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# Project Summary

# Environmental Assessment of Combustion Modification Controls for Stationary Internal Combustion Engines

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**This report gives results of an evaluation of combustion modification techniques for stationary internal combustion (IC) engines, with respect to $NO_x$ control reduction effectiveness, operational impact, thermal efficiency impact, capital and annualized operating costs, and effects on emissions of pollutants other than $NO_x$. Currently available operational adjustments for $NO_x$ control can reduce emissions by about 40 percent, but significantly increase operating costs. The total annualized cost to control can increase the cost of power by 3 to 14 percent, due to additional fuel and maintenance requirements. Combustion modifications can reduce $NO_x$ emissions without significantly increasing CO and hydrocarbon emissions for most engines. However, the kinds and distribution of organic compounds emitted from stationary diesel engines are not well characterized, and therefore are of concern.**

*This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

## Introduction

With the increasing extent of $NO_x$ control applications in the field, and expanded $NO_x$ control development anticipated for the future, there is currently a need to ensure that: (1) the current and emerging control techniques are technically and environmentally sound and compatible with efficient and economical operation of systems to which they are applied, and (2) the scope and timing of new control development programs are adequate to allow stationary sources of $NO_x$ to comply with potential air quality standards. With these needs as background, EPA's Industrial Environmental Research Laboratory, Research Triangle Park (IERL-RTP) initiated the "Environmental Assessment of Stationary Source $NO_x$ Combustion Modification Technologies Program" ($NO^x$ EA) in 1976. This program has two main objectives: (1) to identify the multimedia environmental impact of stationary combustion sources and $NO_x$ combustion modification controls applied to these sources, and (2) to identify the most cost-effective, environmentally sound $NO_x$ combustion modification controls for attaining and maintaining current and projected $NO_2$ air quality standards to the year 2000.

The $NO_x$ EA's assessment activities have placed primary emphasis on major stationary fuel combustion $NO_x$ sources (utility and industrial boilers, gas turbines, IC engines, and commercial and residential warm air furnaces); conventional gaseous, liquid, and solid fuels burned in these sources; and combustion modification controls applicable to these sources with potential for implementation to the year 2000.

This summary outlines the environmental, economic, and operational impacts of applying combustion modification controls to this source category.

## Conclusions

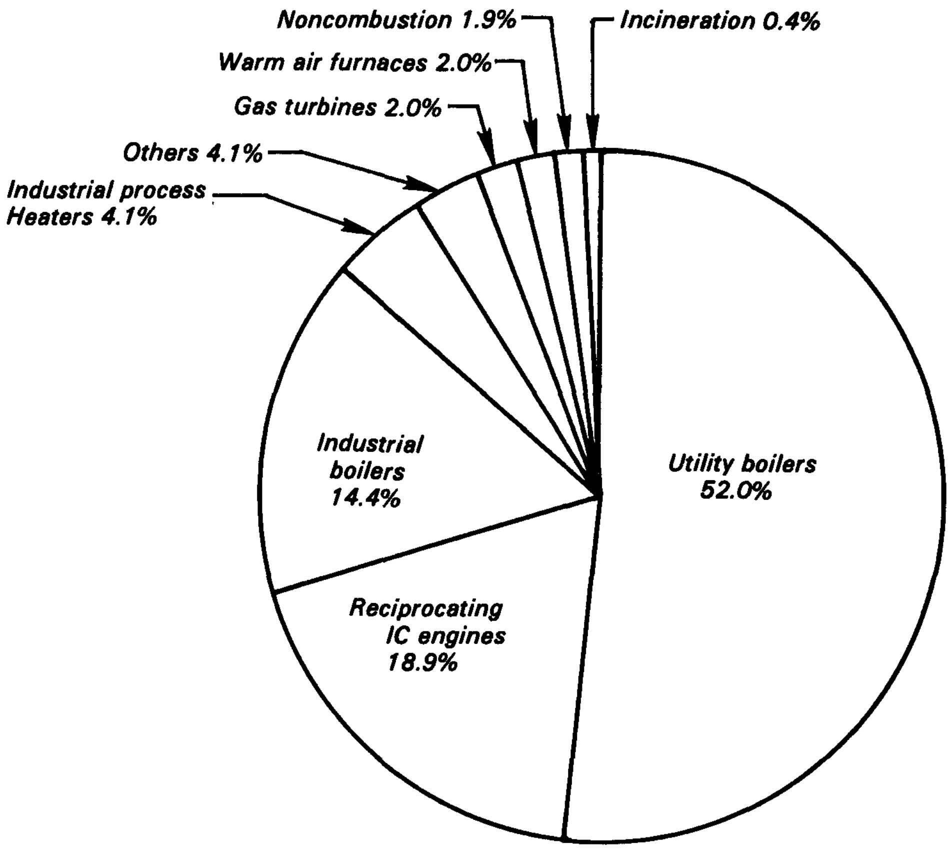
### *Source Characterization*

Stationary reciprocating IC engines are the second largest contributor of $NO_x$ emissions from stationary sources in the U.S. Figure 1 shows that this source constituted about 19 percent in 1977. Because of this high level of $NO_x$ emissions and their potential for control, stationary IC engines represent a priority source category for control evaluation in the $NO_x$ EA.

Stationary IC engines can be classified into three characteristic size ranges: large bore, high power, low to medium speed; medium bore, high speed; and small.

Large bore engines (>75 kW/cyl) operate at lower speeds (usually less than 1000rpm) and burn three major types of fuel: diesel, natural gas, and dual fuel (mixture of diesel and gas). Natural gas engines are spark ignited, and diesel and dual fuel engines are compression ignited. Both two- and four-stroke models are in this size range, and the engine may be turbocharged, which usually increases efficiency. Typical heat rates are 9 to 11 MJ/kWh (8500 to 10,500 Btu/kWh). Typical industries using these large bore engines are municipal electric power generation, oil and gas pipeline transmission, and oil and gas production. In these industries, the engine is run continuously. Based on 1976 data, only about 1000 to 2000 of these engines are sold per year, with a total production value of $80 to $150 million (1976 dollars). Sales have generally been declining, although sales of diesel engines for electric power generation are up.

Medium power engines (7.5 to 75 kW/cyl) exhibit the greatest variety; some large units equal the power of large bore engines. However, where large bore engines produce high power output at low speeds due to their large displacement and consequently high power per cylinder, medium bore engines have lower power per cylinder and, therefore, more cylinders for the same engine horsepower. Fuels burned in medium power engines are typical mobile fuels, either diesel oil or gasoline, although there are a few (usually modified) natural gas engines of this size. These engines are used in miscellaneous industrial, commercial, nonpropulsive marine, and agricultural applications where shaft power is needed and electric motors cannot be used.



*Total: 10.5 Tg/yr (11.6 x $10^6$ tons/yr)*

***Figure 1.*** ***Distribution of stationary anthropogenic $NO_x$ emissions for the year 1977 (controlled $NO_x$ levels).***

Small engines are mostly one- and two-cylinder engines of less than 40 hp. These engines are mostly diesel and gasoline, one- and two-cylinder models, with some four-cylinder models. Almost all have four stroke cycles and are usually air cooled. Small engines are used typically in generator sets, small pumps and blowers, off-the-road vehicles, and refrigeration compressors for trucks and railroad cars.

This report focuses on large bore engines since these represent the largest $NO_x$ emitters in the category, and they are most amenable to combustion modification control.

### *Source Emissions*

Air emissions in the form of exhaust gases are essentially the only effluent stream from stationary IC engines. Hydrocarbons (HC) can be emitted from the fuel before combustion, especially from natural-gas-fired engines, but these emissions are considered minor. There may also be some emissions from the crankcase caused by blowby, but this is also a minor source. The cooling system may release minor water pollutant emissions, and liquid wastes in the form of used crankcase oil may be another pollutant. Neither of these is a major release.

$NO_x$, CO, and HC are the major pollutants of concern in the exhaust gases from stationary IC engines. $SO_x$ emissions are possible if the fuel burned has appreciable sulfur content, but this is rarely the case with the clean fuels burned in these engines. Particulate emissions are low from stationary engines. Diesel engines may also emit polycyclic organic matter (POM) at low levels, but even low level emissions of these compounds would be of concern because of their mutagenicity and potential carcinogenicity.

$NO_x$ in IC engines, as in all combustion sources, is formed primarily by two mechanisms — thermal fixation and fuel $NO_x$ formation. Thermal $NO_x$ results from the termal fixation of molecular nitrogen and oxygen in the combustion air, and the rate of formation increases exponentially with local flame temperature. Fuel $NO_x$ results from the oxidation of organically bound nitrogen found in certain fuels and primarily depends on the nitrogen content of the fuel. Since IC engines generally burn clean fuels, with correspondingly low nitrogen contents, thermal $NO_x$ predominates.

Of the other pollutants, HC and CO are mainly the result of incomplete combustion. HC emissions are believed to be caused by three general mechanisms: wall quenching (fuel impingement on the walls causing the fuel to be cooled below the combustion temperature), variations in engine operation (mixing inside the cylinder, wrong air-to-fuel ratio, defective ignition, etc.), and, in two-cycle engines, cooling the exhaust gases by scavenging air before combustion is completed. CO emissions are also formed by the same general mechanisms.

Typical uncontrolled emission factors for IC engines are listed in Table 1. The HC emissions listed are total HCs; for natural gas engines, these are mainly methane. Although Table 1 lists factors for all engine sizes, this report focuses on the larger engines. Note that $NO_x$ is the major pollutant for large engines.

***Table 1.*** *Emissions Factors for IC Engines, g/kWh*[a]

| *Fuel* | | *$NO_x$* | *CO* | *HC* |
|---|---|---|---|---|
| *Gasoline* | *> 15 kW* | *11.9* | *137* | *11.2* |
| | *< 15 kW* | *7.5* | *395* | *27.5* |
| *Diesel* | *>375 kW*[b] | *17.3* | *2.4* | *0.6* |
| | *<375 kW*[c] | *16.6* | *6.0* | *2.8* |
| *Natural gas* | | *15.4* | *3.8* | *6.5* |
| *Dual Fuel* | | *11.0* | *2.7* | *4.1* |

[a] *Emission factors for gasoline and diesel engines are modal averages; those for natural gas and dual fuel are for rated conditions. Modal averages mean that some of the $NO_x$ numbers are taken from the constant power out portion of mobile tests.*

[b] *Based on an average of rated condition levels from engines considered.*

[c] *Weighted average of two- and four-stroke engines. Weighting factors = 2/3 for four-stroke and 1/3 for two-stroke.*

## *Control Alternatives*

Since $NO_x$ is the major pollutant emitted by stationary large bore IC engines, control development has focused on limiting $NO_x$ emissions. There are three major approaches to controlling $NO_x$ from IC engines: operational adjustment, combustion chamber redesign, and catalytic exhaust gas treatment. Operational adjustment techniques can be considered demonstrated and are finding current application. Combustion system redesigns are currently being developed and have seen, at best, laboratory scale testing. The use of catalysts to reduce $NO_x$ emissions from lean-running engines (selective catalytic reduction) has seen only laboratory scale testing. Similarly, early limited testing of $NO_x$ reduction catalysts for rich-running engines (nonselective catalytic reduction) has been performed.

The operational adjustment techniques are derate, ignition retard, air-to-fuel ratio change, reduced manifold air temperature, exhaust gas recirculation (EGR) (both internal-restricting the exit of exhaust gases from the cylinder, and external-reintroducing exhaust gases into the intake manifold), and water injection. All these techniques essentially act to lower the peak combustion temperatures, thereby limiting thermal $NO_x$ formation. These techniques can be seen used in combustion, although $NO_x$ reductions are not always additive.

Combustion system redesigns have been aimed at improving cylinder mixing, enhancing combustion, or establishing some form of staged combustion. The first two allow efficient combustion to occur under leaner lower-temperature conditions. The third, in addition to lowering peak temperature, lowers oxygen availability at peak temperature.

For diesel engines, mixing can be improved by circumferential injection, chamber shape, or a variable area prechamber. Combustion in gas engines can be improved by torch ignition, multiple spark plugs, high energy spark, increased turbulence through swirl or "squish," or diesel fuel injection. Staged combustion techniques include divided chambers, open chambers, or degraded mixing for gas engines, and a prechamber or pilot injection for diesel engines.

Catalytic reduction is a flue gas treatment technique in which exhaust gas is passed over a reduction catalyst which reduces $NO_x$ to $NO_2$. Nonselective reduction catalysts can be used with rich-running engines since very little oxygen exists in their exhaust. However, lean-running engines require selective reduction catalysts which further require injecting a reducing agent, ammonia, into the exhaust stream.

Table 2 lists the various combustion modifications that have been investigated for IC engines and shows the $NO_x$ reduction and fuel penalties associated with these controls as a function of engine type.

Currently, the best demonstrated controls, the only ones sufficiently demonstrated to allow meeting the proposed IC new source performance standards (NSPS), are: (1) retarded ignition or retarded fuel injection, (2) air-to-fuel ratio changes, (3) increased manifold air, or (4) in combinations with the others. The best combination will be very engine dependent. But in general, retard is best for diesel-fueled engines, air-to-fuel ratio changes for natural gas, and either control for dual fuel. A 40 percent reduction in $NO_x$ can usually be achieved without causing any major operational problems, but there are fuel consumption penalties.

For the future, combustion system redesigns have the potential for obtaining the same level of $NO_x$ reduction (40 percent) but with lower costs and fuel penalty. For very low $NO_x$ emissions, only catalytic reduction techniques show promise.

Table 3 compares the estimated annualized incremental costs of retard, air-to-fuel increase, and exhaust gas recirculation applied to various engines to those of the corresponding uncontrolled engines Costs in Table 3 represent annualized costs in mills/kWh (assuming 8000 hours of operation per year) and are in 1978 dollars. Table 3 shows that ignition retard increases the total cost of power 6 to 7 percent, air-to-fuel increase increases power costs 3 to 7 percent, and EGR increases power costs 5 to 14 percent. Though not shown in Table 3, manifold air temperature reduction should only have a small cost impact, about a 1.5 percent increase in initial engine cost and an increase in the cost of power of about 1 percent. Derate is a viable technique only if spare power is available elsewhere. Though derating

***Table 2.*** *$NO_x$ Reduction and Fuel Comsumption Penalties for Diesel, Dual-Fuel, and Gas Engines*

| Control Approach | | Engine Fuel Type | | | | | |
|---|---|---|---|---|---|---|---|
| | | Diesel | | Dual Fuel | | Natural Gas | |
| | | % $NO_x$ Reduction | ΔBSFC, %[a] | % $NO_x$ Reduction | ΔBSFC, %[a] | % $NO_x$ Reduction | ΔBSFC, %[a] |
| Derate | 3% | — | — | — | — | <20 | 2 |
| | 6% | — | — | — | — | <40 | 3 |
| | 10% | — | — | <20 | 4 | — | — |
| | 20% | <20 | 4 | — | — | — | — |
| | 25% | 5-23 | 1-5 | 1-33 | 1-7 | 5-90 | 2-12 |
| Retard | 2° | <20 | 4 | <20 | 3 | — | — |
| | 4° | <40 | 4 | <40 | 1 | <20 | 3 |
| | 8° | 28-45 | 2-8 | 50-73 | 3-5 | 8-40 | 2-7 |
| Air-to-Fuel | 2% | — | — | — | — | <20 | 2 |
| | 3% | — | — | <20 | 0 | — | — |
| | 5% | — | — | — | — | <40 | 7 |
| | ±10% | 7-8 | 3 | 25-40 | 1-3 | 20-80 | 5-12 |
| Manifold | 311k(100°F) | 7-15 | 0-2 | 18-37 | 0-1 | 28 | 0 |
| Air | 315k(107°F) | — | — | — | — | <20 | 0 |
| Temperature | 318k(113°F) | — | — | <20 | 1 | — | — |
| Internal EGR | | 5 | 2 | — | — | <20 | 5 |
| | | — | — | — | — | 5-35 | 0-8 |
| External EGR | 10% | <20 | 1 | 20 | 1 | <20 | 0 |
| | | 33 | 1 | — | — | 33 | 0 |
| Retard and Manifold | | <20 | 1 | <20 | 1 | <20 | 3 |
| Air Temperature | | 10-24 | 0-1 | 25 | 2 | 30-40 | 5-6 |
| Retard & Air-to-Fuel | | <20 | 8 | <20 | 1 | <20 | 4 |
| | | <40 | 16 | <40 | 2 | <40 | 8 |
| | | 35-65 | 5-26 | 56 | 2 | 17-52 | 4-11 |
| Retard and Manifold | | 20 | 0 | <20 | 2 | <20 | 2 |
| Air Temperature and | | — | — | 40 | 3 | <40 | 4 |
| Air-to-Fuel | | — | — | — | — | 40-65 | 6-7 |
| Air-to-Fuel and | | <20 | 2 | — | — | — | — |
| Manifold Air Temperature | | 20-30 | 3 | — | — | — | — |
| Water Injection | 50% | 25-35 | 2-4 | — | — | 25-35 | 1-2 |
| ($H_2O$/fuel ratio) | 100% | | | — | — | 60-75 | 2-5 |
| Catalytic Reduction | | 50-80 | 0 | 50-80 | 0 | 50-80 | 0 |
| (Projected | | | | | | | |
| Combustion Chamber Modifications | Increased Mixing | 10-30 | <5 | 20-40 | <5 | 20-40 | <5 |
| (Projected) | Staged Combustion | 10-30 | 0 | 10-30 | 0-7 | 10-30 | 0-2 |

[a] *Brake specific fuel consumption penalty.*

would increase fuel consumption and raise operating costs, specific figures are not given because of the difficulty in specifying highly site dependent costs.

In general, as shown in Table 3, the incremental initial capital costs of the available controls range from 0 to 5 percent of an uncontrolled engine's cost. However, the total annualized cost to control can increase the cost of power from an engine by 3 to 14 percent, the significant impact due to additional fuel and maintenance requirements.

By combining control techniques, it may be possible to achieve the same $NO_x$ reductions with a smaller fuel penalty, or reduce $NO_x$ levels more than could be achieved by each technique alone. Table 4 compares three different methods for reducing $NO_x$ by 40 percent from a large bore diesel engine. For this case, there is a definite advantage to using combined controls since the two combined techniques, air-to-fuel ratio change and manifold air cooling (or air-to-fuel ratio change and retard), had a lower brake specific fuel consumption penalty (BSFC) than retard alone.

Cost estimates for combustion system redesign controls vary significantly due to the developmental state of these techniques. Estimates indicate that these redesigns will fall between 0.5 and 20 percent of the capital cost of a large engine, with 3 percent being typical. Operational and maintenance costs should increase very little because the goal of development is to keep BSFC changes negligible.

## Operational Impacts of Controls

Since engines are currently optimized for minimum maintenance requirements and fuel use, any control technique which varies engine parameters from standard conditions will impact operation and maintenance. Some of these impacts have been well characterized, especially from control techniques which involve engine operational changes

**Table 3.** *Annualized Control Costs for IC Engines*[a]

| | | | Control Techniques | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Retard | | Air-to-Fuel Ratio Change | | External EGR | |
| Typical Engine | Uncontrolled Engine Cost, Mills/kWh | | Percent $NO_x$ Reduction | Incremental Cost, mills/kWh | Percent $NO_x$ Reduction | Incremental Cost, mills/kWh | Percent $NO_x$ Reduction | Incremental Cost, mills/kWh |
| 3000kW Diesel | Capital | 6 | | 0 | | 0 | | 0.3 |
| (Electrical | Maintenance | 5 | 20-30 | 1.6 | 20 | 0.2 | 20 | 2 |
| Generation) | Fuel | 32 | | 1.2 | | 3.1 | | 0 |
| | Total | 43 | | 2.8 | | 3.3 | | 2.3 |
| 3000 kW Dual Fuel | Capital | 6 | | 0 | | 0 | | 0.3 |
| (Electrical | Maintenance | 5 | 20-30 | 1.6 | 40 | 0.2 | 20 | 4 |
| Generation) | Fuel | 20 | | 0.7 | | 0.4 | | 0 |
| | Total | 31 | | 2.3 | | 0.6 | | 4.3 |
| 3000 kW Natural Gas | Capital | 6 | | 0 | | 0 | | 0.3 |
| (Gas Transport) | Maintenance | 5 | 20-30 | 1.6 | 40 | 0.2 | 20 | 4 |
| | Fuel | 22 | | 0.8 | | 0.4 | | 0 |
| | Total | 33 | | 2.4 | | 0.6 | | 4.3 |
| 750 kW Natural Gas | Capital | 2 | | 0 | | 0 | | 0 1 |
| (Gas Production) | Maintenance | 5 | 20-30 | 1.6 | 40 | 0.2 | 20 | 4 |
| | Fuel | 25 | | 0.9 | | 0.4 | | 0 |
| | Total | 32 | | 2.5 | | 0.6 | | 4.1 |

[a] Assumes 8000 hours of operation per year, 1978 dollars.

**Table 4.** *Estimated Incremental Cost of Combined Controls for a Large Bore Diesel Engine at 40 percent $NO_x$ Reduction*

| | Control Technique | | |
|---|---|---|---|
| Incremental Annualized Control Cost,[a] mills/kWh | Retard | Air-to-Fuel Changes and Manifold Air Cooling | Air-to-Fuel and Retard |
| Capital | 0 | 0.1 | 0 |
| Maintenance | 1.6 | 1.0 | 1.8 |
| Fuel | 2.4 | 1.5 | 1.5 |
| Total | 4.0 | 2.6 | 3.3 |

[a] Assumes 8000 hours in operating year, 1978 dollars.

Other control techniques will require various degrees of evaluation before impacts are clearly understood.

Derate, air-to-fuel ratio changes, manifold air cooling, and ignition retard present the fewest problems in operation and maintenance. Derate has no impact mechanically and can improve durability because of lower operating temperatures and pressures However, additional engines may be required to replace the lost power. Fuel penalties are usually low.

Air-to-fuel ratio changes in the lean direction cause a power loss if larger blowers or turbochargers must be used. If the engine must be operated richer to reduce $NO_x$ emissions, other emissions (e.g., smoke, CO, and HC) can increase. This could cause an attendant increase in engine maintenance. Changes in air-to-fuel ratio in either direction will also generally increase fuel consumption. Finally, operation at air-to-fuel ratios where misfiring or detonation occur can cause severe engine damage

Increased manifold air cooling has little operational or maintenance impact for a unit that is already intercooled, but will increase the size of the heat exchanger, water or air pump, control system, and other system components. Of course, backfitting intercooling on an engine will add maintenance attendant to additional temperature reductions. Changes in fuel consumption are small.

When properly applied, ignition retard has no serious mechanical drawbacks. Some increase in operational and maintenance time would be needed to ensure that the degree of retard is always within safe limits. Increases in fuel consumption are moderate. Excessive amounts of retard, however, can create severe engine problems. Fuel consumption increases rapidly, power drops, misfiring can occur, and smoke levels increase. In addition, mechanical maintenance will increase if the exhaust temperature exceeds the safe limits for valves or the turobcharger (usually 920 K-1200°F). More frequent engine teardown will be required, and higher initial costs will result for higher temperature materials.

Exhaust gas recirculation requires new hardware components which may require added maintenance. Problems of fouling the flow passages of the cooling heat exchanger, the engine turbocharger, and the aftercooler with particulate must be solved, or frequent engine teardown will be required. Under varying load conditions a sophisticated control system is required or the engine may stall or emit unacceptable smoke levels Fuel consumption penalties with EGR are small.

Water injection can cause severe maintenance problems. Deposits from untreated water can build up on internal engine surfaces, and also foul the lubricating oil. The problem can lead to major engine maintenance. Water injection also adds another system to the engine which must be maintained and controlled.

Although not demonstrated, combustion system modifications are expected to present the least impact to operation and maintenance. Maintenance requirements can be expected to increase slightly if additional injectors, spark plugs, and valves are added to the chamber. However, because this control technique involves new design, many of the additional maintenance requirements can be designed out. Fuel penalties are expected to be small.

Catalytic reduction will require no additional engine maintenance, since it is a flue gas treatment technique, rather than an engine modification. However, operating the catalyst system may be expensive. Fouling the catalytic surfaces with particulate may require frequent regeneration. The catalyst may also have a relatively short life and need to be replaced. Another system, ammonia injection, must be included in engine operation. Finally, harmful products of the reaction may be produced if the catalyst temperature varies from the proper level, or if excessive ammonia is injected. The catalyst must be installed and operated on an engine before all these effects can be quantified.

Currently available operational adjustment $NO_x$ controls can only reduce emissions by approximatley 40 percent, while significantly increasing operating cost and maintenance. Advanced combustion chamber redesigns have the potential of achieving similar $NO_x$ reductions but at lower cost and smaller fuel penalty. If very low $NO_x$ emissions are required, catalytic exhaust gas treatment is the only developing technique with that potential.

Table 5 lists achievable control levels and associated control techniques and costs for typical diesel, natural gas, and dual fuel engines, all assumed to be turbocharged. In the case of natural gas and dual fuel engines, the obvious preferred approach from a cost-effectiveness view would be to go directly to the more stringent control level with air-to-fuel adjustment. Note that all values discussed are typical, and may vary from engine to engine.

Combustion modification controls can reduce $NO_x$ emissions without significantly increasing CO and HC emissions from most engines. However, the kinds and distribution of organic compounds emitted from diesel engines are not well characterized and, therefore, are of potential concern.

*Table 5. Projected Control Requirements and Costs for Alternate $NO_x$ Emission Levels*

| *Type* | *$NO_x$ Emission, g $NO_x$/kWh output* | *Control Techniques* | *Control Cost, mills/kWh output* |
|---|---|---|---|
| *Diesel* | *17* | *Baseline* | — |
| | *14* | *Exhaust gas recirculation* | *2.3* |
| | *12* | *Retard* | *2.8* |
| | *10* | *A/F increase + retard* | *3.3* |
| *Natural Gas* | *15* | *Baseline* | — |
| | *12* | *Exhaust gas recirculation* | *4.3* |
| | *11* | *Retard* | *2.4* |
| | *9* | *A/F increase* | *1.0* |
| *Dual Fuel* | *11* | *Baseline* | — |
| | *9* | *Exhaust gas recirculation* | *4.3* |
| | *8* | *Retard* | *2.3* |
| | *7* | *A/F increase* | *1.0* |

## Recommendations

There are two major weaknesses in the data base for combustion modification controls on IC engines. The information on operational effects and long-term durability of these control techniques is incomplete, especially concerning combustion system redesign and catalytic exhaust gas treatment. Information on combining these controls to achieve an optimum of low emissions other than $NO_x$, CO, and total HC is very limited. The amounts and types of organics emitted from these large bore engines are not very well characterized. The potential mutagenicity of organic emissions in diesel exhaust is of major concern.

Research is needed on designing high efficiency low-$NO_x$ emitting engine Even with the best available contro applied, the large bore stationar reciprocating IC engine is the highes $NO_x$ emitter on a heat input basis of al major combustion sources.

EPA is currently sponsoring severa programs in the health effects area a well as new engine designs for low-NO and high efficiency. These program should help resolve many of the majo data gaps in the operational an environmental impacts of $NO_x$ controls

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*The complete report, entitled "Environmental Assessment of Combustion Modification Controls for Stationary Internal Combustion Engines," (Order No. PB 82-224 973; Cost: $13.50, subject to change) will be available only from:*

*National Technical Information Service*
*5285 Port Royal Road*
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