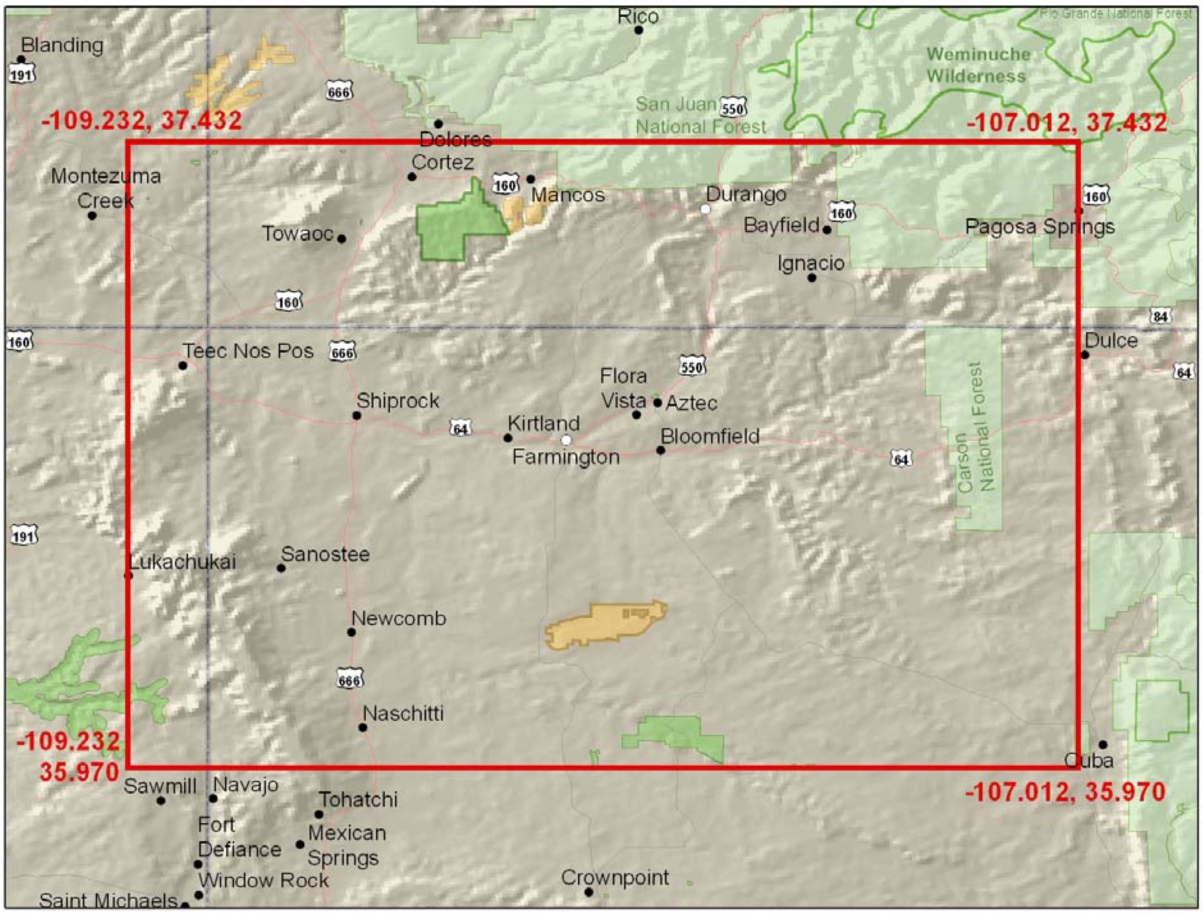
# CUMULATIVE EFFECTS SECTION

# Four Corners Air Quality Task Force
## Report of Mitigation Options




**November 1, 2007**

**The report is a compilation of mitigation options drafted by members of the Four Corners Air Quality Task Force. This is not a document to be endorsed by the agencies involved, but rather, a compendium of options for consideration following completion of the Task Force's work in November 2007.**

# Cumulative Effects Section
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# Cumulative Effects: Preface

## Overview

The Cumulative Effects work group was charged with assisting the source work groups to understand current and future air quality conditions in the region, using existing information. The cumulative effects workgroup was also to assist the other work groups in performing their analysis of the mitigation strategies being developed, within the scope of the Task Force's timeframe and resources. The Cumulative Effects work group was also tasked with suggesting ways for filling technical gaps and addressing uncertainties as identified by the other work groups.

The Cumulative Effects work group was a small group with approximately a half dozen active members representing state governments, tribal governments, local citizens, industry, and the federal government.

## Scope of Work

The following was the original scope of work for the Cumulative Effects (CE) work group.

Specific Tasks:

1. Evaluate air quality effects of candidate mitigation measures as requested by other Task Force work groups, or provide guidance on how candidate mitigation measures could be evaluated.
2. Prepare overarching cumulative estimate of the air quality effects from implementation of all the Task Force recommended mitigation measures.
3. Describe a "gold standard" for the best technical analyses that can be done, and provide recommendations for future analyses. Describe the uncertainty associated with the air quality estimates.
4. Respond to issues referred to the CE work group from other work groups.
5. Recommend additional analysis, studies, etc. that may be necessary for the CE work group to fully carry out its tasks. For example, the CE may feel that it is necessary to conduct an ozone precursor field study with advice from the monitoring group, or an ammonium field study for particulate matter.

## Discussion

In accomplishing #1, the Cumulative Effects work group was charged with assessing upwards of 20 of the numerous mitigation options being proposed by the source-related work groups. For these options, the emissions reductions associated with undertaking the mitigation approach have been estimated. In addition, the work group also detailed methods, assumptions, limitations, and sources of information.

All of the tasks associated with estimating emissions reductions were relative to the oil and gas sector. In order to make much of this work as accurate as possible, the Cumulative Effects work group undertook improvements to the base case inventory for drilling and production activities in the Four Corners region. The base case inventory shows what current and future emissions would be in the absence of additional air pollution mitigation. The best data from the Western Regional Air Partnership (WRAP), the States of New Mexico and Colorado, the Southern Ute Indian Tribe, and industry participants were consolidated and quality assured to create a more accurate and complete inventory than previously existed. Using estimates of the effectiveness of the various mitigation options and applying them to the base case, estimates of the number of tons of pollution that would be reduced by each mitigation option were calculated. Emissions reductions associated with mitigation options directed and motor vehicles used in oil and gas activities were also estimated.

Because of the length of time and resources required to set up modeling analyses and to accomplish them, the modeling task (#2) was moved outside the Task Force process. It will inform regulatory agencies of the air quality benefits of options after the Task Force report is completed. The approach taken is akin to the "gold standard," and thus #3 was addressed as part of the agencies' modeling effort.

Consistent with #4, the Cumulative Effects work group also responded to requests for additional information relative to a few of mitigation options, for example, answering questions about monitoring at a power plant and providing a bit more detailed description of overall emissions.

Related to #5, suggestions for future research associated with implementation of the mitigation options are presented, for example, with regard to the sources and impacts of ammonia emissions and the economic effect of various mitigation option

## OVERVIEW OF WORK PERFORMED

The Cumulative Effects (CE) work group was requested to provide information on a number of mitigation options described by the source work groups. Table 1 summarizes the reasons why the Cumulative Effects work group may or may not have researched a particular question, and a brief description of the outcome if work was performed.

**Table 1: Summary of mitigation option findings.**

| OPTION | ACTION TAKEN BY CE | SUMMARY OF RESULT |
|---|---|---|
| Tax or Economic Incentives for Environmental Mitigation | CE did not have expertise to address this option. | No action. |
| Selective Catalytic Reduction (SCR) on Drilling Rig Engines | There was insufficient time to address this option. | Some data exists on drilling emissions. The State of Wyoming evaluated this technology based on a pilot study in the Jonah Field & concluded that is not a cost effective technology, but further analysis is needed.[1] |
| Implementation of EPA's Non Road Diesel Engine Rule – Tier 2 through Tier 4 Standards for Drilling Rigs | There was insufficient time to address this topic. | An important piece of information is that these engines typically last 4-10 years and then need to be replaced. This means that there will be a constant infusion of new technology engines over time. However, faster turnover would reduce emissions in the near-term. |
| Industry Collaboration for RICE | This option was not evaluated because it is not possible to quantify emission reductions. | No action. |
| Install Electric Compression for RICE | This option was evaluated. | Replacement of low emission engines with electric power grid would result in an overall increase in emissions. A reduction in NOx emissions would occur, however, there would be an increase greenhouse gas emissions due to increased electrical generation requirements. |
| Follow EPA Proposed New Source Performance Standards (NSPS) for RICE | This option was evaluated. | This proposed emission standard will become the baseline for new modified and reconstructed engines. Future year projections indicate that these standards will minimize growth in oil and gas emissions from natural gas fired engines. |
| Install Selective Catalytic Reduction (SCR) on Lean Burn Engines for RICE | This option was evaluated. | There is very little information on the installation of this control technology on natural gas fired engines. What is available indicates that in the Four Corners area the installation of this technology would result in small NOx reductions. In addition, the cost to control emissions would be relatively high.[2] **Differing Opinion:** Disagree with the last two sentences. |
| Install Non Selective Catalytic Reduction (NSCR) on Rich Burn Engines for RICE | This option was evaluated. | It was found that installation of NSCR on small engines could reduce NOx emissions significantly. The USEPA performance standard for rich burn engines will likely require installation of NSCR for new, modified and reconstructed rich burn engines. |

| OPTION | ACTION TAKEN BY CE | SUMMARY OF RESULT |
|---|---|---|
| Install Lean Burn Engines for RICE | This option was evaluated. | Emission inventory data indicated that on large engines of greater than 500 horsepower this technology or NSCR is already being used on the majority of the engines in the region. The use of these engines results in significant reductions in NOx over the use of rich burn engines, and may be beneficial when applied to smaller engines. |
| Install Selective Non Catalytic Reduction (SNCR) for RICE | This option was evaluated. | It was determined that this technology is unlikely to be used because it is less effective than SCR or NSCR. |
| Install Oxidation Catalyst on Lean Burn Engines for RICE | This option was evaluated. | This mitigation option was evaluated in terms of HAPs emissions and VOCs. Previous modeling analyses indicated that HAPs impacts are localized. It was found that VOC emission reductions would be primarily methane and ethane which have a low photochemical reactivity, and likely do not contribute to ozone formation.<br>**Differing opinion:** Contest the previous statement as to accuracy. Methane is a greenhouse gas and reduction of methane emissions is desirable in combating global climate change. |
| Install Optimized/Centralized Compression | This option was evaluated. | It was concluded that there would be no opportunities for reducing emissions as a result of implementing this option. |
| Next Generation Control Technology for RICE | This option was evaluated. | Because these technologies are emerging, it is not possible to quantify the additional benefits of controls. |
| Automation of Wells to Reduce Truck Traffic | This option was evaluated. | Potential fugitive dust emission reductions were evaluated. The effect of dust emissions which are primarily PM10 is not regional. Although there are dirt roads over much of the area, impacts will be localized. |
| Centralized Produced Water | This option was evaluated. | Potential fugitive emission reductions were evaluated. The effect of dust emissions which are primarily PM10 is not regional. Although there are dirt roads over much of the area, impacts will be localized. |
| Efficient Routing of Water Trucks | This option was evaluated. | Potential fugitive emission reductions were evaluated. The effect of dust emissions which are primarily PM10 is not regional. Although there are dirt roads over much of the area, impacts will be localized. |
| Cover Lease Roads with Rock or Gravel | This option was evaluated. | Potential fugitive emission reductions were evaluated. The effect of dust emissions which are primarily PM10 is not regional. Although there are dirt roads over much of the area, impacts will be localized. |
| Enforcing Speed Limits on Dirt Roads | This option was evaluated. | Potential fugitive emission reductions were evaluated. The effect of dust emissions which are primarily PM10 is not regional. Although there are dirt roads over much of the area, impacts will be localized. |

| OPTION | ACTION TAKEN BY CE | SUMMARY OF RESULT |
|---|---|---|
| Selective Catalytic Reduction (SCR) NOx Control Retrofit | This option was not evaluated. | Only emission reductions were estimated, not effects on visibility or ozone, so could be done as a part of future work. |
| Emissions Monitoring for Proposed desert Rock Energy Facility to be Used Over Time | This option was assessed. | The option was looked at by the CE Work Group, and an assessment included. |
| Declining Cap and Trade Program for NOx Emissions for Existing and Proposed Power Plants | This option was not evaluated. | Only emission reductions were estimated, not effects on visibility or ozone, so could be done as a part of future work. |
| Chronic Respiratory Disease Study for the Four Corners Area | A brief look at the data was done. | A summary of ozone trends generally showed an upward trend. Another look at this question will be provided by future work. |
| Install Electric Compression | This option was evaluated. | See above. |

**Emissions Summary**

The overall emissions of nitrogen oxides (NOx) and volatile organic compounds (VOC) broken into broad source categories can provide some perspective when reductions from various mitigation options are presented in subsequent sections. Table 2 shows the relative importance of groups of sources in the Four Corners region:

**Table 2: Percentage of total future year emissions in 2018 by pollutant.**

| SOURCES | NOx EMISSIONS (%) | VOC EMISSIONS (%) |
|---|---|---|
| Mobile | 2 | 5 |
| Area | 1 | 23 |
| Oil & Gas | 26 | 32 |
| Power Plants | 40 | 1 |
| Other Point Sources | 30 | 39 |

This table demonstrates that oil and gas production, electrical generation, and other industrial activities are the largest emitters of nitrogen oxides, while oil and gas production, industrial facilities other than those related to power plants and oil and gas production, and area sources emit the majority of VOC. Area sources are those industrial and commercial activities that are small enough to not be required to obtain an air quality permit to operate. Area sources also include a broad range of human activities that result in small amounts of pollution on an individual basis.

The data presented in the summary table have been derived primarily from the Western Regional Air Partnership (WRAP) emission inventory. For these categories, the Four Corners Air Quality Task Force requested an extraction from the WRAP regional database for the Four Corners area that encompasses portions of Colorado, New Mexico, Arizona, and Utah. The one exception is for oil and gas sources, which were estimated using updated information developed by the Cumulative Effects work group.

**Emissions Reduction Summary**

Table 3 summarizes emission reductions for mitigation options for which the estimates were made in order to facilitate comparison. Some estimates were made by the Cumulative Effects work group for the Oil and Gas work group, while some were made by the Power Plants (PP) work group for their own options. Descriptions of the mitigation options and how the estimates were derived can be found in the section of each work group, respectively.

**Table 3: Mitigation Option Summary**

| Mitigation Option | Work Performed By | Pollutant Reduced | Reduction Estimate (tpy) |
|---|---|---|---|
| Control Technology Options for Four Corners Power Plant | PP | NOx | 11,688 |
| Control Technology Option for San Juan Generating Sta. | PP | NOx | 6,166 |
| Enhanced SO2 Scrubbing | PP | SO2 | 2,083 |
| Selective Catalytic Reduction (SCR) NOx Control Retrofit | PP | NOx | 29,987 to 46,684 |
| BOC LoTOx System for Control of NOx Emissions | PP | NOx | 43,257 |
| Baghouse Particulate Control Benefit | PP | PM10 | 465 |
| Declining Cap and Trade Program for NOx Emissions | PP | NOx | 3,428 |
| Install Electric Compression w/ Grid Power | CE | NOX & SO2 | Variable – See note below |
| Install Electric Compression w/ Onsite Gen Power | CE | NOX & SO2 | 12,000 to 40,721 |
| Use of NSCR for NOx Control on Rich Burn Engines | CE | NOx | 16,588 to 21,327 |
| Use of SCR for NOx Control on Lean Burn Engines | CE | NOx | Insufficient information to quantify |
| NSPS Regulations | CE | NOx | 0 |
| Optimization/Centralization | CE | NOx | 0 |
| Use of Oxidation Catalyst for Formaldehyde & VOC Control on Lean Burn Engines | CE | VOC | 1619 |
| Automation of Wells to Reduce Truck Traffic | CE | PM10 & NOx | 196 & 92 |
| Reduced Truck Traffic by Centralizing Produced Water Storage | CE | PM10 | 39 |
| Reduced Truck Traffic by Efficiently Routing Produced Water Disposal Trucks | CE | PM10 | 196 |
| Reduced Vehicular Dust Protection by Covering Lease Roads with Rock or Gravel | CE | PM10 | 206 |
| Reduced Vehicular Dust Production by Enforcing Speed Limits | CE | PM10 | 73 |

Note: Some engine configurations are as efficient as current coal-fired generating stations without being subject to line losses, whereas other engines would be less efficient than using commercially available line power.

**Suggestions for Future Work**

As the Cumulative Effects work group completed the tasks of evaluating mitigation options, it became clear that there is a need for future work to provide regulatory agencies additional information on the benefits of reducing pollution emissions into the air in the Four Corners region. Additional detailed modeling is planned by the agencies that will provide more refined information regarding the actual effects of proposed mitigation programs. The modeling analysis is scheduled for completion in the fall of 2007. Leading into the analysis of mitigation programs, some updating of source information will be necessary. An example would be for drilling rigs.

To supplement the modeling analyses, additional monitoring of pollutants and meteorology throughout the Four Corners region would be useful. This monitoring would provide a basis for establishing whether model predictions are accurate and would help determine air quality trends. Currently, there are relatively few air monitoring sites in the Four Corners region to use in testing model performance. Monitoring for ammonia would be particularly useful as it enhances the ability of the model to estimate the effects of air pollutant emissions on visibility.

The Cumulative Effects work group was required to delve into agency emissions inventories in detail, and this work exposed many weaknesses in state and tribal inventories. For future analysis of options, it is recommended that states and tribes require more robust reporting of industrial entities, including reporting of facilities that may currently fall below permitting or reporting thresholds. States and tribes may require regulatory changes to reporting requirements to accomplish this. Lack of detailed reported data introduces a high level of uncertainty into analysis of options for mitigation. State and tribal agencies need to be able to quantify cumulative reductions with certainty in order to appropriately evaluate and prioritize options. By performing analyses that combine trends in emissions with trends in monitoring data, information may be identified regarding source receptor relationships.

The work group also recommends a review of existing field test data and an expansion of the existing state and tribal field testing programs for source emissions. Improvement of inventory emissions estimates will result in better modeled estimates of air pollution concentrations. A focused effort to obtain and share emissions data from a variety of oil and gas engines under different operating conditions would be particularly beneficial in inventory improvement.

Finally, the work group recommends that economic analysis of options be conducted to provide cost/benefit information to state and tribal agencies. The work group did not have the time or resources to conduct economic modeling, but economic data is of great importance in analyzing and prioritizing options. Such modeling could analyze “bundled” options to minimize analysis costs.

Endnotes:

1 Personal communication between Reid Smith (BP) and David Finley (WDEQ).

2 EPA Speciate data for natural gas-fired engines.

## DETAILED DESCRIPTIONS OF MITIGATION OPTION ANALYSES

### Mitigation Option: Install Electric Compression with Grid Power

**Description of Option**
Under this option, existing or new natural gas fired internal combustion engines would be replaced with electric motors for powering compressors. Electric motors would be selected to deliver equal horsepower to that of the internal combustion engines being replaced.

**Assumptions**
It is assumed that electricity to power the electric motors would come from the existing electrical grid. The majority of the base load electricity in the region is produced from coal-fired electrical generation.

This option did not consider the installation of natural gas electrical generation systems, which would have entirely different emissions characteristics from coal-fired electrical generation. In this approach, small high-emission natural-gas engines would be replaced by electric motors driven by a larger low-emission natural-gas engine. Although natural gas fired generators have not been used in the region, the feasibility for possible future use should be investigated. [1]

In evaluating the changes in emissions for shifting from natural gas to electric (coal) powered compression, it is necessary to examine the emissions for each power source on an equivalent energy basis. Thus, for the same amount of energy consumption, the change in emissions from natural gas versus electricity must be considered.

In the evaluation of this mitigation option, it is not appropriate to consider emission modifications to existing electrical generating facilities. While such modifications may occur or new lower emitting facilities may be developed, the inclusion of such changes in emissions are speculative at this point in time. The emission data was developed using the EPA program EGRID. [2]

In this analysis, it was assumed that for visibility SO2 and NOx emissions are equivalent in terms of impacts because they cause approximately the same amount of visibility impairment. This is because the dry scattering coefficients for converting SO4 and NO3 concentrations into visual range are approximately equivalent. NOx emissions do participate in photochemical reactions that produce ozone.

However, ozone modeling analyses performed by the state of New Mexico as part of the Early Action Compact (EAC) and ozone monitoring data in the area suggest that ozone formation is VOC limited and consequently NOx emission reductions may cause increases in ozone concentrations. Both SO2 and NO2 ambient concentrations are in compliance with federal and state air quality standards.

As a first order approximation, 1 ton per year of SO2 emissions will result in the same amount of potential visibility impairment as 1 ton per year of NOx. In reality, because of the more complex and competitive reactions involving both SO4 and NO3, SO2 emissions may result in more visibility impairment than NOx emissions.

From an economic basis, conversion of natural gas-fired engines to electric compression is only practical for large engines and only in areas where electricity is already available within close proximity. This is because most locations do not currently have electrical power and it would not be cost effective to install power for small engines.[3]

In Colorado, most large engines (greater than 500 hp) are lean burn or have NSCR installed to reduce emissions (average emission factor for this size engine is 1.4 g/hp-hr). In addition, any new engines in this size category must achieve an emission limit of 1 g/hp-hr.[4] These engines are typically located at remote sites where power is not available.

In New Mexico, for large engines (greater than 500 hp) the average emission factor is 3.0 g/hp-hr. There are a total of 354 engines in this size category.[5] Of that total, 221 engines have NOx emission less than or equal to 1.5 g/hp-hr (62 percent), 108 engines have NOx emissions in the range of 1.6 to 5 g/hp-hr (31 percent) and 25 engines have NOx emissions greater than 5 g/hp-hr (7 percent). Under a recent BLM EIS Record of Decision (ROD), new engines must achieve 2 g/hp-hr.

**Method**

The energy consumption of a typical lean burn engine was calculated, converted into pounds per mega watt-hour and was compared to SO2 and NOx emissions from existing coal-fired power plants. This was done assuming an emission factor between 1 g/hp-hr and 5 g/hp-hr. It was then assumed that the computed emissions per mega watt of power represented emissions for 1-hour and were converted into tons per year by multiplying by 8760 hours per year and dividing by 2000 pounds per ton.

As indicated in Table 4, a shift from natural gas to electric (coal) for an engine of 1 MWhr capacity (approximately 1,342) hp with an emission factor of 1 g/hp-hr would result in an **increase** of 14 tons per year of SO2 + NOx. With engine emissions of approximately 2.0 g/hp-hr there is no net change in overall emissions by shifting from natural gas to electric. For all cases, the shift from natural gas to electricity results in higher greenhouse gas emissions.

**Conclusions**

NOx emissions from large engines in Colorado and the remaining engines in New Mexico are currently controlled at sufficient levels so that shifting from natural gas to electric compression may only result in a small reduction in emissions and in many cases would result in an increase in SO2 and NOx emissions.

For all categories of engines, greenhouse emissions would increase by shifting compressors from natural gas to electric.

**Table 4: Change in SO2, NOx and Greenhouse Gas Emissions by Shifting from Natural Gas Compression to Electricity**

| **Four Corners Grid Average Emissions lbs/MWh** | | **tons/MWh/yr** |
|---|---|---|
| **SO2** | **2.65** | **11.6** |
| **NOx** | **3.64** | **15.9** |
| **NOx + SO2** | **6.29** | **27.6** |
| **CO2** | **1,989** | **8711.8** |

**Table 4A: Example Engine Changes**

| Caterpillar 3608 LE Average Emissions lbs/MWh (equivalent) | | Other Emission Rates (gr/hp-hr) | | | | |
|---|---|---|---|---|---|---|
| SO2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hp/kw-hr | 1.342 | 1.342 | 1.342 | 1.342 | 1.342 | 1.342 |
| Hp/mw-hr | 1,342 | 1,342 | 1,342 | 1,342 | 1,342 | 1,342 |
| Cubic feet gas/mw-hr | 9,815 | 9,815 | 9,815 | 9,815 | 9,815 | 9,815 |
| NOx Emission Rate gr/hp-hr | 1 | 2 | 3 | 4 | 5 | 16 |
| SO2 lbs/mw-hr | 0 | 0 | 0 | 0 | 0 | 0 |
| NOx lbs/mw-hr | 3.0 | 5.9 | 8.9 | 11.8 | 14.8 | 47.3 |
| CO2 lbs/mw-hr | 1,138 | 1,138 | 1,138 | 1,138 | 1,138 | 1,138 |
| | | | | | | |
| SO2 tons/MWh/yr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NOx tons/MWh/yr | 13.0 | 25.9 | 38.9 | 51.8 | 64.8 | 207.4 |
| CO2 tons/MWh/yr | 4985 | 4985 | 4985 | 4985 | 4985 | 4985 |
| | | | | | | |
| Delta SO2 tons/Mwh/yr | 11.6 | 11.6 | 11.6 | 11.6 | 11.6 | 11.6 |
| Delta NOx tons/Mwh/yr | 3.0 | -10.0 | -22.9 | -35.9 | -48.9 | -191.4 |
| Delta NOx +SO2 tons/MWh/yr | 14.6 | 1.6 | -11.3 | -24.3 | -37.3 | -179.8 |
| Delta CO2 tons/Mwh/yr | 3727 | 3727 | 3727 | 3727 | 3727 | 3727 |
| Cat. 3608 Assumptions:<br>9815 Btu/kw-hr<br>"Sweet" Natural Gas<br>NOx - 1 gr/hp-hr<br>1 cu ft gas = 1,000 btu | | | | | | |

**Endnotes:**

1 Factors that need to be considered for use of a natural gas fired electrical generation system are: engines must be located in clusters that lend themselves to being interconnected by power lines; generator and line reliability need to be evaluated; the efficiency of electrical generators systems compared to natural gas fired compression must be evaluated; it needs to be determined if natural gas fired electrical

generators have substantially lower emissions than new natural gas fired compressor engines; cost and the benefits of this analysis need to be evaluated in terms of potential ambient air quality benefits, not simply emission reductions.

[2] EPA EGRID Program http://www.epa.gov/cleanenergy/egrid/index.htm

[3] The quantification of changes in emissions of this option does not address the cost of implementation or the reliability of the electrical grid. These issues must be considered if this option is deemed beneficial from an environmental perspective.

[4] Northern San Juan EIS Record of Decision (April 2007)

[5] NMED Part 70 permits, Minor source permits and Environ inventory.

## Mitigation Option Analyses: Replace RICE Engines with Electric Motors for Selected Oil and Gas Operations (Alternative 2 – Power Source: On-Site Natural Gas-Fired Generators)

**Description of Analysis of the Alternative Option**

As an alternative to grid power, dedicated on-site, natural gas-fired, electrical generators can be used to supply power to electric motors suitable for selected replacement of "dirty" compression and other E&P RICE engines. This alternative to the Install Electric Compression (Grid Power Alternative) expands candidate engines for replacement beyond compressor engines since some existing compressor engines, particularly in the Northern San Juan Basin, are already well controlled. The electric motors are rated on an equivalent horsepower basis to RICE engines targeted for replacement. This analysis covers both the top 25 "dirtiest" and all essentially uncontrolled, primarily small, rich burn engines, with emissions greater than 4 g/hp-hr. Net NOx and CO emission reductions are reported in mass emission rates (tons/yr) and normalized mass emission rates (tons/yr/MW).

**Assumption**

The currently available gas electric generators run on variety of fuels including low fuel landfill gas or bio-gas, pipeline natural gas and field gas. The gas electric generators are available in the power rating from 11 kW to 4,900 kW. The calculated net reduction in emissions from existing RICE engines to electric motors powered by on-site electric generators were done based on an equivalent power basis.

In order to implement this option an electrical infrastructure would need to be constructed between the locations of the gas fired generator and the electric compressors. In addition, a control system would have to be developed so that as the engine load (demand) varies the generator supply would be adjusted to meet the demand. In order to implement this option it may be necessary to connect the generator to the power grid so that excess electricity could be utilized. Several engine companies manufacture gas electric generators. We assumed use of a mid-size Caterpillar gas electric generator as the reference natural gas on-site generator for calculating the net emissions for this alternative (not to be construed as an endorsement). The Caterpillar G3612 gas electric generator with power rating of 2275 kW emits 0.7 gram/hp-hr NOx and 2.5 g/hp-hr CO. It is important to note that the emissions from such generators are not different than what can be achieved from a lean burn engine (available with a capacity in excess of 500 hp) and not appreciable different emissions from new NSPS engines.(2 g/hp-hr vs 0.75g/hp-hr).

The selection of RICE engines for electrification analysis did not consider important factors that would need to be weighed in determining the degree of implementation that might be feasible. This would include the locations and spatial distribution of engines (e.g., proximity of with each other), the number and cost of required on-site generators, maximum transmission line lengths and any ROW issues, number of electric motors and costs, and operational and environmental factors.

Available engine inventories, for producers in New Mexico and Colorado (e.g., bp) were combined in order to obtain a representative engine inventory for the San Juan Basin.

**Method**

The NOx and CO emission of the reference Caterpillar G3612 generator were given in g/hp-hr which was converted into lbs/MW-hr by multiplying the (1,342 hp/MW) and divided by (454 gm/lbs). Further, the NOx and CO emissions in tons/yr/MW units were obtained by multiplying 8760 hrs/yr and dividing by 2000 lbs/ton. The NOx and CO emission factors and calculated normalized emission rates for NG generator are given in Table 5.

**Table 5: Gas Electric Generator Emissions**

| 2,275 kW | | | |
|---|---|---|---|
| | (g/hp-hr) | (lbs/MWh) | (tons/yr/MW) |
| **NOx** | 0.70 | 2.07 | 9.06 |
| **CO** | 2.50 | 7.39 | 32.37 |

The net emission reduction was first calculated for the replacement the 25 worst NOx emitters and compared with a greater subset of replaced engines (e.g., engines emitting more than 4 g/hp-hr engines). The selection of the 25 worst engines is based on potential tons/yr NOx emission of individual engines. The potential engine emission calculation assumes 100% load and 8760 hrs operation per year. Engine emission factors were obtained by combining the New Mexico and Colorado engine inventory database used the Alternative 1 analysis.

The following illustrates how the mass emission rates (ER) and normalized mass emission rates (NER) were calculated for each engine size group.

EF (24.6 g/hp-hr) * Engine Size (1,350 hp) * (# of engines) * (8,760 hrs/yr) * (1/454g/lbs) * (1/2,000 lbs/ton) = 320.4 (tons/yr)

EF (24.6 g/hp-hr) * (1,342 hp/MW) * (8,760 hrs/yr)*(1/454g/lbs)*(1/2,000 lbs/ton) = 318.5 (tons/yr/MW)

The 25 engines with the highest mass emission rates in the combined inventory were identified. The total power of these was obtained by adding the rated power of individual engines, which was used to calculate equivalent emission from gas generator needed to run the 25 electric motors replacing the replaced RICE engines. For the case of the 25 highest emitting engines, the average capacity is 684 hp, the maximum capacity is 2,400 hp and the lowest capacity is 325 hp. What is important about the capacities is that for the majority of these engines lean burn engines are available. Table 6 shows the normalized average emissions in tons/yr/MW as well as net potential mass emission reductions for both NOx and CO emission based on the 25 worst NOx emitters. The average emission factor for the top 25 engines is 23.9 g/hp-hr.

**Table 6: Emission change if 25 worst NOx emitting engines retired**

| Total rated power = 17,108 hp = 12.8 MW | | |
|---|---|---|
| | **NOx** | |
| | Avg. NER (tons/yr/MW) | Total ER (tons/yr) |
| Caterpillar G3612 | +9.06 | +115.51 |
| Worst 25 Engines | -251.21 | -3,106.40 |
| Net Reduction | -242.14 | -2,990.89 |

Table 7 shows the same calculations based on all the engines emitting more than 9 g/hp-hr.

**Table 7: Emission change if all engines emitting > 4g/hp-hr NOx retired**

| 2925 engines with total rated power = 233,278 hp = 205.7 MW Emitting > 9 g/hp-hr NOx | | |
|---|---|---|
| | | |
| | **NOx** | |
| | avg/engine (tons/yr/MW) | Total (tons/yr) |
| Caterpillar G3612 | 9.06 | 1,863.75 |
| All engines emitting more than 4.0g/hp-hr | 211.36 | 40,562.21 |
| Net Reduction | -202.30 | -38,698.45 |

## Conclusion

A net reduction of approximately 2,991 tons/yr of NOx  can be achieved if the 25 engines with the highest NOx mass emission rate t operating in the San Juan Basin are replaced with nine 2 MW well controlled on-site natural gas electrical generators.  Although most large RICE engines operating in the San Juan Basin are relatively small emitters individually and collectively, a significant number of small and medium range engines are not controlled well and collectively represent a relatively large E &P emission source group.  The analysis in this alternative reveals a potentially significant emission reductions are possible for this group of engines.  The calculation of emission reduction for replacing all the engines emitting more than  9.0  g/hp-hr NOx (over 2925  engines) with electric motors powered by several similar natural gas generators show that 38,698  tons/ per year of NOx reduction might be achieved by this option.  This level of replacement would require approximately 90 on-site generators rated at 2 MW.

The potential emission reductions presented in this analysis assume optimal mitigation option implementation conditions which may not be nearly as optimistic if more detailed data were available and factored into the analysis.  The selection of engines for electrification analysis did not consider important factors that would need to be weighed in determining the option feasibility and what degree of implementation would be possible. Factors such as the locations and spatial distribution of engines and operational and environmental issues would need to be considered.  These and other factors would need to be carefully evaluated to better quantify the effectiveness of this alternative in terms of potential emission reductions achievable and certainly in quantifying implementation costs.

## References

1. The emission and power information for the Caterpillar G3612 Gas Generator was obtained from Caterpillar's website. www.cat.com.

2. The engine inventory for NM and CO used to calculate emission reduction was provided by BP America, which includes contributions from: BP, New Mexico Environment Department, Colorado Dept. of Public Health & Environment and ENVIRON

## Mitigation Option: Use of NSCR for NOx Control on Rich Burn Engines

**Description of the Option**

$NO_X$, CO, HC, and formaldehyde emissions from a stoichiometric engine can be reduced by chemically converting these pollutants into nitrogen, carbon dioxide and water vapor. The most common method for achieving this is through the use of a catalytic converter. In a catalytic converter, the catalyst will either oxidize (oxidation catalyst) a CO or fuel molecule or reduce (reduction catalyst) a $NO_X$ molecule.

A process which causes reaction of several pollutant components is referred to as a Non Selective Catalyst Reduction (NSCR) and is applicable only to stoichiometric engines. Engines must operate in a very narrow air/fuel ratio (AFR) operating range in order to maintain the catalyst efficiency. Maintaining low emissions in a stoichiometric combustion engine using exhaust gas treatment requires a very closely regulated air/fuel ratio. Without an AFR controller, emission reduction efficiencies will vary. Most AFR controllers utilize closed loop control based on the readings of an exhaust gas oxygen sensor to determine the air/fuel ratio.

An AFR controller will only maintain an operator determined set point. For this set point to be at the lowest possible emission setting, an exhaust gas analyzer must be utilized and frequently checked.

Some issues associated with current practice NSCR retrofits on existing small engines operating at reduced loads are:

- a problem maintaining sufficient flue gas inlet temperature for correct oxygen sensor operation and the resulting effectiveness of the catalysts
- On engines with carburetors, there is difficulty maintaining the AFR at a proper setting
- On older engines, the linkage and fuel control may not provide an accurate enough air/ fuel mixture
- If the AFR drifts low (i.e., richer), ammonia formation will increase in proportion to the NOx reduction but not necessarily in equal amounts.

The first issue can be mitigated by retarding the ignition timing when the engine operates at reduced loads. The retarded ignition timing reduces NOx emissions and also raises the flue inlet temperature which helps maintain the catalyst efficiency. Eliminating or mitigating the second, third, and fourth issues require a closed-loop feedback control with an exhaust oxygen sensor to continuously adjust the AFR. One way of doing this is to adjust the carburetor so it operates slightly lean and use the feedback control to adjust the amount of supplemental fuel supplied to a port downstream of the carburetor. Worn carburetors and linkages should be replaced as a maintenance issue.

**Assumptions**

Currently, recent EIS RODs in Colorado and New Mexico require performance standards for new or replacement engines that will accelerate the implementation of the 2008 and 2010 federal NSPS for non road engines. Most engines in the 4 Corners Region in excess of 500 hp are lean burn engines and that trend is expected to continue in the future. These engines meet low emission standards through lean burn combustion technology and NSCR catalyst cannot be installed on this type of source. Therefore, the implementation of NSCR technology would have little or no effect on emission levels for new or replacement engines in excess of 500 hp. New or replacement engines having capacities of less than 500 hp and 300 hp will be required to meet an emission limit of 2 g/hp-hr in Colorado and New Mexico, respectively. Because of the limited availability of lean burn engines in this size range, NSCR will have to be used to achieve the prescribed emission levels. Thus, it is very likely that new or replacement engines will use this technology and there will be no additional possible NOx emissions reductions. It is important to note that a properly designed and operated NSCR system can achieve emission levels less than 2 g/hp-hr. However, the question becomes one of maintaining emissions at lower levels on a continuous basis and the operator's need to have a safety factor for ensuring continuous compliance with source emission limits. Thus, on average, actual emissions will be less than the prescribed regulatory limits, however, there will be times when emissions will approach the regulatory limit.

In examining additional NOx mitigation (beyond current regulatory drivers), NSCR would be applicable to existing rich burn engines that have a capacity of less than 500 hp.

In order for NSCR technology to result in any reduction of NOx emissions in the 4 Corners Region, it would have to be implemented on existing engines less than 500 hp. Estimates of potential emission reductions were calculated for engines in the range of 300 to 500 hp, 100 to 300 hp and between 75 hp and100 hp. Currently, there is no single retrofit kit that can be installed on existing engines. Even if an air fuel ratio controller with an oxygen sensor were installed, it is uncertain if the carburetor linkage would allow an accurate and precise enough control required to maintain the proper air fuel mixture without repair or upgrade.

However, compliance data (unannounced tests) obtained from the SCAQMD for 215 retrofitted rich burn engines show that over 90% of these engines, with installed AFRC, were able to meet or do better than 2 g/hp-hr. Six engines were essentially uncontrolled due to lack of any installed AFRC. Over 77% of the tested engines did better than 1 g/hp-hr (SCAQMD, 2007).

**Engine Size >300 hp and < 500 hp**

The uncontrolled NOx emission factor for existing rich burn engines between 300 hp to 500 hp in Colorado and New Mexico ranges from 11.4 to 21 g/hp-hr. The average emissions from the 11 rich burn engines in this size group are 18.3 g/hp-hr. The mass emission rate of a combined 3,660 hp for these engines total nearly 650 tons NOx/yr. Many of the engines in the 300-500 hp range already had some emission controls on them (such as being lean burn).

In new applications, laboratory data shows that NSCR can exceed 90% NOx reduction and in some cases possibly 95%. Because mitigation is being considered on a fleet of older existing engines, it may not be possible to achieve a 90% plus level of performance reliably in the field. Field tests to address this and other issues are being planned by Kansas State and are expected to start soon. Based on what we know now, lab data and existing compliance data from an inventory of over 200 retrofitted operating engines in southern CA., it was assumed that a well designed NSCR retrofit kit could reliably achieve NOx reduction in the range of 70% to 90%, Applying NSCR retrofits on the identified 11 "dirty engines" could reduce the NOx emissions to 1.8 tg/hp-hr (an ~ 450 tons/yr reduction) at the low end and 5.5 g/hp-hr at the high end (an ~ 590 ton/y reduction).

**Engine Size > 100 hp < 300 hp**

The uncontrolled NOx emission factor for existing rich burn engines between 100 hp to 300 hp in Colorado and New Mexico ranges from 15 to 24 g/hp-hr. The average emissions from the 240 rich burn engines in this size group are 19.1 g/hp-hr. The mass emission rate of the combined 38,394 hp for these engines total over 7,000 tons NOx/yr. Some engines in this size range were excluded from this group because they were identified as lean burn

Based on what we know now, lab data and existing compliance data from an inventory of over 200 retrofitted operating engines in southern CA, it was assumed that a well designed NSCR retrofit kit could reliably achieve NOx reduction in the range of 70% to 90%, Applying NSCR retrofits on the 240 identified "dirty engines" could reduce the NOx emissions to 1.9 g/hp-hr (an ~ 6,500 tons/yr reduction) at the low end and 5.7 g/hp-hr at the high end (an ~ 5,000 ton/y reduction). Not all retrofits may be operationally practical or economically feasible.

**Engine Size > 75 hp and < 100 hp**

The uncontrolled NOx emission factor for existing rich burn engines between 75 hp to 100 hp in Colorado and New Mexico ranges from 9.4 to 22.4 g/hp-hr. The average emissions from the 901 rich burn engines in this size group are 19.7 g/hp-hr. The mass emission rate of the combined 84,307 hp for these engines total over 11,200 tons NOx/yr. The lowest emitters are a group of Ford engines that may have EGR, but the database does not specify whether they have EGR.

Based on what we know now, lab data and existing compliance data from an inventory of over 200 retrofitted operating engines in southern CA, it was assumed that a well designed NSCR retrofit kit could reliably achieve NOx reduction in the range of 70% to 90%, Applying NSCR retrofits on the 900 identified “dirty engines” could reduce the NOx emissions to 5.9 g/hp-hr (an ~ 11,200 tons/yr reduction) at the low end and 2.0 g/hp-hr at the high end (an ~ 14,400 ton/y reduction). Not all retrofits may be operationally practical or economically feasible.

There is considerable uncertainty in the NOx reduction in these engines, which tend to be older than the engines in other size ranges. Attention to worn linkages and carburetor parts as well as closed-loop AFR control is expected to be necessary if these engines are to achieve effective NOx reduction.

Additional long term testing of the use of NSCR on existing small engines must be performed prior to any large scale implementation of this option. Currently, testing is beginning that will address the field application of this technology for retrofit conditions on rich burn small engines..[1]

**Method**

A spreadsheet containing the combined engine inventories for Colorado and New Mexico was developed. For each of the three size ranges of interest, a new database was created in which engines outside the size range of interest were deleted. Each of the three newly created databases were further modified by deleting all engines that are identified by their model designation as “lean-burn” and by deleting all remaining engines whose NOx emissions are 5.0 g/hp-hr or less. The resulting three databases contain only rich-burn engines in the size ranges of interest. Overall NOx emissions were totaled for each of the three size ranges, and emissions reductions of 70% and 90% were applied. resulted in a reduction in NOx emissions of 723 tons per year (a 7 percent reduction of Colorado oil and gas emissions). The engines in the New Mexico inventory were treated similarly.

One important point is that the New Mexico inventory indicated that 1,024 engines were less than 40 hp, which is the proposed de minimus threshold in the NSPS. Under the proposed regulation, EPA concluded that control of this size engine is not appropriate or cost effective. In New Mexico this class of engines had emissions of 2,049 tons per year (i.e., each engine had emissions of approximately 2 tons per year).

Table 8 presents the projected changes in NOx emissions if NSCR were installed on existing engines in Colorado and New Mexico.

**Table 8: Emission Reductions from implementing NSCR on Existing Rich Burn Engines in Colorado and New Mexico**

Colorado and New Mexico, 70% Reduction - NSCR on all Existing Rich-Burn Engines

| Engine Size | Reduction (%) | Average Mitigated Emission Factor (g/hp-hr) | Unmitigated Total (16-year 2018-year) Average NOx Emissions (t/yr) | NOx Reduction (t/yr) |
|---|---|---|---|---|
| < 500 hp Eng > 300 hp | 70 | 5.5 | 3150 | 453 |
| < 300 hp Eng > 100 hp | 70 | 5.7 | 5948 | 4934 |
| < 100 hp Eng > 75 hp | 70 | 5.9 | 13317 | 11201 |
| **Total Reduction** | | | **51783** | **16588** |
| **Percent Reduction** | | | | **32** |

Colorado and New Mexico, 90% Reduction – NSCR on all Existing Rich-Burn Engines

| Engine Size | Reduction (%) | Mitigated Emission Factor (g/hp-hr) | Unmitigated Total (16-year 2018-year) Average NOx Emissions (t/yr) | NOx Reduction (t/yr) |
|---|---|---|---|---|
| < 500 hp Eng > 300 hp | 90 | 1.8 | 3150 | 582 |
| < 300 hp Eng > 100 hp | 90 | 1.9 | 5948 | 6343 |
| < 100 hp Eng > 75 hp | 90 | 2.0 | 13317 | 14402 |
| **Total Reduction** | | | **51783** | **21327** |
| **Percent Reduction** | | | | **41** |

## Conclusions

Installing NSCR on existing engines less than 500 hp in Colorado and New Mexico would result in a reduction of approximately 16,588–21,327 tons per year of NOx over current projected emissions in 2018.

Additional field testing on the installation of retrofit NSCR on engines less than 500 hp is needed to document what level of emission control could be achieved on a continuous basis.

Detailed modeling is planned that will quantify the air quality benefit of such reductions either separately or in combination with other potential mitigation measures. For visibility, currently in the Mesa Verde and Wimenuche Class I Areas NOx emissions are a very small portion of the total extinction budget, however in recent years the trend has been flat or showed slight increases. Also, because of complex photochemical reactions involving VOC emissions and NOx emissions, changes in NOx emissions could result in localized increases or decreases in ozone. Regional effects of changes in ozone precursor emissions would need to be determined using a photochemical model.

## Mitigation Option: Use of SCR for NOx Control on Lean Burn Engines

**Description of the Option**

Using this option, existing or new lean burn natural gas fired internal combustion engines would be installed with selective catalytic reduction (SCR). This technology uses excess oxygen in a selective catalytic reduction system. Reactant injection of industrial grade urea, anhydrous ammonia, or aqueous ammonia is required to facilitate the chemical conversion. A programmable logic controller (PLC) based control software for engine mapping/reactant injection requirements is used to control the SCR system. Sampling cells are used to determine the amount of ammonia injected which depends on the amount of NO measured downstream of the catalyst bed.

In the proposed standards for Stationary Spark Ignition Internal Combustion Engines, EPA states the following with respect to the installation of SCR on natural gas fired engines: "For SI lean burn engines, EPA considered SCR. The technology is effective in reducing NOx emissions as well as other pollutant emissions, if an oxidation catalyst is included. However, the technology has not been widely applied to stationary SI engines and has mostly been used with diesel engines and larger applications thousands of HP in size. This technology requires a significant understanding of its operation and maintenance requirements and is not a simple process to manage. Installation can be complex and requires experienced operators. Costs of SCR are high, and have been rejected by States for this reason. EPA does not believe that SCR is a reasonable option for stationary SI lean burn engines. Consequently, this technology is not readily applicable to unattended oil and gas operation that do not have electricity.[1] However, the technology has been used successfully on lean-burn engines to meet Southern California's stringent limit of 0.15 g/hp-hr. The SCAQMD's staff report supporting Rule 1110 identifies SCR as a RACT on lean burn engines capably of achieving over 80% NOx control. The staff report also notes that SCR is a relatively high cost control technology option for RICE engines. Reasons given include the "capital cost for the catalyst, the added cost and complexity of using ammonia, and the instrumentation and controls needed to carefully monitor NOx emissions and meter the proper amount of ammonia." However they also note that the estimated costs have been declining over the past several years and are currently estimated to range from $50 to $125 per horsepower.

**Assumptions**

There is very little information in the literature regarding the incremental NOx emission reduction of SCR beyond lean burn technology for remote unattended oil and gas operations because there have been very limited installations of this technology for oil and gas compressor engines. Table 9 presents a summary of incremental SCR emission reductions and cost effective control estimates for SCR on a lean burn engine.[2]

**Table 9: Incremental SCR Emission Reductions and Cost Effective Control Estimates for SCR**

| Incremental Cost-Effectiveness Estimates for ICE | | | Control Techniques and Technologies | |
|---|---|---|---|---|
| | | | **Incremental** | **Incremental $NO_X$** |
| **Engine Type** | **Control Comparison** | **Horsepower** | **$NO_X$ Reduction** | **Cost-Effectiveness** |
| | | | **(tons/year)** | **($/ton of $NO_X$ Removed)** |
| **Lean Burn** | | | | |
| | From Low-Emission Combustion to SCR (96%) | 300-500 | **3.3** | 8,800 |
| | | 500-1000 | **6.6** | 10,300 |

There are several concerns regarding this information. First, it is not known if the emission reductions are based on actual performance tests or theoretical emission calculations. It is also not known what the reference basis is for the emission reduction of 6.6 tons per year of NOx. Review of CARB databases regarding NOx engine emissions does not provide any data regarding actual installations of SCR on lean burn engines for oil and gas operations. There is some very limited performance testing on SCR with lean burn engines that operate on pipeline natural gas (as opposed to field gas) for cogeneration facilities. Such emission data for cogeneration facilities is not applicable to oil and gas compressor engines. This is because cogeneration facilities tend to operate at a continuous load and have personnel present to operate the equipment. The CARB databases also provide testing of oil and gas SCR for high emitting 2 cycle engines (removal rates in the range of approximately 50 to 85 percent). These installations are not comparable to adding SCR to a well controlled engine.

Because of the limited application data for SCR on natural gas fired engines for oil and gas operations it is difficult to estimate the amount of potential emission reduction that could be achieved through the implementation of this technology. In addition, it is not clear how well this technology would perform in unattended remote applications. The limited data that does exist suggests that there may only be a small incremental reduction in NOx emissions beyond lean burn technology and this reduction would result at a very high incremental cost. This technology should be considered an emerging technology and merits additional testing for this unique application.

Because of non-linear chemistry involved in photochemical reactions of ozone and secondary aerosols that result in a reduction of visibility, NOx emission reductions estimated in this analysis may or may not result in equal improvement in ambient air quality levels. Also, excess ammonia slip within the discharge plume of an engine may accelerate the conversion of NOx emissions into particulate nitrate.

Table 10 presents CARB budgetary costs for the installation of SCR on lean burn engines.

**Table 10: Cost-Effectiveness Estimates for ICE Control Techniques and Technologies**

| **Selective Catalytic Reduction for Lean Burn** | | | | |
|---|---|---|---|---|
| **Horse Power Range** | **Capital Cost (S)** | **Installation Cost(S)** | **O&M Cost (S/year)** | **Annualized Cost (S/year)** |
| 301-500 | 43,000 | 17,000 | 35,000 | 36,000 |
| 501-1000 | 116,000 | 33,000 | 78,000 | 78,000 |
| 1001-1500 | 132,000 | 53,000 | 117,000 | 148,000 |
| **Average gt 500 hp** | **124,000** | **43,000** | **97,500** | **113,000** |

It should be noted that in a white paper prepared by Thomas P. Mark regarding control of Engines in Colorado that he estimates the annual operating cost of SCR on an engine having a capacity of 1000 hp is approximately $140,000 per year and is consistent with the CARB estimate.[3]

## Conclusions

The installation of SCR beyond lean burn technology is not a proven or cost effective technology at the present time. With additional development and testing for oil and gas operations, it may become an effective control technology for tertiary control of lean burn engines.

## Endnotes

1 Federal Register Monday, June 12, 2006 40 CFR Parts 69, 63, et al. Standards of Performance for Stationary Spark Ignition Internal Combustion Engines and National Emission Standards for Hazardous Air Pollutants for Reciprocating internal Combustion Engines; Proposed Rule

2 California Environmental Protection Agency Air Resources Board, 2001, "Determination of Reasonably Available Control Technology.

3 Thomas P. Mark, October 31, 2003, Control of Compressor Engine Emissions Related Costs and Considerations.

## Mitigation Option: NSPS Regulations

**<u>Description of Option</u>**
EPA is in the process of developing the first national requirements for the control of criteria pollutants from stationary engines. Separate rulemakings are in process for compression-ignition (CI) and spark-ignition (SI) engines. These NSPS will serve as the national requirements, leaving states with the authority to regulate more stringently as might be required in unique situations.

**CI NSPS:** The final NSPS for stationary CI (diesel) engines was published in the Federal Register on July 11, 2006. It requires that new CI engines built from April 1, 2006, through December 31, 2006, for stationary use meet EPA's nonroad Tier 1 emission requirements. From January 1, 2007, all new CI engines built for stationary use must be certified to the prevailing nonroad standards. (Minor exceptions are beyond the scope of this discussion.)

**SI NSPS:** The NSPS proposal for stationary SI engines, including those operating on gaseous fuels, was published in the Federal Register on June 12, 2006. Per court order, the rule is to be finalized by December 20, 2007. Like the CI NSPS, certain elements of the SI NSPS will be retroactively effective once finalized. The following summarizes the proposed requirements:

**New Source performance Standards (NSPS)**

**EPA SI NSPS NPRM**

| NOx/CO/NMHC (g/bhp-hr) | | 2007 | | 2008 | | 2009 | | 2010 | | 2011 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1-Jan | 1-Jul | 1-Jan | 1-Jul | 1-Jan | 1-Jul | 1-Jan | 1-Jul | 1-Jan | 1-Jul |
| All engines | ≤ 25 hp | | | 40 CFR 90 | | | | | | | |
| Gasoline & RB LPG | 26-499 hp | | | 40 CFR 1048 | | | | | | | |
| | ≥ 500 hp | | 40 CFR 1048 | | | | | | | | |
| Natural gas & LB LPG | | | | | | | | | | | |
| Non-emergency | 26-499 hp | | | 2.0/4.0/1.0 | | | | | | 1.0/2.0/0.7 | |
| | > 500 hp | | 2.0/4.0/1.0 | | | | | | 1.0/2.0/0.7 | | |
| Emergency | > 25 hp | | | | | 2.0/4.0/1.0 | | | | | |
| Landfill / digester gas | < 500 hp | | | 3.0/5.0/1.0 | | | | | | 2.0/5.0/1.0 | |
| | ≥ 500 hp | | 3.0/5.0/1.0 | | | | | | 2.0/5.0/1.0 | | |

Notes: NG & LB LPG, 25-50 hp, may instead comply with 40 CFR 1048.
Engines ≤ 40 hp that are ≤ 1000 cc may instead comply with 40 CFR 90.
Emergency engines limited to 100 hours per year for maintenance and testing.

Since the proposed NSPS will become an EPA regulation, it will become the base case for emissions for new modified and reconstructed engines. As such, the benefits of this regulation are already incorporated into the Cumulative Effects emission inventories.

## Mitigation Option: Optimization/Centralization

**Description of Option**

Under this option, natural gas fired internal combustion engines that are used to power various oil and gas related operations would be installed with appropriate sized engines (horsepower) for the activity being conducted. The advantage of this approach would be reducing the cumulative amount of horsepower deployed and might result in reducing emissions. This may also be accomplished by using larger central compression in lieu of deploying numerous smaller compressor engines at a number of individual locations such as well sites.

**Assumptions**

1) Current lease agreements for production cannot be easily changed.
2) Engine emission factors do not change with load.
3) Emission factors on small new, modified and reconstructed engines are consistent with large engines (proposed NSPS will require this).

**Method**

Short term emissions from compressor engines are based on the amount of fuel used which is a function of capacity (hp) and load. In determining annual emissions, the hours of operation are important. Assuming that emission factors do not change with load, as the load is reduced emissions will decrease. If it is assumed that all engines have the same rate of emissions, simply reducing the number of engines and operating them at higher capacity will likely result in the same amount of fuel usage and the same amount of emissions

**Conclusions**

Implementation of this option will not result in any quantifiable reduction in emissions.

## Mitigation Option: Use of Oxidation Catalyst for Formaldehyde and VOC Control on Lean Burn Engines

**Description of Option**

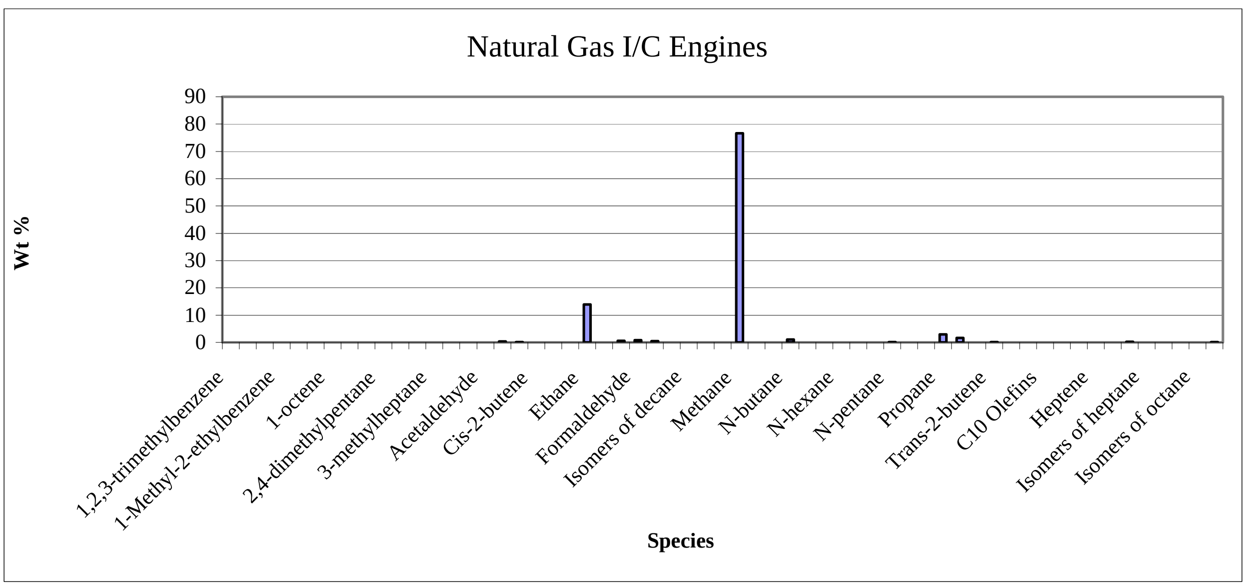
Using this option, existing or new lean burn natural gas fired internal combustion engines would be installed with oxidation catalyst to convert formaldehyde and VOC emissions to CO2. This technology requires the use of an air fuel ratio controller (AFR) in conjunction with the catalyst.

**Assumptions**

In developing emission inventories for the Four Corners Region, it was assumed that formaldehyde emissions from natural gas fired engines were 0.22 g/hp-hr for all types of engines. There is a large uncertainty in emission factors for formaldehyde which is why a conservative value of 0.22 g/hp-hr was assumed for all engines. In reality, lean burn engines have higher formaldehyde emissions than rich burn engines and therefore it is more appropriate to consider oxidation catalyst technology only for lean burn engines.

The emission inventory for VOC engines used manufacturers' emission factors. There is a large uncertainty if those emission factors represent total hydrocarbons (THC) or VOCs and also they do not include formaldehyde. THC includes methane (C1) and ethane (C2) which EPA does not regulate because they have low photochemical reactivity. The following figure presents the speciation of organics from natural gas fired engines from the EPA Speciate data base and indicates that the majority of the hydrocarbon emissions are methane and ethane. Thus, the projected reductions in hydrocarbon emissions may not affect ozone formation.

**Composition of Hydrocarbon Emissions from Natural Gas Fired Engines**

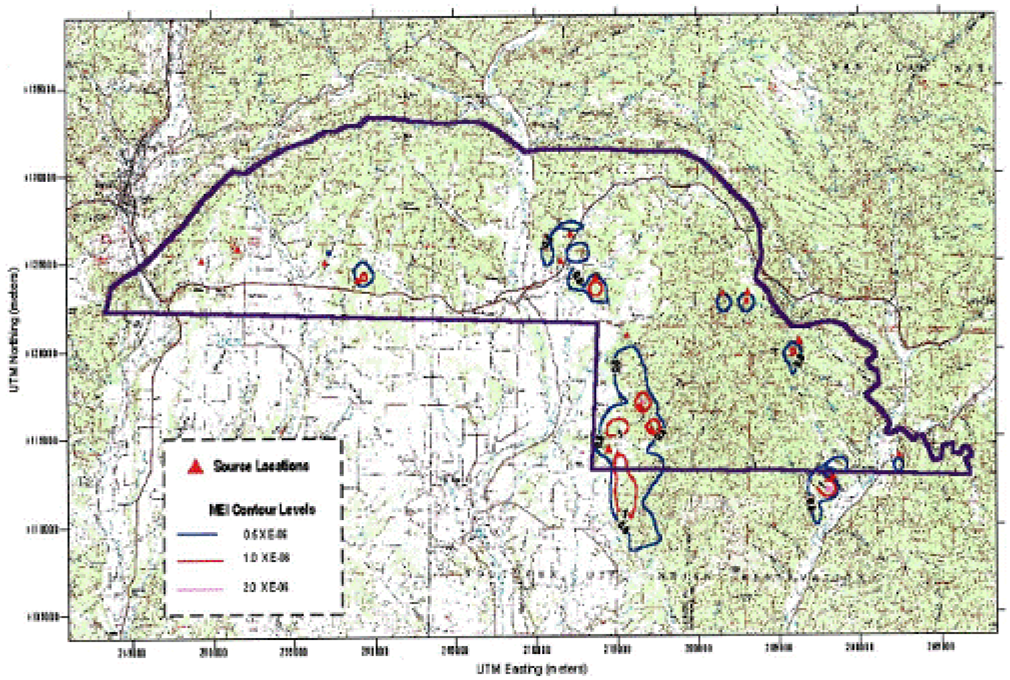



It was assumed that this technology could obtain a 90 percent reduction in hydrocarbons and 80 percent reduction in formaldehyde.

Previous modeling analyses of formaldehyde HAP impacts indicate that maximum impacts for the most likely exposed individual (MLE) are approximately 4x10-6 and have a very localized impact.[1,2] A plot indicating the formaldehyde impacts is presented in the following figure.[3]

**Formaldehyde Isopleths from Northern San Juan EIS**

Figure 7-5. HAP Incremental Risk Analysis for Formaldehyde MEI (Maximum Development)




**<u>Method</u>**
Table 11 presents the projected changes in formaldehyde and hydrocarbon emissions if oxidation catalyst were installed on new engines in Colorado and New Mexico.

**Table 11: Estimated Changes in VOC and Formaldehyde Emissions with the Installation of Oxidation Catalyst**

| | VOC Reduction (t/yr) | Unmitigated VOC (t/yr) | Percent VOC Reduction | Formaldehyde Reduction (t/yr) | Unmitigated Formaldehyde (t/yr) | Percent Formaldehyde Reduction |
|---|---|---|---|---|---|---|
| Colorado | 204 | 3115 | 7 | 42 | 471 | 9 |
| New Mexico | 1415 | [Frame2] 42,117 | 3.4 | 382 | 365 | 40 |

In Colorado, the installation of oxidation catalyst on new engines greater than 300 hp[4] would result in formaldehyde emission reductions of 42 tons per year (a 9 percent reduction in emissions) in 2018. This option would also result in a reduction of 204 tons per year of VOC emissions (a 7 percent reduction in emissions) in 2018. In New Mexico, the installation of oxidation catalyst on new engines greater than 300 hp would result in formaldehyde emission reductions of 385 tons per year (a 40 percent reduction) in 2018. This option would result in a reduction of 1,415 tons per year of hydrocarbon emissions (primarily methane and ethane) and would correspond to a 3.4 percent reduction in total emissions in 2018.

**Conclusions**

Installing oxidation catalyst on new engines greater than 300 hp in Colorado would result in a reduction of approximately 42 tons per year of formaldehyde over current projected emissions in 2018. and 204 tons per year of VOCs (primarily methane and ethane).

Installing oxidation catalyst on new engines greater than 300 hp in New Mexico would result in a reduction of approximately 382 tons per year of formaldehyde and 1,415 tons per year of hydrocarbons (primarily methane and ethane) for new engines in 2018.

There is a large uncertainty in the VOC estimates because the emitted compounds may be methane and ethane which are not regulated VOCs.
Detailed modeling is necessary to determine the air quality benefit of such reductions with respect to VOCs.

Previous HAP modeling indicates that there are minimal and very localized HAP impacts from natural gas fired engines.

**Endnotes**

1 Dames and Moore 1999, “Southern Ute Environmental Impact Statement.
2 RTP Environmental, 2004, “Northern San Juan EIS 2002 Air Quality Impact Assessment Technical Support Document Northern San Juan Basin Coalbed Methane Environmental Impact Statement.”
3 RTP Environmental, 2004, “Northern San Juan EIS 2002 Air Quality Impact Assessment Technical Support Document Northern San Juan Basin Coalbed Methane Environmental Impact Statement.”
4 The lower size cutoff for current lean burn technology.

## Mitigation Option: SNCR for Lean Burn Engines

**Description of the mitigation option**
SNCR stands for Selective Non-Catalytic Reduction. It is similar to Selective Catalytic Reduction (SCR), except that it lacks a catalyst. Like SCR, SNCR can be applied to lean-burn or diesel engines and urea or ammonia is injected into the exhaust manifold. Because it lacks a catalyst, SNCR has a lower conversion efficiency than SCR has.

Do not confuse SNCR with NSCR (Non-Selective Catalytic Reduction), which is applicable to rich-burn engines and uses a catalyst but does not use ammonia or urea as a reductant.

SNCR is used primarily for NOx reduction in boilers. It use in engines has been supplanted by SCR because it has a higher NOx reduction efficiency than SNCR.
SNCR at best can convert only about 60% of the NOx in the exhaust stream compared to about 90% for SCR. Like SCR, SNCR is subject to ammonia slippage.

Because of the low NOx removal rate, the uncertainty in application to natural gas fired engines and because more effective proven technologies exist, this option was not evaluated further.

## Mitigation Option: Next Generation Stationary RICE Control Technologies

In evaluating the next generation RICE control technology, it is important to note that current engine technology has resulted in substantial NOx reductions in natural gas fired engines compared to engines that were installed 10 years ago. New large lean burn engines are achieving over 90 percent control reliably and cost effectively. In order for the next generation of controls to be implemented in the field they must achieve the same standards.

In the near term lean-burn technology could be applied to engines smaller than 500 hp. This is a decision to be made by the engine manufacturers with the driving force being emissions regulations. Alternatively, the engine manufacturers or after market control technology companies could partner with researchers at universities and/or national laboratories to test, verify and develop reliable rich burn engine non-selective catalytic reduction (NSCR) system retrofit kits (e.g., air/fuel ratio controllers, lambda sensors, TWC, ion sensors). A next generation NSCR system could include nitrogen injection to achieve higher levels of NOx control (> 95%). The NSCR for rich burn engines may be a very attractive option for the oil and gas industry and for control technology vendors since the technology is well developed and certified for automobile applications.

With that preface this analysis investigates the status of three new and/or evolving emissions-control technologies. They are: laser ignition, air-separation membranes, and lean-burn NOx catalyst (including NOx traps).

Laser ignition is under development in the laboratory, but it has not reached a point where technology transfer viability can be determined.

Air separation membranes have been demonstrated in the laboratory, but have not been commercially available because the membrane manufacturers do not have the production capacity for the heavy-duty trucking industry. Since stationary engines are a smaller market, there is a high probability that the membrane manufacturers could ramp up production in this area.

There are several variations of lean-burn NOx catalysts, but the one of most interest is the NOx trap. NOx traps are being used primarily in European on-road diesel engines, but are expected to become common in the U.S. as low-sulfur fuel becomes available. Applicability to lean-burn natural-gas engines is possible but it will require a fuel reformer to make use of the natural gas as a reductant.

### I. Laser Ignition

### Description of the Mitigation Option

Laser ignition replaces the conventional spark plugs with a laser beam that is focused to a point in the combustion chamber. There, the focused, coherent light ionizes the fuel-air mixture to initiate combustion. Applicability is primarily to lean burn engines, although laser ignition could be applied to rich burn engines. Air at high pressure is a good electrical insulator that requires high voltage to overcome. This limits the turbocharging pressure and compression ratio because the insulation on spark-plug wires breaks down at high voltage. Laser ignition is not subject to the same limitation, so a lean-burn engine with laser ignition can have a higher turbocharging pressure and a higher compression ratio than one with spark plugs.

Advantages of laser ignition compared to spark plugs include: 1. Longer intervals between shutdowns for maintenance because wear of the electrodes is eliminated, 2. More consistent ignition with less misfiring because higher energy is imparted to the ignition kernel, 3. The ability to operate at leaner air-fuel mixtures because higher energy is imparted to the ignition kernel, 4. The ability to operate at higher turbocharger pressure ratio or compression ratio because the laser is not subject to the insulating effect of high-pressure air, and, 5. Greater freedom of combustion chamber design because the laser can be focused at the geometric center of the combustion chamber, whereas the spark plug generally ignites the mixture near the boundary of the combustion chamber.

However, laser ignition has some unresolved research issues that must be resolved before it can become commercially available.  These include:  1. Lasers are intolerant of vibration that is found in the engine's environment. 2. Some means of transmitting the laser light to each combustion chamber should be developed while accommodating relative motion between the engine and the laser.  This might be done with mirrors or with fiber optics. Fiber optics generally lead to a simpler solution to the problem.  3. Current fiber optics is limited in the energy flux they can transmit. This leads to a less-than-optimum energy density at the focal point. 4. Wear of the fiber optic due to vibration may limit its lifetime. 5. The cost of a laser is such that multiple lasers per engine are too expensive.  Therefore, a means of distributing the light beam with the correct timing to each cylinder must be developed.

Although laser ignition could be applied to rich burn engines, environmental benefits would accrue to lean burn engines.  Laser ignition may be able to reduce NOx emissions by as much as 70% compared to spark-ignited engines.[1]  However, in the reference cited, the baseline emissions for the engine with spark ignition were higher than the emissions that are currently achievable with lean burn engines. The more consistent ignition compared to spark ignition can be expected to decrease emissions of unburned hydrocarbons.  The ability to operate at leaner air-fuel ratios and at higher turbocharging pressure are responsible for the decrease of NOx emissions because of lower combustion temperatures.  Laser ignition systems have not been developed to the point where the effect of improved combustion chamber design can be measured.  It is reasonable to expect that a better combustion chamber design would further decrease emissions of unburned hydrocarbons, carbon monoxide, and NOx.  In actual operation of the engine, misfiring of one or more cylinders contributes to loss in efficiency and increase in emissions.  With the laser ignition system, misfiring can be significantly reduced.  Whether laser ignition combined with lean-burn engine technology can meet the Southern California NOx limit of 0.15 g/hp-hr will be the subject of further research.

One of the advantages of laser ignition is its potential to eliminate downtime due to the need to change spark plugs.  This advantage would accrue to both rich burn engines and lean burn engines.  Higher efficiency due to near elimination of cylinder misfirings is an additional benefit.

Laser ignition would compete with selective catalytic reduction (SCR) applied to lean-burn engines.  Although costs are unknown at this time, laser ignition is likely to be the lower cost alternative.

A tradeoff for engine manufacturers, assuming that laser ignition can be developed to the point of commercial feasibility, is whether or not to develop retrofit kits.  Retrofits would be expected to take away sales of new engines.

A tradeoff for engine users is whether to continue using spark ignition or to purchase a laser ignition that is initially more expensive but has a future economic benefit.

Another tradeoff for engine users is whether to retrofit laser ignition to an existing engine or to spend more money for a new engine in return for future benefits.

**<u>Assumptions</u>**

In the analysis, it is assumed that the limitations of laser ignition described above can be overcome through research and development.  It is further assumed that NOx emissions can be reduced by 70% compared to spark-ignition lean-burn engines.  Until more research is done, the 70% reduction is most likely an upper limit.  This reduction is due to the ability to operate at higher turbocharging pressure, hence leaner air/fuel ratios and lower combustion temperature than is currently possible with spark-ignition engines.  Since lean-burn engines are primarily those over 500 hp, the technology is assumed to apply only to engines larger than 500 hp.  The technology is assumed to be retrofitable to any engine that uses 18-mm spark plugs, so it is applied to all engines, new and existing, in the Colorado and New Mexico databases.

## Conclusions

Testing in the laboratory has shown potential emissions reductions in the 30% to 60% range, which may or may not be achievable when this technology is implemented in the field.

### II. Air-Separation Membranes

## Description of the Mitigation Option

The purpose of air-separation membranes is to change the proportion of nitrogen to oxygen in air. A membrane can be optimized to either enrich the oxygen content or to enrich the nitrogen content. Both the oxygen enrichment mode and the nitrogen enrichment mode have been tested in the laboratory with diesel engines. The nitrogen enrichment mode has been tested in the laboratory with Natural Gas Fuel as well. The oxygen enrichment mode and the nitrogen enrichment mode are mutually exclusive.

Oxygen enrichment produces a dramatic reduction in particulate emissions in diesel engines at the expense of increased NOx emissions. However, Poola[2] has shown that the effects are non linear such that a small enrichment (1 percentage point or less) produces a significant reduction in particulate emissions with only a small increase in NOx emissions. By retarding the injection timing, one can achieve a reduction in both NOx and particulate emissions. The overall benefits of oxygen enrichment are relatively small and have not been tested with natural gas-fueled engines, so it will not be considered further.

Nitrogen enrichment produces the same effect on emissions as exhaust-gas recirculation; NOx decreases. It can be applies to either diesel or rich-burn natural-gas engines. Unlike exhaust-gas recirculation (EGR), nitrogen-enriched air contains only the components of pure air. Manufacturers of both diesel and natural-gas engines are concerned that components of exhaust gas could shorten the life of the engines with EGR. In the case of diesel engines, it is clear that exhaust particulate matter could cause wear between the piston rings and cylinder liners. Even in the case of rich-burn engines, the exhaust gas contains condensed liquids that may cause wear. As recently as August, 2004, the Engine Manufacturers Association does not consider EGA to be a viable option for rich-burn engines.[3] Thus, nitrogen enriched air is seen as an alternative to EGR because it contains no components that are not found in air. Published data from tests in natural-gas engines show engine-out NOx reductions of 70% are possible with nitrogen-enriched combustion air.[4] When combined with non-selective catalytic reduction (NSCR), the overall NOx reduction can reliably exceed 90%.

The cost of nitrogen-enriched air systems are expected to be higher than that of EGR. However, nitrogen-enriched air does not have components that can cause increased engine wear as EGR does.

## Assumptions

Only nitrogen-enriched air is considered in this analysis. The technology is assumed to be retrofittable to all rich-burn engines, new and existing. While nitrogen-enriched air can be combined with non-selective catalytic reduction (NSCR), only the effects of nitrogen-enriched air are considered here. The effect is assumed to be the same as that of EGR; it can produce a 70% reduction in NOx emissions. This is most likely an upper limit.

## Conclusions

Testing in the laboratory has shown potential emissions reductions in the 50% to 90% range, which may or may not be achievable when this technology is implemented in the field. The upper end assumes integration as a component of a reasonably well-designed (use of current state of the art air fuel ratio controllers / sensor technologies) NSCR system.

## III. Lean-Burn NOx Catalyst, Including NOx Trap

**Description of the Mitigation Option**

Lean-burn NOx catalysts have been under development for at least two decades in the laboratory with the intent of producing a lower cost alternative to SCR. They do not have the ammonia slip problem associated with SCR, but they typically use some of the fuel as a reductant.

Several variants of lean-burn NOx catalysts have been studied: (1) Passive lean-burn NOx catalysts simply pass the exhaust over a catalyst. The difficulty has been low NOx conversion efficiency because the oxygen content of a lean-burn exhaust works against chemical reduction of NOx. Conversion efficiencies of the order of 10% are typical.[5]

(2) Active lean-burn NOx catalysts use a fuel as a reductant. The catalyst decomposes the fuel, and the resulting fuel fragments either react with the NOx or oxidize. Methane is much more difficult to decompose than heavier fuels, such as diesel [aardahl.pdf. A wide range of NOx reduction efficiencies from 40% to more than 80% have been published. [6,7] Variants of active lean-burn catalyst systems may use plasma or a fuel reformer to produce a more effective reductant than neat fuel.[8,9,10]

(3) NOx trap catalysts are a more recent development that has seen some laboratory success. Operation is a two-step cyclic process. In the first stage the NOx trap adsorbs NOx while the engine operates in a lean-burn mode. In the second stage, the engine operates with excess fuel in the exhaust. The fuel decomposes on the catalyst and reduces the NOx to molecular nitrogen and water. With natural gas as the fuel, a fuel reformer is necessary to break up the extremely stable methane molecule for use as a reductant When the supply of trapped NOx is exhausted, the system reverts back to first-stage operation. NOx reduction efficiencies in excess of 90% have been published.[11] A sophisticated engine control is required to make this system work.

NOx traps have been proven to be effective and have seen some limited commercial success in Europe. NOx traps are one of the reasons for the dramatic reduction in sulfur content of diesel fuel in the U.S. Fuel-borne sulfur causes permanent poisoning of NOx-trap catalysts. There are doubts regarding the NOx conversion efficiency levels after 1,000 hours or longer use. This should be evaluated, as well as the durability of the equipment.

Active lean-NOx catalysts have seen limited commercial success because they are less effective than NOx traps and are not being considered for on-road diesel engines. Some instances of formation of nitrous oxide (N2O) rather than complete reduction of NOx have been reported.

Passive Lean-NOx catalysts do not provide enough NOx reduction to be considered viable.

Costs of retrofitting a lean-burn NOx catalyst are estimated at $6,500 to $10,000 per engine [retropotentialtech.htm.][11] $15,000-$20,000 including a diesel particulate filter [V2-S4_Final_11-18-05.pdf] for off-road trucks.[12] Estimates are $10-$20/BHP for stationary engines [icengine.pdf]. [14]

Little information on the cost of NOx-trap catalytic systems was found. The overall complexity of a NOx-trap system is only slightly more than that of a lean-burn NOx catalyst, so costs can be expected to be slightly higher. With methane-burning engines, both active lean-burn NOx catalysts and NOx-trap catalysts require a fuel reformer or other means of dissociating methane. This will add an increment of cost.

Both active lean-NOx technology and NOx-trap technology impose a fuel penalty of 3-7%.

**Assumptions**

Only NOx-trap catalysts, which can remove up to 90% of the NOx in the exhaust stream are considered for this analysis. The technology is applicable to lean-burn engines, which are considered to be those having more than 500 hp in the Colorado and New Mexico databases. The technology is assumed to be retrofitable, so it is applied to all new and existing engines greater than 500 hp.

**Conclusions**

Testing in the laboratory has shown potential emissions reductions in the 40% to 70% range, which may or may not be achievable when this technology is implemented in the field.

**Summary**

Three technologies are reported: laser ignition, air-separation membranes, and lean-burn NOx catalyst.

Laser ignition is not presently a commercial product. The impetus for investigating it is the potential to eliminate the need for changing spark plugs. It will also allow operation at leaner air-fuel ratios, higher compression ratios, and higher turbocharging pressure. Leaner air-fuel ratios imply lower engine-out NOx emissions so the after treatment can be smaller or can give lower overall emissions. Higher compression ratios and turbocharging ratios imply higher engine efficiency.

Air-separation membranes used to deplete oxygen from the combustion air can serve as a clean replacement for EGR. That is, an engine using oxygen-depleted air would not be ingesting combustion products. Engine manufacturers are concerned that EGR will shorten the life of their engines and lead to premature overhauls and warranty repairs. The technology has been demonstrated in the laboratory, but has not been used for heavy-duty trucks because membrane manufacturers do not have enough production capacity for the market. Stationary engines are a smaller market, so the membrane manufacturers may be able to ramp up their capacity with stationary engines. Applicability is to diesel engines and rich-burn natural-gas engines. Oxygen-depletion membranes are not applicable to lean-burn natural-gas engines.

Lean-burn NOx catalysts have several forms, but the one that is of most interest is the NOx-trap catalyst. Unlike SCR, lean-burn NOx catalysts use the engine's fuel as a reductant and do not require a separate supply of reductant. It is a well proven in the laboratory and is commercially available in Europe for diesel engines, but it requires a fuel reformer if natural gas is used as the reductant. A sophisticated control system is required to cycle the engine between its two modes of operation. Ammonia slippage is not an issue with NOx traps, and if there is any slippage of unburned fuel it can be removed with an oxidation catalyst. Cost is high but less than that of SCR systems. A large part of the cost of SCR is the ammonia or urea reductant necessary to make it work. A disadvantage of NOx traps is that they are intolerant of fuel-borne sulfur. For diesel fuel, the sulfur content must be less than 15 ppm. Fuel-borne sulfur permanently poisons the catalyst. Since fuel is used as a reductant, there is a fuel consumption penalty of 3-7%.

**Endnotes**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[11] James E. Parks II, H. Douglas Ferguson III, and John M.E. Storey, “NOx reduction with Natrual Gas for Lean Large-Bore Engine Applications Using Lean NOx Trap Aftertreatment,” Oak Ridge National Laboratory, Knoxville, TN, 2005.

[12] “Summary of Potential Retrofit Technologies, Technical Summary,” U.S. Environmental Protection Agency, March, 2006.

[13] “WRAP Off-raod Diesel Retrofit Guidance Document, Volume 2, Section 4,” November, 2005.

[14] Manufacturers of Emissions Controls Association, op cit.

## Mitigation Option: Automation of Wells to Reduce Truck Traffic

**Assumptions**

About 50% of traffic on dirt roads in the Four Corners region is oil and gas related.

Substantially less than widespread implementation is likely, assume 25%.

Emissions estimates for road dust are of medium to low quality.

Road dust estimates made by the Western Regional Air Partnership (WRAP) have an EPA-recommended factor applied that estimates the transportable fraction, i.e. that which would move beyond the immediate vicinity.

Automation would not quite “zero out” vehicle-related emissions for those wells that are automated because of non-routine maintenance, perhaps it would be reduced by 80%.

Vehicle miles traveled is proportional to dust generated.

**Method**

Applying the percent reduction, 80% reduced by 50% to account for extent of oil and gas traffic and further reduced by 75% to account for effectiveness. So, the over all reduction would be 10%.

**Conclusions**

For road dust, the total PM10 emissions in the region are 1959 tpy (tons per year), while the total of PM2.5 is 196 tpy based on WRAP inventory information. Hence, the estimated reduction in road dust emissions because of automation would by 196 tpy of PM10 and 20 of PM2.5.

For tailpipe emissions, the total NOx emissions in the region are 916 tpy, which means the reduction because of automation would be 92 tpy.

## Mitigation Option: Reduced Truck Traffic by Centralizing Produced Water Storage Facilities

**Assumptions**

About 50% of traffic on dirt roads in the Four Corners region is oil and gas related.

Substantially less than widespread implementation is likely because it is voluntary, assume 20% participation which is a bit higher than is usually assumed for regulatory programs.

Emissions estimates for road dust are of medium to low quality.

Road dust estimates made by the Western Regional Air Partnership (WRAP) have an EPA-recommended factor applied that estimates the transportable fraction, i.e. that which would move beyond the immediate vicinity.

Hauling of produced water constitutes about 20% of total O&G traffic.

Streamlining hauling might reduce such traffic by about 50%.

The relative mix of heavy duty compared to light duty vehicles is unknown, so estimating emissions reductions for this option might be a bit conservative since it is based on an overall average that includes both light- and heavy-duty and the approach is intended just for heavy-duty which produce more dust on a per unit basis.

**Method**

Based on the above assumptions of 50% of total traffic is oil and gas related, of which 20% are hauling produced water and of which 20% will likely undertake the program. Therefore, of the total unpaved road traffic generating road dust, 2% would be reducing emissions under this approach. One would then apply the 50% control efficiency.

**Conclusions**

For road dust, the total PM10 emissions in the region are 1959 tpy (tons per year), while the total of PM2.5 is 196 tpy based on WRAP inventory information. Hence, the estimated reduction in road dust emissions because of automation would by 39 tpy of PM10 and 4 tpy of PM2.5.

## Mitigation Option: Reduced Truck Traffic by Efficiently Routing Produced Water Disposal Trucks

**Assumptions**
About 50% of traffic on dirt roads in the Four Corners region is oil and gas related.

Emissions estimates for road dust are of medium to low quality.

Road dust estimates made by the Western Regional Air Partnership (WRAP) have an EPA-recommended factor applied that estimates the transportable fraction, i.e. that which would move beyond the immediate vicinity.

Hauling of produced water constitutes about 20% of total O&G traffic.

Streamlining hauling might reduce such traffic by about 50%.

Miles traveled is proportional to dust generated.

The relative mix of heavy duty compared to light duty vehicles is unknown, so estimating emissions reductions for this option might be a bit conservative since it is based on an overall average that includes both light- and heavy-duty and the approach is intended just for heavy-duty which produce more dust on a per unit basis.

**Method**
Based on the above assumptions of 50% of total traffic is oil and gas related, of which 20% are hauling produced water. Therefore, of the total unpaved road traffic generating road dust, 2% would be reducing emissions under this approach. One would then apply the 50% control efficiency.

**Conclusions**
For road dust, the total PM10 emissions in the region are 1959 tpy (tons per year), while the total of PM2.5 is 196 tpy based on WRAP inventory information. Hence, the estimated reduction in road dust emissions because of automation would by 196 tpy of PM10 and 20 tpy of PM2.5.

## Mitigation Option: Reduced Vehicular Dust Production by Covering Lease Roads with Rock or Gravel

**Assumptions**

About 25% of traffic on dirt roads in the Four Corners region is on oil field lease roads.

Once applied, the improved surface would be maintained regularly by grading and reapplying gravel or rock.

Emissions estimates for road dust are of medium to low quality.

Road dust estimates made by the Western Regional Air Partnership (WRAP) have had an EPA-recommended factor that estimates the transportable fraction, i.e. that which would move beyond the immediate vicinity.

The level of emissions reductions achieved by the application of gravel to roadways can vary from place to place.

Considering uncertainties in road dust emissions estimates, the more conservative end of a range will be used.

**Method**

The total annual road dust emissions of PM10 in the Four Corners region are 1959 tpy (tons per year), and 196 tpy of PM2.5 based on the inventory information from the WRAP.

Based on a comprehensive EPA study (Raile, 1996) conducted in the Kansas City, Missouri area, emissions of PM10 were reduced by 42% to 52% by the application of gravel.

**Conclusions**

Therefore, emissions of PM10 on lease roads would be reduced by about 206 tpy, and by about 21 tpy of PM2.5. This is based on the following:

reduction of particulate from lease roads =
total road dust emissions times 25% times 42%.

**References**

Raile, M.M. 1996. Characterization of Mud/Dirt Carryout onto Paved Roads from Construction and Demolition Activities. U.S. EPA. EPA/600/SR-95/171.

## Mitigation Option: Reduced Vehicular Dust Production by Enforcing Speed Limits

**Assumptions**

The average posted speed is 30 mph.

About half of the vehicles on dirt road exceed the posted limit by more than 5 mph. The average for these drivers is 40 mph or 10 mph over.

Therefore, the reduction in speed for those exceeding posted limits would be about 10 mph if enforcement was undertaken and was 100% effective. Such enforcement is not 100% effective.

Road dust estimates made by the Western Regional Air Partnership (WRAP) have an EPA-recommended factor that estimates the transportable fraction, i.e. how much would move beyond the immediate vicinity.

The effectiveness of enforcement initiatives is dependent on resources allocated.

**Method**

The equation for estimating road dust PM10 emissions from EPA's AP-42 is:

((1.8*(silt content/12)^.1) * (veh. Speed/30)^.5) - .00036) /
(surface moisture/.5)^.2

Therefore, adjusting the vehicle speed would change the multiplier in the numerator from 1.15 (i.e. (40/30)^.5) to 1.0 (i.e. (30/30)^.5).

So, assuming even 50% effectiveness in mitigating speeding, and generally the assumption is lower, the reduction from enforcing a 30 mph speed limit on dirt roads in the entire Four Corners region would be about 7.5%.

**Conclusions**

Remembering that half of the traffic on dirt roads are exceeding the speed limit by more than the threshold 5%, applied to the total road dust emissions of PM10 of 1959 tpy, the reduction would be approximately 73 tpy. The reduction in PM2.5 from a total of 196 tpy would be 7 tpy.

## Mitigation Option: Emissions Monitoring for Proposed Desert Rock Energy Facility to be Used Over Time to Assess and Mitigate Deterioration to Air Quality in Four Corners Region

**Assumptions**

Generally, much post-construction ambient monitoring for permitted facilities by the source is conducted on-site. Air quality permits generally contain conditions to require continuous emissions monitoring from the stacks for criteria pollutants. New federal mercury rules will require continuous emissions monitoring for mercury for Desert Rock Energy Facility beginning in 2010.

Given the tall stack heights of the proposed facility, the greatest air pollution impacts from emissions from the facility will be quite some distance from the facility.

**Review of Proposed Approach**

Continuous PM2.5 monitoring of primary fine particulate by the facility on-site would not likely provide useful information where the effect of emissions would be well downwind, plus direct fine particulate emissions by more modern power plants are usually not substantial. However, monitoring fine particulates and its chemical components (including ammonia) at off-site locations where models indicate significant impacts from the facility would be useful. Also, since much fine particulate is formed in the atmosphere rather than emitted directly, measurements of sulfur dioxide and oxides of nitrogen offsite would also be useful.

Stack mercury measurements might be useful from a research perspective in performing source apportionment work in the Four Corners region.

As is discussed above, on-site ambient monitoring of volatile organic compounds (VOC) may not be an effective means of understanding the ambient impact of these emissions, but off-site monitoring of ozone precursors like VOC and nitrogen oxides at predicted maximum impact locations would be useful.

## CUMULATIVE EFFECTS: PUBLIC COMMENTS

**Cumulative Effects Public Comments**

| Comment | Mitigation Option |
|---|---|
| I have been concerned for many years about the air quality of the Four Corner's region because of the coal fired power plants in N.M. I attended two of the Four Corner's air quality forums in the past and was disturbed by their reports. As a nurse, I am especially concerned for the health of the Native Americans and other people who reside close to the power plants because of their incidence of lung disease. As a resident of La Plata canyon for 20+ years with a high mercury level, I am concerned about my own health and notice more air pollution, lack of visibility, every time I hike in the mountains. I believe for everyone's health, alternative sources of energy; e.g. solar, wind energy is a much better solution and would still serve as a revenue source to the Navajo nation. Desert Rock should not be built and the others should be phased out as planned many years ago or at least upgraded to standards that were set by the Clinton administration. | General Comment |
| We do NOT need another power plant in the 4 Corners. I notice the dirty air in this area all of the time and especially on weekends. Drive up from Albuquerque and see the air get dirtier. Also, go out from the 4 Corners and notice the beautiful blue skies as you progressively leave the area.<br><br>I teach school and stress to my students they need to take care of the this planet earth because there is no spare earth. I would like to stress to everyone else that this needs to be done. Solar, wind and other energy sources should be used. | General Comment |
| It breaks my heart to think that another coal fired plant may be added to our "pristine" 4 corners area. Even in Pagosa Springs we have some hazy smog some days, and when driving south and west of Farmington, that horrible yellow-brown cloud can be seen for miles! I was shocked to see that poisonous cloud in Monument valley, and northwest Utah. It's all pervasive now so I can't imagine what it will be like with more coal -spewing plants. We must use non polluting energy sources for the health of all of us! | General Comment |
| The Task Force report presents data on the potential emission reductions for the Four Corners Power Plant and the San Juan Power Plant. The Cumulative Effects Work Group needs to evaluate potential power plant mitigation options that are presented in the report and develop a quantitative summary of all potential mitigations options which have technical merit.<br><br>It is useful to place the emission reductions suggested for power plants in perspective to those developed for oil and gas sources. As stated in the Draft Report, for the Four Corners Power Plant the installation of presumptive BART could result in SO2 emission reductions from a minimum of 12,455 tons per year to a maximum of 19,927 tons per year. Similarly, NOx emission reductions could range from 13,651 tons per year to 57,118 tons per year. Since SO2 and NOx emissions are considered as having similar visibility impairment potential, the magnitude of the total emission reductions possibly affecting visibility could range from 26,106 to 77,045 tons per year.<br><br>For the San Juan Power Plant using data presented in the Task Force Report, estimated SO2 emission reductions could be approximately 9,000 tons per year and NOx reductions could be approximately 11,000 tons per year. For this plant the combination of SO2 and NOx possible reductions of 20,000 tons per year might be achieved. The information contained in the Draft Report regarding possible emission reductions for this source is not as complete as for the Four | General Comment |

| Comment | Mitigation Option |
|---|---|
| Corners Plant and additional data should be developed and presented.<br><br>If the suggested emission reduction strategies were implemented at both plants, total SO2 and NOx emission reductions of visibility impairment pollutants could range from 46,106 tons per year to 97,046 tons per year.<br><br>In addition, review of the emission data in the Draft Report indicates that at the Four Corners Power Plant NOx emissions are greater than SO2 emissions (Figure 2 FCPP Emission Trends). However, in 2003 SO2 emissions were further reduced so that the ratio of NOx to SO2 emissions increased.<br><br>At the San Juan Power Plant prior to 1990, SO2 emissions were greater than NOx emissions while in 1999 SO2 and NOx emissions were equal (Figure 1 San Juan SO2 and NOx). After that time, SO2 emissions were less than NOx emissions. The trends in emissions at these facilities may be important in understanding the trends in the IMPROVE monitoring data. Engineering and economic feasibility studies need to evaluate the ability of the facilities to continuously achieve emission reductions in a cost effective manner.<br><br>The potential emission reduction that could be realized with the installation of additional controls on power plants need to compared with the emission reductions reported by the Draft Task Force Report for oil and gas sources. The installation of NSCR on existing small engines in Colorado and New Mexico could result in emission reductions of approximately 10,244 tons per year. These emission reductions are only a small fraction of the reductions possible from power plants (minimum ratio of power plant reduction to oil and gas reductions 4.5 – maximum ratio of power plant reduction to oil and gas reductions 9.5). | |
| The Draft Task Force Report presents recommendations for mitigating emissions from drilling rig diesel engines. At the present time there is insufficient information regarding the level of emissions from these sources in the region. The Cumulative Effects Group should develop emission data regarding the magnitude of emissions in both Colorado and New Mexico and then develop estimates of potential emission reductions that could be achieved. The emission calculations should be based on site specific information that represents the length of time to drill a new well, engine loads and engine capacity. One important fact that needs to be considered is that the drilling rig engines are typically replaced at a frequency of every 5 years (replaced not rebuilt). This rate of turnover is very important because the engines are replaced with the required current control technology. This should be the baseline against which alternative mitigation options should be considered. It is recommended that the Cumulative Effects Group continue to analyze and evaluate emission reduction options for this source group. | General Comment |
| The following plots present selected years of rolling 5 data point averages of the SO4 and NO3 concentrations compared to Julian day for the IMPROVE data from Mesa Verde. Using a rolling 5 data point average provides some smoothing of the data but allows correlations between SO4 and NO3 to be observed. The plots for 1988 and 1990 indicate a large fraction of coincident peaks of SO4 and NO3. This is an important finding because it suggests that these events may result from coal fired sources because natural gas fired sources or mobile sources do not emit significant SO2. In addition, NO3 concentrations are smaller than SO4 concentrations. The data from 2002, 2003 and 2004 indicate that a change has occurred in the relationship of SO4 and NO3 measurements and that there is a very strong correlation of SO4 and NO3 | General Comment |

| Comment | Mitigation Option |
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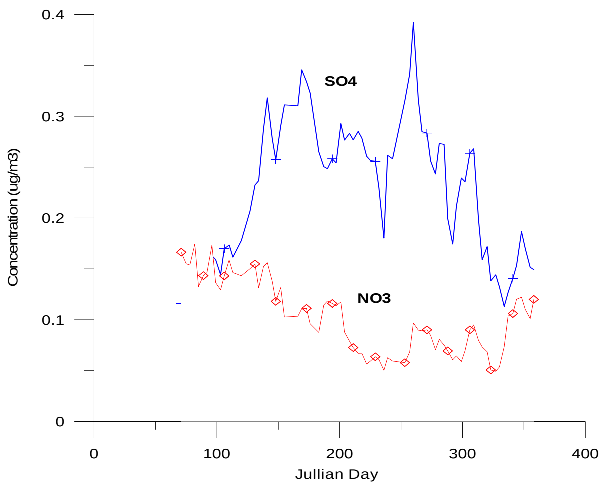
| events, again suggesting a coal fired source. However, in 2002, 2003 and 2004 NO3 concentrations are equal to or greater than SO4 concentrations. As mentioned in the power plant emission section, SO2 reductions began in 1999 and after that time NOx emissions were greater than SO2 emissions. This trend in changes in emissions is very consistent with the monitoring data and again suggests visibility impacts are likely from coal fired sources. This is a preliminary hypothesis that needs more evaluation and may explain why NO3 levels have been increasing at Mesa Verde.<br><br>If this finding is confirmed, it has important ramifications regarding improvement in air quality. This is the type of focused analyses that needs to be conducted before mitigation options are selected and implemented.<br><br><br>**1988 SO4 and NO3 Concentrations 5 Day Running Average Mesa Verde** | |

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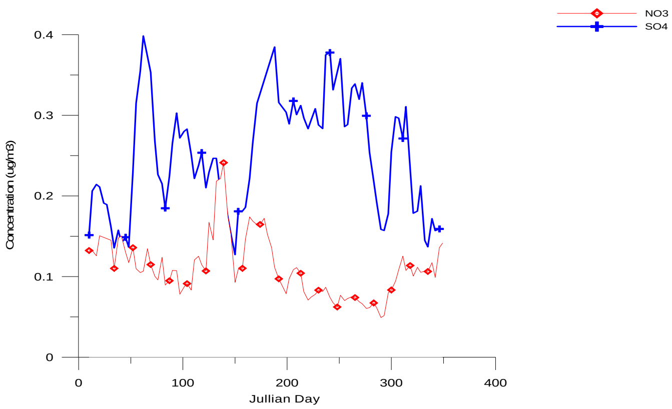
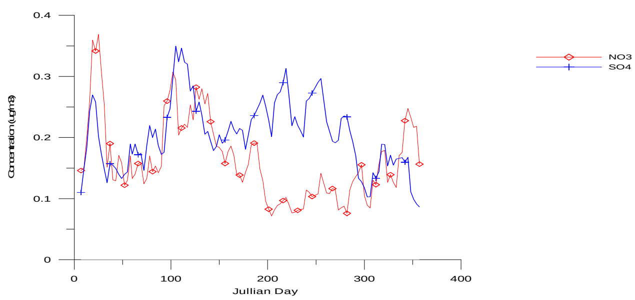
| <br>1990 SO4 and NO3 concentrations 5 day running average<br><br>**2002 SO4 and NO3 Concentrations 5 Day Running Average Mesa Verde** | |

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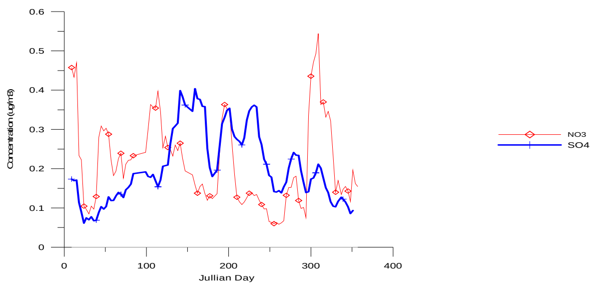
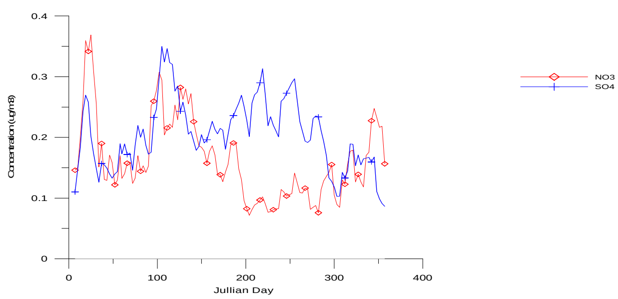
|  <br>**2003 SO4 and NO3 Concentrations 5 Day Running Average**<br>**Mesa Verde**<br> <br>**2004 SO4 and NO3 Concentrations 5 Day Running Average**<br>**Mesa Verde** | |
| last paragraph before Suggestions for Future Work...should the reference be to Table 2 rather than Table 1? | Overview of Work Performed |

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| Table 1 - Selective Catalytic Reduction (SCR) on Drilling Rig Engines: It is stated "that some data exists on drilling emissions. The State of Wyoming evaluated this technology based on a pilot study in the Jonah Field & concluded that is not a cost effective technology, but further analysis is needed." This paragraph references the cost analysis WY did for SCR on diesel rig engines, but does not provide or reference any information on what conditions and assumptions WY used in conducting this analysis. If possible the CE workgroup should obtain and review the WY analysis on SCR, in addition to other diesel control options WY analyzed.<br><br>Table 1 - Follow EPA New Source Performance Standards (NSPS) for RICE: EPA suggests revising the Summary of Result first sentence "This proposed emission standard will become the baseline for new, **modified, and reconstructed** engines.<br><br>Table 1 - Install Non Selective Catalytic Reduction (NSCR) on Rich Burn Engines for RICE. It is unclear in the Summary of Result what EPA performance standard is being referenced, and how the 4 Corners Task Force Interim Emissions Recommendations for Stationary RICE have been considered by the CE workgroup. The NSPS for spark ignition engines will apply to **new, modified, and reconstructed** units starting in January 2008. The 4 Corners Task Force Interim Emissions Recommendations for Stationary RICE notes that BLM/USFS, at the request of CO and NM, is currently requiring NSPS comparable emission limits on as a Condition of Approval for their Applications for Permits to Drill. The States' request was that BLM/USFS immediately establish in every Application for Permit to Drill (APD) a nitrogen oxide (NOx) limit of 2.0 grams per horsepower hour for all **new and replacement** engines less than 300 hp (excluding engines with horsepower less than 40). In addition, New Mexico and Colorado have requested that for all new and replacement engines greater than 300 hp, the BLM and the USFS establish in every APD a NOx limit of 1.0 gram per horsepower hour. EPA Region 8 formally supports both these requests from Colorado and New Mexico. It should also be noted that the Mitigation Option: Interim Emissions Recommendations for Stationary RICE section in the Draft Mitigation Options Report states that "BLM in New Mexico and Colorado are currently requiring these emission limits as a Condition of Approval for their Applications for Permits to Drill. These limits currently apply only to **new and relocated** engines ... (compressors assigned to the well APD)..." In developing assumptions for potential NOx reductions from this requirement in APDs, how did the CE workgroup determine, or assume, what percentage of the existing engines (compressors) in the 4 Corners area would be required to meet this requirement? | Overview of Work Performed |

| Comment | Mitigation Option |
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| 1. Given electric compression would shift emissions generated from NG compressor engines through use of electric engines to emissions from power generation (i.e., "the grid"), this option is clearly "cross-cutting." We recommend that the coordination with the Power Plant WG in the analysis of this option.<br><br>2. We were unable to reproduce the emission reduction numbers from the data provided in the analysis (tons/yr deltas provided in Table 4). Based on the data provided we calculate a total of 631 tons/yr reductions in NOx and SO2 based the 25 worst engines and the average power plant emissions in Table 3.<br><br>3. In course of installing electric compression to replace the natural gas fired compression engines, the analysis correctly assumes that the emission of pollutants will shift from the replaced compressor engines to increased electric load demand from the grid. In course of review of the Natural Resources Defense Council (NRDC) "Emission Data for the 100 Largest Power Producers", it appears that baseline average emission factors used for emission difference calculation are the national average emission factors for the identified owner utility companies (average of all plants, regardless of location or on which power grid).<br><br>The electric power for electric compression will come from the Western Grid which draws power from generating stations in the western United States. Among the three electric power producers, Xcel is the largest producer with 81,283,493 MWhs capacity compare to 21,230,675 MWhs for both PNM and Tri-state. The baseline average emission factors based on national average emission factors of these three electric power producers have potential to distort the emission difference calculation because Xcel's power generation facilities in Minnesota, South Dakota, Texas, and Wisconsin are not supplying electricity to the Western Grid. A brief description of grid system is provided later in this document.<br><br>A better measure of the effectiveness of this option would be the use of average NOx and SO2 emissions from Four Corners Generating Station and San Juan Generating Station. In case example case provided in the analysis, replacing 25 worst engines with total 2,701 hp in NM side with electric compression, will result in net NOx + SO2 reduction of 610 tons/year. A net NOx +SO2 reduction of approximately 20,000 tons/year can be achieved by replacing all rich burn engines (approximately 1,500 in NM inventory) emitting greater than 5 g/hp-hr.<br><br>Although it may not be practical or economically feasible to replace all rich burn compressor engines with electric motors, further analysis of the locations/ configurations of existing compressor stations may reveal that conversion to electric is practical and makes sense. Factors like proximity to the electric grid, ROW, number of engines, are factors that would need to be evaluated.<br><br>4. The electricity for the electric compression in the San Juan area will be drawn from Western Interconnect or Grid. We recommend that a good approximation for baseline emission factors will be the averages of emission factors for the power plants supplying electricity to the Western Grid. The following steps can be taken to obtain the baseline average emission factors for the emission difference calculation:<br><br>a. The average emission factors for fossil fuel powered power plants supplying electric power to the Western Grid can be calculated using the emission data | Install Electric Compression |

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| from the EPA's CAMD inventory. The EPA's Clean Air Market Data (CAMD) (http://camddataandmaps.epa.gov/gdm/index.cfm) provides NOx, SO2, and CO2 emission as well as heat input for the Title IV power generating units.<br><br>b. The net power generation by state by type of producer by energy source is available at the Energy Information Administration (EIA) website (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html).<br><br>c. A fraction between calculated average baseline emission factors for the Western Grid based on EPA data and the total power generation for the Western Grid obtained from EIA's website will used to obtain the average baseline emission factors for emission difference calculations.<br><br>5. The worst case NOx emissions from coal-fired plants is 4.5 lbs/MWh, which is equivalent to 1.5 g/hp-hr. The coal-fired plants produce a lot more NOx emissions than the gas field sources do: 160,264 tons/year compared to 38,632 tons/year. A 5% reduction of NOx emissions from the coal-fired plants is the same as a 21% reduction in NOx from gas field sources.<br><br>6. We recommend that the Task Force evaluate on-site lean-burn electric generators as an alternative power source for electric compression. | |
| The SUGF recommends further research and testing of this mitigation option to help determine the amount of emissions reduction that can be accomplished on a continual, reliable basis. If technology could be developed and maintained on a regular basis, this option could prove to be valuable in retrofitting existing rich burn units. | Use of NSCR for NOx Control on Rich Burn Engines |
| In the section Mitigation Option: Use of NSCR for NOx Control on Rich Burn Engines it is stated in the Assumptions (p. 13): "Currently, recent EIS RODs in Colorado and New Mexico require performance standards for new engines that will accelerate the implementation of the 2008 and 2010 federal NSPS for non road engines." The term "replacement" is not used, only "new" engines. What is the CE workgroups understanding related to what type of engines would fall under the replacement category, and was this type of engine considered in the assumptions as being retrofitted to meet the interim recommendation of 2 g/hp/hr?<br><br>Engine Size < 100 hp Case 1 (p. 14): It is stated that "it was assumed that NSCR for this situation would reduce NOx emissions by 50 percent in Colorado and New Mexico and would result in a NOx emission factor of 6.7 g/hp-hr in Colorado and 8.0 g/hp-hr in New Mexico." What is the basis for this assumption? The 2 g/hp-hr interim recommendation for new and replacement engines 300 hp and less (excluding engines less than 40 hp) has been in place since '05, which is almost 3 years ahead of the NSPS implementation date. Does the CE Workgroup have any information on how much impact this interim recommendation, as implemented through BLM/USFS APDs, has had on the average NOx emission factor from the current engine fleet in the 4 Corners area.<br><br>Tables 6 and 7: Can some narrative be added that explains how emissions reductions are calculated and what each column in the tables represents? Why is table 6 (CO) different from table 7 (NM)? It is unclear how some of the emission reduction values have been calculated in tables 6 and 7. For example, in table 6 why is the emission reduction for < 100 Hp engines 130 TPY instead 143 TPY (50% x 286 TPY)? | Use of NSCR for NOx Control on Rich Burn Engines |

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| 1. Test data on small two-stroke NSCR retrofitted engines (Ajax DP-115) show NSCR can achieve large NOx emission reductions between 79% and 93% (Chapman, 2004a). On four stroke engines Chapman (2004b) indicates that "these catalyst systems reduce NOX emissions by over 98 percent, while reducing VOC by 80 percent and carbon monoxide by over 97 percent. NOx levels in the range of 0.1 to 1.0 g/bhp-hr have been achieved." Although this is consistent with the statement in the Draft Report that NSCR can achieve NOx emissions of less than 2 g/hp-hr, tighter control levels can certainly be achieved in retrofitting rich burn engines with a well controlled NSCR system.<br><br>2. Not all rich-burn engines would need to be retrofitted to NSCR to achieve the reductions postulated in the Draft Report. For example, if 57% of the under-100-hp engines in New Mexico were retrofitted with NSCR, which achieves less than 2 g/hp-hr NOx emissions (this is a conservative number, since NOx emissions that are well under 1 g/hp-hr are possible), then the overall emissions rate for that class of engine would decrease from 16 g/hp-hr to 8 g/hp-hr. According to Table 7 in the Draft Report, this would mitigate 6337 tons/yr of NOx (6694 tons/yr with growth).<br><br>Since only 57% of the engines in this classification would need to be retrofitted, a retrofit kit would need to be developed only for the most common engine model (or a few models, at most.) This would save the expense of engineering development for engine models that have only a few examples represented in the Four Corners area and would concentrate the engineering effort where it would do the greatest amount of good. If more that 57% of the engines were controlled at the 2 g/hp-hr level, then more that 6337 tons/yr of NOx would be mitigated, but the incremental cost per tons/yr of NOx would be higher than that of the first 6337 tons/yr. It should also be noted that if the 57% of engines with NSCR controlled NOx at the 1 g/hp-hr rather than 2 g/hp-hr, 6773 tons/yr of NOx world be mitigated. This is an additional 436 tons/yr.<br><br>A number of issues are identified with the use of NSRC on small engines. All of these issues, including ammonia formation, can be eliminated or minimized through use of a NSCR retrofit package that includes all the right components.<br><br>The appropriate NSCR retrofit kit should include:<br><br>- A 3-way catalytic converter<br>- Exhaust oxygen sensor<br>- Replace existing carburetor with a controllable air/fuel ratio (AFR) controller device. The ratio of an engine's actual AFR to the stoichiometric AFR for the fuel being used is referred to as the Lambda parameter. To ensure that exhaust bound $O_2$ comprises no more that 0.5% (by volume) of the total engine exhaust, rich burn engines operate at $\lambda$'s of between 0.988 and 0.992 (Chapman, 2004b). (For engines burning clean, dry natural gas, the air to fuel ratio (AFR) for stoichiometry is ~16.1:1, Chapman, 2004a).<br>- Computerized control using feedback from the exhaust oxygen sensor to control the air/fuel ratio $\lambda$'s of between 0.988 and 0.992 with the retrofitted NSCR system.<br>- Exhaust gas recirculation (EGR) and controllable ignition timing could also be included and controlled by the same computer. Both EGR and retarded ignition timing reduce engine-out NOx emissions and enhance the effectiveness of the catalyst. Retarded ignition timing also has the effect of increasing exhaust temperature, which will improve the effectiveness of the catalyst at light engine | Use of NSCR for NOx Control on Rich Burn Engines |

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| loads. Although considerable engineering effort is required to develop the retrofit kit, it needs to be done for only one engine model or a few engine models, at most.<br><br>In the 3rd parg. under engines < 100 hp, it states; "Also, research indicates that if the AFR drifts off the optimal setting, then NOx emissions may be converted (on an equal basis) to ammonia. If this occurs within the discharge plume of an engine, it may accelerate the conversion of NOx emissions into particulate nitrate. This is the reason that the carburetor must be replaced with a more accurate AFR controller having feedback from an exhaust oxygen sensor. With such a system, accurate AFR control is achieved, and generation of ammonia is not an issue.<br><br>________________________________________<br>Chapman, K., 2004a, Report 6: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines, Technical Progress Report, DOE Award DE-FC26-02NT15464, Kansas State University, August<br><br>Chapman, K., 2004b, Report 4: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines, Technical Progress Report, DOE Award DE-FC26-02NT15464, Kansas State University, January | |
| The assumption of 50% reduction of NOx in the Draft Report is too pessimistic or small. Other information indicates that NOx reduction greater than 90% is achievable. Another report indicated 95.9% NOx reduction on a 320 kW (430 hp) natural-gas fueled engine. The same report gave costs of $2,205-$3,684 per ton of NOx removed. This is considerably less than the $10,300 per ton of NOx removed indicated in the Draft Report. Another report indicated that the cost of SCR on reciprocating natural-gas engines varied from $30-$250 per horsepower with no correlation to engine size. Considering that the date of the fourth report is 1990, one reason for the variation in cost may be lack of experience on the part of some installers.<br><br>Using the same methodology that was used in the Draft Report, but allowing a 90% NOx reduction on new engines instead of 50% gives a reduction of 1789 tons/year (16.5% reduction of overall NOx) in Colorado and a reduction of 2015 tons/year (4.6% reduction of overall NOx in New Mexico. The 90% NOx reduction should be achievable with good operation and maintenance practice in light of the 95.9% NOx reduction already achieved in the field. These figures were for new engines greater than 500 hp. Since the reported engine was smaller than 500 hp, the same calculation was performed for new engines greater than 300 hp. These gave a reduction of 2,109 tons/year (19.5%) in Colorado and 2502 tons/year (5.8%) in New Mexico. The engines with SCR would have NOx emissions of about 0.1 g/hp-hr.<br><br>______________________________________________________________<br>1. Jim McDonald and Xavier Palacios, "Compressor Tech 2: SCR for Gaz de France," Miratech Corporation, Tulsa, OK, December 1, 2002.<br>2. Johnson Matthey Corp., "Maximum NOx Control for Stationary Diesel and Gas Engines," brochure number "jm_brochure_scr_062306b.pdf".<br>3. Ravi Krishnan, RJM Corp., "Urea-based SCR technology achieves 12 ppm NOx on natural gas engine," PennWell Power Group Online Article available at http://pepei.pennet.com/Articles/Article_Display.cfm?ARTICLE_ID=156191, | Use of SCR for NOx Control on Lean Burn Engines |

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| October 1, 2002.<br>4. G.S. Shareef and D.K. Stone, "Evaluation of SCR NOx controls for small natural gas-fueled prime movers. Phase 1. Topical Report," report number PB-90-270398/XAB; DCN-90-209-028-11; GRI-5089-254-1899, Radian Corp., Research Triangle Park, NC, July 1, 1990. | |
| The first paragraph of the section on Next Generation RICE Stationary Technology in the Draft Report does not give adequate weight to the importance of next generation technology. As emissions regulations become tighter (e.g., 0.2 g/hp-hr NOx in 2010), those limits will become increasingly difficult to meet with existing technology. Continuing research on advanced technologies is necessary to ensure than ever tighter limits in the future can be met. Three of the technologies listed below, NOx trap catalysts, laser ignition, and HCCI, are close to meeting the 0.2 g/hp-hr limit by themselves. Two of the technologies, laser ignition and HCCI, may be able to meet the 0.2 g/hp-hr limit without aftertreatment. With aftertreatments they may be able to meet an even lower limit. NOx trap catalysts are an aftertreatment that offers the same performance as SCR, but with potentially lower cost. Air separation membranes may be used in combination with other technologies to outperform the 0.2 g/hp-hr limit.<br><br>NOx trap catalysts are similar in performance to SCR, that is they can reduce more than 90% of the engine-out NOx to achieve less than 1 g/hp-hr NOx emissions.[1] The estimates of NOx abatement used in the Cumulative Effects SCR section of the draft report may be used as a guide to the abatement potential of NOx trap catalysts. The cost is expected to be less than that of SCR because ammonia or urea is not used as a reductant. Instead, some of the fuel is used as a reductant. The increase in fuel consumption may be up to 8%, but is typically about 4%.<br><br>Air separation membranes used to deplete oxygen from the intake air have an effect on NOx emissions that is similar to that of exhaust gas recirculation (EGR) in rich-burn and diesel engines. Combined with ignition retardation, a reduction in engine-out NOx of up to 40% can be expected.[2,3] For engines in the 300-500 hp range, air separation membranes with ignition retard could reduce overall NOx emissions to 2 g/hp-hr in both Colorado and New Mexico. For the 100-300 hp range, these technologies could reduce overall NOx emissions from 16.3 to 10 g/hp-hr in Colorado and from 12.5 to 7.5 g/hp-hr in New Mexico. For engines under 100 hp, the technologies could reduce overall NOx emissions from 13.4 to 8 g/hp-hr in Colorado and from 16 to 9.6 g/hp-hr.<br><br>Laser ignition may be able to reduce NOx emissions by as much as 70% in lean burn engines.[4] However, in the reference cited, the baseline emissions for the engine with spark ignition were higher than the emissions that are currently achievable with lean burn engines. Additional development and testing will be required to verify the reduction of NOx emissions.<br><br>There is little information in the literature about lean NOx catalysts used with lean burn natural gas engines. Information about lean NOx catalysts used with diesel engines indicates NOx reductions of 10-40% depending on whether fuel is used as a reductant.[5,6] NOx reductions for lean burn natural gas engines is expected to be similar. Although researchers are attempting to improve the conversion efficiency of lean NOx catalysts, their current low performance makes them unsuitable for the short term.<br><br>Only a few experimental measurements of NOx from homogeneous-charge | Next Generation Stationary RICE Technology |

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| compression-ignition (HCCI) engines have been reported. The measurements are typically reported as a raw NOx meter measurement in parts per million rather than being converted to grams per horsepower-hour. Dibble reported a baseline measurement of 5 ppm when operated on natural gas.[7] Green reported NOx emissions from HCCI-like (not true HCCI) combustion of 0.25 g/hp-hr.[8] Whether HCCI technology can be applied to all engine types and sizes is not known. In addition, the ultimately achievable NOx emissions from such engines is not known. However, if all reciprocating engines could be converted to HCCI so that the engines produce no more than 0.25 g/hp-hr, then the overall NOx emissions reduction would be 80% in both Colorado and New Mexico using the calculation methodology of the SCR mitigation option.<br><br>____________________<br>1 James E. Parks II, Douglas Ferguson III, and John M. E. Storey, "NOx Reduction With Natural Gas for Lean Large-Bore Engine Applications Using Lean NOx Trap Aftertreatment." Oak Ridge National Laboratory, 2360 Cherahala Blvd., Oak Ridge, TN 37932.<br>2 K. Stork and R. Poola, "Membrane-Based Air Composition Control for Light-Duty Diesel Vehicles: A Cost and Benefit Assessment," Report Number ANL/ESD/TM-144, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, October 1998.<br>3 Joe Kubsh, "Retrofit Emission Control Technologies for Diesel Engines," NAMVECC 2003, Manufacturers of Emission Controls Association, www.meca.org, Chattanooga, TN, November 4, 2003.<br>4 B. Bihari, S. B. Gupta, R. R. Sekar, J. Gingrich, and J. Smith, "Development of Advanced Laser Ignition System for Stationary Natural Gas Reciprocating Engines," ICEF2005-1325, ASME-ICE 2005 Fall Technical Conference, Ottawa, Canada, 2005.<br>5 Joe Kubsh, op.cit.<br>6 Carrie Boyer, Svetlana Zemskova, Paul Park, Lou Balmer-Millar, Dennis Endicott, and Steve Faulkner, "Lean NOx Catalysis Research and Development", Caterpillar Inc., presented at the 2003 Diesel Engine Engineering Research Conference.<br>7 Robert Dibble, et al, "Landfill Gas Fueled HCCI Demonstration System," CA CEC Grant No: PIR-02-003, Markel Engineering Inc.<br>8 Johney Green, Jr., "Novel Combustion Regimes for Higher Efficiency and Lower Emissions," Oak Ridge National Laboratory, "Brown Bag" Luncheon Series, December 16, 2002. | |
| The SUGF recommends further examination of the above listed mitigation options as particulates associated with each option contribute to local visibility issues. | Automation of Wells to Reduce Truck Traffic<br><br>Reduced Truck Traffic by Centralizing Produced Water Storage Facilities |