuel injector systems to enhance the mixing of air and fuel in the combustion cylinder. According to a control equipment vendor, HPFI does not require precombustion chambers or as much excess air. Reducing the amount of excess air required would diminish the turbocharging and intercooling requirements. HPFI could significantly reduce the cost and complexity of retrofits. HPFI is sometimes used in LEC retrofits and also may be used in combination with ignition timing adjustment and improved A/F ratio and ignition system controls.[32] According to another HPFI vendor, HPFI has a fraction of the cost of traditional combustion retrofit technology and reduces NOx by up to 80%; CO emissions up to 50%; and has up to 8% fuel savings.[33]

Table 10 . Large IC Engines with Retrofit HPFI

Engine Model	Number of engines tested	Test Results (g/bhp-hr)	% of total units in the SIP Call Area
C-B GMW	6	0.4, 0.5(2); 0.6, 0.8, 1.0	17
C-B GMWA	4	0.7, 0.8, 0.9, 1.0	8
I-R KVS	3	2.1, 2.3, 2.4	7

[32]EC/R - p.4-24.

[33]See www.enginuityinc.com/products/HPFi.htm.

Totals	13	0.4 - 2.4(Avg- 1.1)	32

2. Data on IC Engines with LEC that are not large, retrofit gas pipeline engines

Data on the performance of LEC for new IC engine models that are used by the natural gas pipeline industry are contained in the ACT and other documents. These results are shown in Table 11. Seventeen engines with test results were reported with test results that vary from 1.0 - 6.0 g/hp-hr. The next highest test result was 2.6 g/hp-hr. The 6.0 g/hp-hr is contained in the ACT which considers this test result not to be representative of the achievable controlled NOx emission level of LEC. The average of all data including the 6.0 is 1.8 g/hp-hr.

Table 11 - NOx Emissions for New Large IC Engines with LEC

Engine Model/Location	Controlled (G/hp-hr)	Reference
Clark TCV -10 (2 engines)	2.6	ACT (p.5-68)
Clark TCV-10	1	GRI Transmission Report
Clark TCVD(2 engines)	1.6, 1.6	Sanders Memo; INGAA - 9/01; p.33
C-B GMVH -10, 12	6.0, 1.5	ACT - p.5-68
C-B GMVH	1.4	INGAA - 2/17/99
C-B Q155HC/ Consumers Energy/ Ray Station/MI (2 engines)	2.0, 2.0	6/7/02 email - Dennis Dunlap
C-B W330/Tn Gas Station 241 - NY	0.6	5/29/02 Fax from Ted Gardella
C-B W330/Columbia Gas - Crawford, OH(2 engines)	1.4, 1.4	6/14/02 email from John Paslevicz
I-R KVS/National Fuel Gas Supply	1.0	5/24/02 email - Ted Gardella
I-R KVSE (2,100 -2,900 HP)	1.2	INGAA (9/01- -p.33); Sanders Memo - Ref.4

I-R 412	1.1	INGAA 2/17/99 - Attachment C
Superior 16SGTB/Columbia Gas - Gala Station/VA	1.1	Telecon with Dean Down/Roanoke, Va

Data from rebuilt engines were also available. These results are shown in Table 12. There were emission test results on ten engines whose models are used by the natural gas pipeline industry. These results vary from 0.5 - 2.5 g/hp-hr with an average of 1.2 g/hp-hr.

Table 12 - NO_x Emissions for Large IC engines rebuilt with LEC

Engine Model	Controlled NOx (g/hp-hr)	Reference
C-B 10V-250	1.3	ACT- p.5-68
C-B GMV/So Cal Gas - Goleta, CA - 1,100 HP	0.6	EC/R - p. 4-8; INGAA - 9/01 -p.40
C-B GMVA-8/Mobil - Ventura Co, CA	3.0	EC/R - p.4-6; INGAA - 9/01 - p.30
C-B GMVA/Santa Barbara Co, CA -Engine 67	0.5	INGAA 9/01 - D-2
C-B W330 -PG&E - Hinckley, CA(2 engines)	1.0, 1.3	EC/R - p.4-8; INGAA- 9/01 - F-5
I-R KVS/So Cal Gas -Aliso Canyon, CA (3 engines)	0.5, 0.6, 0.6	EC/R - p.4-8
I-R KVS-412 - Williams Gas Pipeline Station 505 -NJ	2.5	INGAA - 9/01 - p.34

3. Miscellaneous LEC Data

There are other data on the performance of LEC on engines that are not large engines (that is, engines that emit less than 1 TPD of NO_x) or are not used by the natural gas pipeline industry or are not retrofit LEC installations. The data listed below are primarily from new IC engines with factory-installed LEC technology.

The ACT on Table 5-5 (p.5-38) has data on 5 rich burn engines that were retrofit to LEC using a precombustion chamber. The engines range in size from 1,200 to 2,000 HP. Emission test results range from 0.37 - 2.0 g/hp-hr. Table 5-9 in the ACT provides information on LEC used on 4 lean burn IC engines (3 rebuilt and 1 new engine): NO_x emissions range from 0.5 - 1.8 g/hp-hr and engine sizes range from 4,000 to 7,000 HP.

In the EC/R report, there are various references with LEC test data. Ventura County, California has 320 tests on 23 engines on 8 engine models. Emissions range from 0.1 - 4.0 g/bhp-hr with an average of 0.7 g/bhp-hr. Only 1 test was greater than 3.0 g/bhp-hr. From Santa Barbara County, California there were 12 tests on 2 rebuilt engines and 1 new engine. The engine range in size from 1,100 - 1,800 HP. Emission test results range from 0.1- 0.7 g/hp-hr. From San Diego County, California there were 121 tests from 13 new engines of 5 engine models. Emission test results range from 0.3- 4.8 g/hp-hr. The average test result was 1.1 g/hp-hr. Only 1 of the 121 emission tests was above 3.0 g/hp-hr(the 4.8 g/hp-hr). Also data from So Cal Gas's - Honor Rancho location was obtained on 5 engines that are each 5,500 HP. There were 7 tests that range from 0.4 - 0.7 g/bhp-hr. The average emissions were 0.6 g/bhp-hr.

Also emission data were summarized in an EPA memo dated May 19, 2000. (Sanders memo). In addition to the test data already mentioned, 7 engines Santa Barbara County that range in size from 25 - 410 HP. There were a total of 24 emission tests for these engines that range from 0.05 - 1.5 g/hp-hr. A 1996 GRI reference in this memo has emission test data on 4 engines and 4 engine models that range in size from 1,800- 4,200 HP that are used by the gas pipeline industry. The 19 emission test results for these engines range from 0.3 - 3.1 g/hp-hr.

Data supplied by INGAA in 1999 to EPA are also summarized in this memo. There are 18 emission tests on 4 new IC engines from 3 engine models. Tests results range from 0.7 - 3.1 g/hp-hr. The average is 1.6 g/hp-hr.

The Sanders memo also cites test results that are contained in the 1997 AP-42. There were a total of 15 emission tests for 2 and 4 stroke engines. For 2-stroke engines, the average was 1.1 g/hp-hr and for the 4-stroke engines- 0.6 g/hp-hr. The size of the engine is uncertain and whether the engine is new, retrofit or rebuilt.

Also, test data on a rebuilt Ingersoll-Rand KVS-412 at Transcontinental Gas Pipeline Station 505 in Neshanic, NJ is presented. For this 2,050 HP engine, emissions were 2.4 g/hp-hr from a uncontrolled estimate of 21.5 g/hp-hr.

Emission test results were obtained on two Texas plants. Transco's Station 40 at Sour Lake, Texas has a Waukesha 3521 GL - 600 hp had emission test results of 0.61, 0.74, 0.68 g/hp-hr.

Colorado Interstate Gas Station at Masterson, TX has a White-Superior 8GTLX-2-825(1,070 HP) engine which had a lean burn conversion. Four emission tests results were 0.5, 0.6, 0.9 and 1.8 g/hp-hr or an average of 1.0 g/hp-hr

From www.energyalliance.com/GMC/GMC99/monday/ingersoll.html, the first ever LEC retrofit of I-R KVG is reported at Texas Eastern Transmission - 6 engines in the Beaumont-Port Arthur area. These are rich-burn engines with a NOx permit limit of 2.0 g/bhp-hr and CO permit limit of 3.0 g/bhp-hr across the engine's normal operating range 75-105% rated torque. The control was designed by Enginuity and consisted of static-mixing single point injection system and water-cooled screw-in PCC was used as the high ignition source. No modification to the heads was required.

From information supplied by Sam Clowney to OTC on 11/20/00, a Worthington UTC 165 in NY reduced NOx from12.0 - 4.4 g/hp/hr; a 63% reduction.

The average of test results for engines with LEC that are not large or not used by the natural gas pipeline industry or are not retrofit was well below 3.0 g/hp-hr. Only 4 of the approximately 82 engines exceed 3.0 g/hp-hr. The highest reading was a Worthington engine at 4.4 g/hp-hr and quite a few engines were below 1.0 g/hp-hr. These data generally show that installation of LEC technology on this group of engines produces emissions less than 3.0 g/bhp-hr, on average.

3. Summary: emission rates with LEC technology

In summary, based on the available test data, EPA believes it is reasonable to assume 79% of the large engines in the SIP Call area are able to meet a 2.3 level, on average, and that 21% are able to meet a 5.0 level, on average, with LEC technology.[34] Thus, calculating the weighted average for installation of LEC technology retrofit on all of these large IC engines results in a 2.9 g/bhp-hr emission rate.

Availability of LEC Technology

As described in the ACT document, LEC technology for lean-burn IC engines generally means the modification of a natural gas fueled, spark ignited, reciprocating internal combustion engine to reduce emissions of NO_X by utilizing ultra-lean air-fuel ratios, high energy ignition systems and/or pre-combustion chambers, increased turbocharging or adding a turbocharger, and increased cooling and/or adding an intercooler or aftercooler. Because there are many types of existing lean burn engines (e.g., some turbocharged, some not), the retrofit of LEC technology would require different modifications depending on the particular engine.

The EPA believes that LEC retrofit kits are available for virtually all affected lean-burn engines.

[34]The total percentage (models with and without test data; 80 and 21) do not add to 100 due to rounding convention. For purposes of the weighted average calculation a 79/21 split is used. The resultant percentage reduction value, 83%, is the same if the split is 79/21 or 80/20.

This is based on the EC/R report on IC engines,[35] references cited in the 9-5-00 TSD,[36] and additional information described below. The EPA also obtained information from various IC engine manufacturers. This information is summarized in Table 10 below.

Table 10 -- Availability of Retrofit LEC for Various Large IC Engine Models in SIP Call Area

Engine Model	Number of Engines	% of Total Units	% of Total HP	LEC Available?
Clark TCV	28	18	22	Yes
Cooper-Bessemer (C-B) GMW	26	17	10	Yes
C-B V-250`	19	12	13	Yes
C-B GMWA	12	8	5	Yes
Ingersoll-Rand(I-R) KVS	11	7	4	Yes
C-B LSV	10	6	7	Yes
C-B GMWC	9	6	5	Yes
Clark HLA	8	5	3	Yes
Worthington MLV	5	3	4	Yes
Clark TCVC	4	3	8	Yes
C-B Z-330	3	2	6	Yes
C-B GMVH	3	2	1	Yes
C-B GMVA	3	2	1	Yes
Clark TCVD	2	1	3	Yes
I-R KVR	2	1	2	Yes

[35]EC/R report on IC engines, section 4.1.2.

[36]March 3, 1999 letter from J. W. Hibbard, Cooper Energy Services, to Bill Neuffer, EPA; March 4, 1999 telecon summary of call between Joe Hibbard, Cooper Energy Services and Bill Neuffer, EPA; and letter of May 7, 1999 from Charles Wilke, Dresser-Rand Company, to Bill Neuffer.

Nordberg FSE	2	1	1	??
Clark TLA	2	1	1	Yes
C-B W-330	1	1	1	Yes
I-R KVT	1	1	1	Yes
Clark BA	1	1	0.3	Yes
I-R KVG	1	1	0.2	Yes
Worthington ML	1	1	1	Yes
C-B GMWH	1	1	1	Yes
C-B GMWS	1	1	1	Yes
Total	156	100	100	All but 2 of 156 engines

For Cooper-Bessemer engines, All 2 and 4 cycle Cooper engines (Cooper-Bessemer, Enterprise, Superior, Ajax) can be retrofitted with LEC; either Clean Burn or EcoJet. Also the EcoJet can be adapted to any IC engine model including Worthingtons and Clarks. The Clean Burn system can only be installed on a Cooper engine (Cooper, Enterprise, Ajax, Superior).[37]

For Clark, Ingersoll-Rand engines several sources of information were obtained. Low cost PCC retrofits are available for engines that are Clark TLA, TLAB-D; TCV, TCVA-D; HLA, BA, HBA models.[38]

According to Dresser-Rand personnel, the screw-in prechamber (SIP) has been installed on 79 engines at 7 different owner/operators in 5 different states. The SIP can be installed on any Dresser-Rand, Ingersoll-Rand, Clark or Worthington engine.[39] Screw-in prechambers are available for TCV, TCVA, TVAD, TLA, TLAD, TCVC, LA, HLA, BA, HBA, RA, HLA,

[37]Telecon with Ron Billig - 7/12/02; docket number XII-E-14.

[38]"Low- Cost NOx Controls for Pipeline Engines" See docket number XII-K-93 or www.gastechnology.org/pub/oldcontent/pubs3/trans/tp_lcncpe.html

[39]Telecon dated 6/7/02; docket number XII-E-15.

KVS, KVS, KVR, and KVT.[40]

LEC using lean-burn operation, precombustion chambers, and enhanced in-cylinder mixing of fuel and air can be applied to Ingersoll-Rand KVS, KVS, KVT, TVS, KVR, and KVS models regardless of the number of cylinders.[41]

Cost Effectiveness of LEC Technology

The average cost effectiveness for large IC engines using LEC technology was estimated in the Pechan IC engines report to be $532/ton (ozone season).[42] The EC/R report on IC engines estimates the average cost effectiveness for IC engines using LEC technology to range from $420-840/ton (ozone season) for engines in the 2,000-8,000 bhp range.[43] The key variables in determining average cost effectiveness for LEC technology are the average uncontrolled emissions at the existing source, the projected level of controlled emissions, annualized costs of the controls, and number of hours of operation in the ozone season. The ACT document uses an average uncontrolled level of 16.8 g/bhp-hr, a controlled level of 2.0 g/bhp-hr (87% decrease), and nearly continuous operation in the ozone season. The EPA believes the ACT document provides a reasonable approach to calculating cost effectiveness for LEC technology.

The EPA acknowledges that specific values will vary from engine to engine. For additional information, we have included sensitivity analyses in this TSD regarding the key variables for cost effectiveness: uncontrolled and controlled levels, hours of operation, and annualized costs. The sensitivity analyses are summarized later in this TSD and indicate a range of cost effectiveness for large IC engines using LEC technology of $540-890/ton (ozone season).

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[40]"The SIP combustion System for NOx Reductions on Existing Dresser-Rand Gas Engines" see (Docket XII-K-96) or (www.dresser-rand.com/e-tech/tp014/tp014prt.htm).

[41]"Low-Cost Nox Controls for Pipeline Engines," see docket at XII-K-90 or www.gastechnology.org/pub/oldcontent/pub3/trans/tp-inger.html,

[42]Pechan IC engines report. Annual costs in 1990 $ per ozone season tons reduced. Note: 1990 $ are used in order to easily compare with the NOx SIP call's "highly cost effective" value of $2000/ton (in 1990 $).

[43]EC/R report on IC engines, section 2.2. Annual costs in 1990 $ per ozone season tons reduced. ($460-910 in 1997 dollars).

Other Cost and Analysis Factors

Monitoring costs

In the NO_x SIP call rulemaking, EPA assumed continuous emissions monitoring systems (CEMS) might be required by States that chose to regulate IC engines. The EPA now believes that CEMS may not be necessary unless an engine is participating in a trading program. Alternate monitoring approaches, such as parametric monitoring and/or annual testing, are less costly and may be sufficient to assure compliance. Monitoring of pressure, which may be correlated with temperature and, thus, NOx emissions, is a form or parametric monitoring that may be successfully applied at a cost of less than $1000/year.[44] Annual testing would add about $3,000/year.[45]

Time to Implement Controls for IC Engines

The pipeline industry has considerable experience with the installation of LEC technology. Based on information primarily from manufacturers of control equipment, and from a regulatory agency and operator of the control equipment, EPA believes the time between a request for cost proposal and field installation on a few engines can be less than 11 months.[46] However, installing controls on many engines in a narrow time frame is more problematic. As discussed below, EPA believes that a reasonable time frame is 24 months from the SIP submittal date and that the initial compliance date should occur within the ozone season.

The EPA obtained additional information regarding this issue. One manufacturer estimated the time between request for cost proposal and contract to be 2-5 months and typically 3-4 months. It then takes 4-5 months for delivery and an additional 1 month to install and commence operation. This adds up to a total of 7-11 months.[47] Another manufacturer estimated the time between cost proposal and contract is 2-4 weeks to obtain bids; 2-3 months for selection of bids;12-20 weeks for parts

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[44]EC/R report on IC engines, section 5.1.4.

[45]The 1993 ACT document for IC engines uses a cost of $2,440 for annual testing, page 6-5. In "CAPCOA/ARB Proposed Determination of Reasonably Available Control Technology and Best Available Retrofit Control Technology for Stationary Internal Combustion Engines," December 3, 1997 the document estimates testing costs at $3,000 per engine (pg.52).

[46]Telephone records by Bill Neuffer dated 5-18-00, (two) 5-19-00, and 5-24-00.

[47] See docket number XII-E-01.

delivery to site; and 2 weeks to 1 ½ month for field installation.[48] Another manufacturer estimated from request for cost bids to shipping of parts takes 6-8 months for delivery and an additional 2-4 weeks to install and commence operation. This adds up to a total of 6 ½ - 6 months.[17] Information from the Ventura County Air Pollution Control District in California estimated 2 weeks to 1 month to install LEC and the total time estimated from request for cost proposal and commencing operation of LEC was 6-9 months. A gas pipeline company, CMS Energy, stated that a compliance schedule of 11 months was easy to meet for 1-2 engines but would put a stress on the system for 200 engines. Columbia Gas Transmission Corporation installed controls on 2 engines in Bedford Co., PA in three days, meeting the 3.0 g/bhp-hr standard set by the State.[49] Thus, there is some agreement that the necessary compliance period for installation of controls on a small number of engines is less than one year.

The EPA expects some companies to choose to phase-in installation of the control equipment over a 2-year period (or longer if the companies begin retrofit activities sooner) and that installation activities would occur primarily in the summer along with normally scheduled maintenance activities. Further, as noted below, not all of the potentially affected IC engines should be expected to need LEC retrofits and not in the same time frame.

In response to Phase II of the NOx SIP call, some States may seek emission reductions from source categories other than IC engines. Other States have already met their NOx budgets and do not need to further control IC engines for purposes of the NOx SIP call. Still other States have met at least a portion of the Phase II NOx SIP Call reductions due to emission reductions affecting other source categories contained in their 1-hour ozone nonattainment area plans. This reduces the need to retrofit IC engines in those States.

In many cases, companies may use "early reductions" achieved at IC engines due to other requirements, such as RACT.[50] For example, many IC engines were previously controlled to meet RACT requirements in many of the NOx SIP call States. These emission reductions help States meet their NOx budgets and, thus, decrease the amount of additional reductions needed. According to a information submitted by INGAA, a 1996-97 survey determined that 245 lean burn engines in the SIP Call area have LEC.[51] Many engines in the NOx SIP call area already have decreased NOx emissions

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[48]See docket number XII-E-02.

[49]See http://www.dieselsupply.com/dscartic.htm for reprint of article from May 1998 of "American Oil & Gas Reporter."

[50]August 22, 2002 memo from Lydia Wegman to EPA Regional Air Directors providing guidance on issues related to stationary internal combustion engines and the NOx SIP call.

[51]"IC Engine OTAG Questions" document prepared by INGAA, 2/17/00. Many of these engines are smaller than the "large" engines identified in the NOx SIP Call.

at rich-burn engines through NSCR.[52] States may choose to credit these reductions instead of requiring new reductions at other engines in order to meet the SIP budget. Many more NOx reductions are likely to result from future MACT controls at IC engines. These factors also reduce the need to retrofit IC engines in some States.

Some pipeline companies will phase-in the control equipment over a multi-year time frame.[53] Stretching out the installation time frame in this manner would help the companies achieve the results on time. Further, companies might choose to install controls early in some of their engines in a time frame that coincides with the engine rebuild cycle.[54] In another case, installation of the LEC retrofit kit was estimated to span 3 to 4 weeks and the installation was not expected to impact the normal maintenance interval.[55] These approaches will help reduce the time needed to install the controls.

The EPA believes the industry has demonstrated that multiple engines at compressor stations can be successfully retrofit over a 24 month time frame. For example, the Jefferson Town Compressor Station's RACT compliance plan of April 2000 describes the installation of LEC using a phased approach over a 2 yr period. Four engines were retrofit during summer 2001 and the remaining 5 engines were retrofit in summer 2002. Each engine was expected to be out of service for approximately 6 weeks and, due to heavy demand during winter heating season, all engines were expected to be operable from October -April. Two additional cases show installation on multiple engines in short time periods. Southern California Gas Co. completed testing of one engine in 1995 and installed precombustion chambers on six engines in its Mojave Desert operating area. The conversion of the first unit was completed in October 1995 and the conversion of the sixth unit was in November 1996. The engines met the 2.0 g/bhp-hr standard set by the Mojave Air District. Furthermore, as cited in a case study in Vidor, Texas, 6 engines in the Beaumont/Port Arthur area were retrofitted in summer of 1999.[56]

As shown below, EPA also examined historic time frames allowed by the Congress and various regulatory agencies to achieve compliance with NOx requirements following State/local rule adoption.

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[52]Alpha Gamma memo of 6-19-02.

[53]INGAA letter of July 16, 2002.

[54]A top-end overhaul is generally recommended between 8,000 and 30,000 hours of operation that entails a cylinder head and turbocharger rebuild (see Table 4 from "Technology Characterization: Reciprocating Engines" prepared by Energy Nexus Group for EPA, 2-02).

[55] GRI 12-98 report "NOx Control for Two-Cycle Pipeline Reciprocating Engines," page 4-11.

[56] See http://www.enginuityinc.com

These time frames generally illustrate the successful implementation of past regulatory programs involving the installation of NOx controls.

> In the 1990 amendments to the CAA, Congress added RACT requirements for major sources of NOx. All categories of major NOx sources in certain areas of the nation were required to install RACT as expeditiously as practicable or no later than May 31, 1995. Thus, Congress allowed a maximum of 30 months from the SIP submittal deadline of November 15, 1992 for a much larger number of sources than affected by this rulemaking.
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> Subsequent to the initial set of NOx RACT SIP revisions, EPA approved NOx RACT SIP submittals in some areas which had been exempt from the requirements. For example, in Dallas, SIP rules required RACT as expeditiously as practicable or 24 months from the State adoption date (rule adopted March 21, 1999). The State of Texas, on December 31, 1997, implemented a requirement for all major NO_x sources in the Houston area to implement RACT; the State adopted a compliance date of November 15, 1999 for this program (22.5 months). In a recent case, the State of Louisiana allowed up to a 3-year period in Baton Rouge, coinciding with their attainment deadline.
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> For engines subject to RACT limits, the California Air Resources Board guidance document on IC engines recommends final compliance within two years of district rule adoption.[57] The guidance states that this time period should be sufficient to evaluate control options, place purchase orders, install equipment, and perform compliance verification testing. The Sacramento Air District in California required compliance within 2 years of rule adoption (June 1995).

Furthermore, EPA believes that States will process permits expeditiously, especially those permits associated with pollution control projects. The EPA has specifically encouraged States in a recent memo to consider exempting pollution control projects from certain permitting requirements.[58] Further, by moving the compliance date to at least 24 months after the SIP submittal date, EPA believes that the time needed to revise permits will not adversely affect the compliance schedule.

In summary, several factors described above will serve to minimize the number of large IC engines that would need to be scheduled for LEC retrofit. Further, companies that phase-in compliance activities over several years would also reduce the number of IC engines needing LEC retrofit per year. It is important to note that RACT experience shows that companies can install LEC

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[57] "Determination of RACT and BARCT for Stationary Spark-Ignited Internal Combustion Engines,"California Air Resources Board, November 2001, pg. IV-15.

[58] August 22, 2002 memo from Lydia Wegman to EPA Regional Air Directors providing guidance on issues related to stationary internal combustion engines and the NOx SIP call.

retrofit over a 2-year time frame, even where multiple engines are located at the same compressor station. In recent RACT compliance time decisions, State/Local regulatory agencies generally specified 24 month periods to install controls. The Congress in its 1990 CAA amendments allowed a maximum of 30 months for all major NOx sources across the nation to install RACT; this was a much larger task than installation of controls at IC engines in certain States. As a result, EPA believes that a 2-year period after the SIP submittal due date is adequate for the installation of controls.

In addition, because the NOx SIP call is directed at emissions during the ozone season, EPA believes that the initial month where compliance is required should occur during the ozone season. Therefore, the compliance date is 24 months from the SIP submittal date if the SIP submittal date occurs during the ozone season or, if not, 24 months from the SIP submittal date plus the days until the next ozone season begins (May 1).

Increased Power Output and Fuel Savings

Implementation of LEC may yield additional benefits of fuel economy and power output. Up to 5% fuel economy improvement is reported in the ACT document from installing LEC (p. 7-12). The 1990 GRI report describes “cost credit due to improved engine performance”and states that fuel economy can be improved up to15% and power output 65% (p.10). The 1994 GRI report indicates increases in power output but slight losses in fuel economy associated with controls that achieve 80-90% NO_x reduction. The 1996 AP-42 indicates improved power output and fuel efficiency with LEC (sect. 3.2.4.2). In the Pechan IC engines report cited earlier in this TSD, a 1% fuel savings is included in the cost analysis.

A CARB report “Sources and Control of Oxides of Nitrogen Emissions” - August 1997 states that at the 80 % reduction level, the efficiency of the precombustion chamber is often improved over that of an uncontrolled engine. At reductions of more than 90 % which is obtained by carefully controlling operating parameters and extreme leaning of the air/fuel mixtures, there is usually some decrease in engine efficiency.

Types of IC Engines

In the February 22, 2002 proposed rule, EPA invited comment on how many of the large natural gas-fired IC engines are from lean-burn operation and how many from rich-burn. The INGAA commented that 156 of the 168 large engines listed in the NOx SIP Call Inventory that have SIC codes associated with the natural gas transmission industry are lean-burn models, with one exception. According to INGAA, the other 12 engines are no longer in service, are owned by a company not included in the industry data base or are duplicates. All but one engine is lean burn and the majority are

2-stroke engines.[59]

For the purposes of calculating the IC engine portion of the NOx SIP Call state budgets, INGAA recommended that EPA should assume that all the large natural gas fired stationary engines in the inventory are lean burn. Thus, the vast majority of large IC engines in the NOx SIP call inventory are natural gas-fired lean-burn engines. Furthermore, the emission inventory does not contain sufficient detail to determine exactly which engines are lean burn and which are not. For these reasons EPA agrees with the comment that it is reasonable to assume that all the large natural gas stationary engines in the inventory are lean-burn for the purposes of calculating the IC engine portion of the NOx SIP Call state budgets.

Results of Cost and Sensitivity Analyses

The discussion below summarizes an August 11, 2000 report by the Pechan-Avanti Group which estimated the control costs and NO_x emission reductions for large IC engines affected under the NO_x SIP Call. The report provides information about the universe of potentially affected stationary IC engines, control cost modeling methods, scenario analyses, and caveats and uncertainties associated with this analysis.[60] The results of the analyses are summarized below. Additional information is contained in EPA's 9-5-00 TSD.

The average cost per ton (ozone season) for the main analysis is $532 per ton. This ozone season cost per ton is affected mostly by the natural gas-fired engine control costs. The uncontrolled NO_x emission level is 16.8 g/bhp-hr. For purposes of this analysis, the controlled NO_x level with LEC is 2.0 g/bhp-hr. Oil-fired engines are about 3 percent of the population of large IC engines. While oil-fired engine costs are just above $1,000 per ton, they have a negligible influence on regionwide costs.

In Scenario B, the control efficiency for low emission combustion applied to lean burn natural gas-fired engines is reduced to 82 percent (3 g/hp-hr). This increases the average cost per ton by $20/ per ton. The tons of NO_x decreased by about 2,000 tons in the ozone season, compared to the 87% reduction in the main analysis.

Scenario C increases the NO_x control efficiency for lean burn engines to 90 percent. This additional emission reduction reduces the average cost per ton to about $520 per ton, which is $12 per ton less than in the main analysis.

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[59]INGAA document dated 9/01, page A-8.

[60]Pechan IC engines report.

Scenario D changes the uncontrolled NO_x emission level for lean burn gas-fired engines to 13.7 g/bhp-hr from 16.8 g/bhp-hr. With fewer NO_x tons being reduced, this raises the cost per ton to $603 per ton.

A control level of 1.2 g/bhp-hr (93% decrease) in Scenario E produces the lowest average cost per ton of $513 (and the largest emission reduction).

Scenario F reduces annual operating hours to 6,500. This changes both the emission reductions and the costs. Compared with other scenarios, there are fewer emission reductions but lower costs, resulting in a cost per ton $49 higher than the main analysis.

Scenario G retains the capital cost estimates that were used in the September 1998 Non-Electricity Generating Unit (EGU) cost analysis for the NO_x SIP Call. The scenario has the same emission reductions as the main analysis, but with $334 per ton higher estimated costs.