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16. Abstract

This research product provides a summary of control measures examined in report 4190-5: "Potential Emission Reduction Effects of Alternative Construction Emission Control Measures." Report 4190-5 compares the potential emission reduction benefits and cost of diesel engine emission control technologies to usage controls known as construction shifting.

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CONTROL MEASURE COMPARISON TABLES

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CONTROL MEASURE COMPARISON TABLES OVERVIEW

Dallas-Fort Worth (DFW) and Houston-Galveston Area (HGA) non-attainment regions are struggling to meet national air quality standards. As a result, the Texas Natural Resource Conservation Commission (TNRCC) and other interested agencies have considered and adopted a variety of control measures. One such control recently adopted by TNRCC is that of postponing or shifting construction activities that require the use of heavy-duty diesel engines. Other control strategies targeting the construction sector include: the implementation of low-emission diesel (LED) fuel; the use of emission control devices; and the accelerated purchase of clean non-road highway diesel equipment.

The tables contained within this research product provide a summary of control measures examined in report 4190-5: "Potential Emission Reduction Effects of Alternative Construction Emission Control Measures"[1]. Report 4190-5 compares the potential emission reduction benefits and cost of diesel engine emission control technologies to usage controls known as construction shifting.

It is important to note that the emphasis for these comparisons is on relative cost and emission benefits. The comparisons are intended as sketch-planning tools to evaluate the various strategies toward meeting air quality goals. Absolute measurements of the costs and emission reductions of the various control measures would require more detailed analysis and research.

CONSTRUCTION SHIFT BACKGROUND

The construction shift rule seeks to delay oxides of nitrogen (NOx) production from construction equipment early in the day to reduce the amount of ozone produced during the afternoon in the presence of sunlight and hot temperatures.

The construction shift rule establishes a restriction on the use of heavy-duty diesel (HDD) construction equipment (≥50 hp) during the ozone season beginning in 2005 for both the DFW and HGA non-attainment areas[2]. The usage restriction in DFW will not allow designated

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[1] Overman, J. and Crawford, J. Potential Emission Reduction Effects of Alternative Construction Emission Control Measures. Texas Transportation Institute January 2001. (Unpublished)

[2] The DFW non-attainment area currently includes Dallas, Tarrant, Collin, and Denton counties. The HGA non-attainment area includes Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller counties.

construction equipment to operate between 6:00 a.m. and 10:00 a.m. from June 1 through October 31. In HGA these equipment usage restrictions are in effect from 6:00 a.m. to noon throughout Daylight Savings Time[3].

The TNRCC estimates that an aggregated 16 tons per day (TPD) of NOx will be reduced in DFW by implementing this rule and the Accelerated Purchase rule[4]. In HGA, 8 TPD are expected to shift, producing an equivalent 6.7 TPD NOx reduction[5].

DIESEL ENGINE EMISSION CONTROL

Diesel emissions control is generally achieved by modifying the engine design, treating the exhaust (after-treatment), modifying the fuel source, or a combination of these controls. Tables 1 and 2 present a summary of emission controls.

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[3] First weekend in April through the last weekend in October.

[4] Texas Natural Resource Conservation Commission. *DFW Attainment Demonstration,* April 2000. p. 6-13.

[5] Texas Natural Resource Conservation Commission. Revisions to the State Implementation Plan (SIP) for the Control of Ozone Air Pollution – Post-999 Rate-of-Progress and Attainment Demonstration SIP for the Houston/Galveston Ozone Non-attainment Area and Inspection/Maintenance SIP for the Houston/Galveston Ozone Non-attainment Area. Rule Log No. 2000-011-SIP-A1, August 9, 2000. p. 6-3.

Table 1. Summary of Particulate Emission Control Cost and Reduction Efficiencies.

Control Technology Category	Emission Reduction Effectiveness (percent)				Cost Information
	PM	HC	CO	NOx	
PM Targeted After-treatments					
Filter / Traps	50-90	50-90	40-90	<1	$10 to $20 per hp, $625 to $2,250 per vehicle
Ex. Clean Diesel Tech. Platinum Plus FBC+DPF (350 ppm Sulfur fuel +fuel-borne catalyst)	96	66	42	0	
Catalyst Based Filters (500 ppm sulfur fuel)	70-90	30-90	30-90	<5	$10 to $20 per hp + O&M
Ex. Johnson Matthey	93	86	90	2	na
Ex. QuadCat by Ceryx w/ NOx catalyst	90	90	90	30-50	$5 to $10K up to 400 hp
Diesel Oxidation Catalyst DOC (500 ppm Sulfur)	20-50	60-90	60-90	<5	$4 to $30 per hp + O&M, annualized cost for 100 hp $200 to $990, for 275 hp $420 to $1,210
Ex. Nett D-Series	10-50	60-86	80	<1	$4 to $20 per hp

PM= particulate matter, HC=hydrocarbon, CO=carbon monoxide, na=not available

Table 2. Summary of NOx After-treatments Cost and Reduction Efficiencies.

Control Technology Category	Emission Reduction Effectiveness (percent)				Cost Information
	PM	HC	CO	NOx	
NOx Targeted After-treatment					
Selective Catalytic Reduction (SCR) (500 ppm sulfur fuel)	30-50	50-90	40-90	75-90	$50 to $70 per hp+ urea cost+ O&M
Ex. SINOx SCR by Siemens Westinghouse	20-50	60-90	40-90	65-85	$50 to $60 per hp +$300/per ton NOx reduced urea+$715 to $1,500 per year O&M+fuel penalty, annualized cost for 275 hp =$2,940 to $4,070
Ex. NOxTECH Inc.	50-90	na	50-90	90-95	$52 to $75 per hp + $300/per ton NOx reduced urea+ O&M+ fuel penalty, annualized cost for 275 hp =$2,460 to $4,460, for 100 hp=$1,370 to $3,050
Lean NOx Catalysts (15 ppm sulfur)	90	na	na	30	Cost per hp na, fuel penalty 7 to 12 percent
NOx Adsorbers (15 ppm fuel)	na	na	na	50-90	$890 for MHDD to $1,410 for HHDD per vehicle

PM= particulate matter, HC=hydrocarbon, CO=carbon monoxide, na=not available

CONTROL MEASURE COMPARISON

The following tables present estimates of the relative cost and benefits of different control measure scenarios. The first estimate is based on the cost and emission benefits for using the construction shift for both HGA and DFW. The second estimate is based on the cost and emission benefit of using emission control technology. Lastly, a comparison of the two control measures is presented. For a complete description of the methodology used to develop these tables refer to research report 4190-5[1].

Tables 3 through 10 compare the following control measures:

- construction shift based on TNRCC estimated emission and cost,
- construction shift based on TNRCC emissions estimate and Texas Transportation Institute (TTI) estimated cost impact[6].
- use of selective catalytic reduction (SCR) as emission control technology on the heavy-highway fleet,
- limited use (30 percent) and limited NOx reduction (30 percent) of SCR,
- Low-Emission Diesel Fuel Program (LED Program), and
- Accelerated Purchase Program.

Construction Shift Comparison

The construction shift in HGA is estimated to produce a NOx reduction benefit of 0.8 TPD, or a total of 171 tons during the 214 days of Daylight Savings Time, from the heavy-highway sector. The cost of the shift to Texas Department of Transportation (TxDOT), based on TNRCC estimates, would be $70 million annually, resulting in a cost of approximately $409,000 per ton of NOx reduced. (See Table 3.)

Assuming $490 million in annual lettings for fiscal year 1999 in HGA, TTI estimated the total cost impact of the construction shift to be approximately $59 million, or $344,000 per ton of NOx reduced. This information is also presented in Table 3.

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[6] Trejo, D., and Anderson, S. Cost and Schedule Impact of Texas Natural Resource Conservation Commission Proposed Rule Restricting Construction Equipment. Texas Transportation Institute, December 2000. (Unpublished)

Table 3. Construction Shift for HGA.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
Construction shift based on SIP and attainment demonstration	Approved by TNRCC. 214-day duration (during Daylight Savings Time)	0.8 TPD for 171 tons annually	$70 million (annually)	$409,000 per ton
Construction shift based on TTI total cost impact	TTI comparison 214-day duration (during Daylight Savings Time)	0.8 TPD (or 171 tons annually)	$59 million (annually)	$344,000 per ton

Using TNRCC cost estimates, the construction shift in DFW is estimated to cost $54 million annually and yield 107 tons of NOx reduced for approximately $505,000 per ton of NOx reduced. In DFW, TTI estimated the total cost impact of the construction shift to be approximately $57 million annually, or $537,000 per ton of NOx reduced based on $359 million in annual lettings. See Table 4.

Table 4. Construction Shift for DFW.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
Construction shift based on SIP and attainment demonstration	Approved by TNRCC. 153-day duration (June 1–October 31)	0.7 TPD (107 tons annually)	$54 million (annually)	$505,000 per ton
Construction shift based on TTI total cost impact	TTI comparison. 153-day duration (June 1–October 31)	0.7 TPD (107 tons annually)	$57 million (annually)	$537,000 per ton

Emission Control Comparison

As presented in Table 5, the estimated cost for installing SCR on the entire heavy-highway fleet in HGA is between $17 million and $24 million and will yield an estimated NOx reduction of 2.1 TPD, or approximately 444 tons annually. In Table 6, the DFW area cost of implementing emission controls is estimated to range from $12.2 to $17.7 million.

Since full implementation is unlikely to occur, an alternative scenario was estimated for both the HGA and DFW area. This partial implementation scenario uses the same basic assumption except that it implements the SCR emission controls on 30 percent of the fleet, and assumes that the emission control is only 30 percent effective.

The DFW full implementation should achieve 0.3 TPD NOx reduction for a total of 510 tons. The partial implementation scenario results in NOx reduction cost of approximately $80,000 to $120,000 per ton of NOx reduced for HGA and DFW.

Table 5. HGA Emission Control Cost.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
Emission control technology using SCR on entire heavy-highway fleet.	Comparison using SCR NOx emission reduction equipment on heavy-highway sector assuming modal hp 100-175 hp and 845 pieces	2.1 TPD (444 tons annually)	$17 million to $24 million	$38,000 per ton to $55,000 per ton
Partial implementation of control technology 30 percent of fleet and 30 percent NOx reduction efficiency	Comparison using SCR NOx emission reduction equipment on heavy-highway sector assuming modal hp 100-175 hp and 254 pieces.	0.28 TPD (61 tons annually)	$5.1 million to $7.4 million	$83,000 per ton to $121,000 per ton

Table 6. DFW Emission Control Cost.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
Emission control technology using SCR	TTI comparison for DFW using SCR NOx emission control on heavy-highway sector assuming modal HP 100-175 hp and 610 pieces	3.3 TPD (510 tons annually)	$12.2 million to $17.7 million	$24,000 per ton to $35,000 per ton
Partial implementation of control technology 30 percent of fleet and 30 percent NOx reduction efficiency	Comparison using SCR NOx emission reduction equipment on heavy-highway sector assuming modal hp 100-175 hp and 183 pieces.	0.3 TPD (46 tons annually)	$3.7 million to $5.3 million	$80,000 per ton to $115,000 per ton

LED and Accelerated Purchase

Tables 7 and 8 present the estimates for both costs and emissions benefits from both the LED and accelerated purchase control measures. Unlike the previous comparisons, the cost and emission benefit information in Tables 7 and 8 relies heavily on information from regulatory impact analyses from TNRCC and Environmental Protection Agency (EPA) sources.

Table 7. HGA LED and Accelerated Purchase Comparison.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
LED Program: < 500 ppm < 10 percent aromatic HC > 48 cetane	Approved by TNRCC. LED Program begins May 1, 2002, requires diesel fuel produced for delivery and sale shall not exceed 500 ppm sulfur, less than 10 percent by vol. aromatic HC, and cetane number of 48 or greater	0.22 TPD 48 tons (7 percent by TNRCC)	*$2.6 million Cost range: $0.04 per gal - $0.14 per gal	*$54,000/ton based on $0.044 per gal.
Accelerated Purchase Tier 2 equipment fleet 50-100 hp: 25 percent Tier 2 by end 2004 50 percent Tier 2 by end 2005 75 percent Tier 2 by end 2006 100 percent Tier 2 by end 2007	Approved by TNRCC. Tier 2 equipment fleet 100-175 hp: 10 percent Tier 2 by end 2004 20 percent Tier 2 by end 2005 30 percent Tier 2 by end 2006 50 percent Tier 2 by end 2007	**60 percent NOx **40 percent PM NA	NA	NA

*Net present value cost based on EPA 15 ppm LED lifetime cost per piece in first year, modal hp 100-175, equip, 845 pieces @ $3,704 ea. = $2,597,530, 7 percent reduction for 48 tons reduced = $54,000/ton
**Based on EPA estimates for entire span of program
NA – not available

Table 8. DFW LED and Accelerated Purchase Comparison.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
LED Program < 500 ppm < 10 percent aromatic HC > 48 cetane	Approved by TNRCC. LED Program begins May 1, 2002, requires diesel fuel produced for delivery and sale shall not exceed 500 ppm sulfur, less than 10 percent by vol. aromatic HC, and cetane number of 48 or greater	0.31 TPD 47 tons (7 percent by TNRCC)	*$2,259,440 Cost range: $0.04 per gal. - $0.14 per gal.	*$48,000 per ton* (based on $0.044 per gal)
Accelerated Purchase Tier 2 equipment 50-100 hp 25 percent Tier 2 by end of 2004 50 percent Tier 2 by end of 2005 75 percent Tier 2 by end of 2006 100 percent Tier 2 by end of 2007	Approved by TNRCC. 100-175 hp 10 percent Tier 2 by end of 2004 20 percent Tier 2 by end of 2005 30 percent Tier 2 by end of 2006 50 percent Tier 2 by end of 2007	**60 percent NOx **40 percent PM	NA	$8,700 per ton- $11,700 per ton (based on TNRCC Ch 114 p. 10 preamble)

*Net present value cost based on EPA 15 ppm LED lifetime cost per piece in first year, modal hp 100-175, equip, 610 pieces @ $3,704 ea. = $2,597,530, 7 percent reduction for 48 tons reduced = $48,000/ton
**Based on EPA estimates for entire span of program
NA – not available

Comparison Summary

The combined comparisons for HGA and DFW are presented in Tables 9 and 10, respectively.

Table 9. HGA Control Measure Comparison Summary.

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
Construction shift based on SIP and attainment demonstration	Approved by TNRCC. 214-day duration (during Daylight Savings Time)	0.8 TPD for 171 tons annually	$70 million (annually)	$409,000 per ton
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Accelerated Purchase Tier 2 equipment fleet 50-100 hp: 25 percent Tier 2 by end of 2004 50 percent Tier 2 by end of 2005 75 percent Tier 2 by end of 2006 100 percent Tier 2 by end of 2007	Approved by TNRCC Tier 2 equipment fleet 100-175 hp: 10 percent Tier 2 by end of 2004 20 percent Tier 2 by end of 2005 30 percent Tier 2 by end of 2006 50 percent Tier 2 by end of 2007	**60 percent NOx **40 percent PM NA	NA	NA

*Net present value cost based on EPA 15 ppm LED lifetime cost per piece in first year, modal hp 100-175, equipment, 845 pieces @ $3,704 ea. = $2,597,530, 7 percent reduction for 48 tons reduced = $54,000/ton
**Based on EPA estimates for entire span of program
NA – not available

Table 10. DFW Control Measure Comparison Summary

Control Measure	Description	Heavy-Highway NOx Benefit	Estimated Cost	Effectiveness
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Construction shift based on TTI totals cost impact	TTI comparison. 153-day duration (June 1-October 31)	0.7 TPD (107 tons annually)	$57 million (annually)	$537,000 per ton
Emission control technology using SCR	TTI comparison for DFW Using SCR NOx emission control on heavy-highway sector assuming modal HP 100-175 hp and 610 pieces	3.3 TPD (510 tons annually)	$12.2 million to $17.7 million	$24,000 per ton to $35,000 per ton
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*Net present value cost based on EPA 15 ppm LED lifetime cost per piece in first year, modal hp 100-175, equipment, 610 pieces @ $3,704 ea. = $2,597,530, 7 percent reduction for 48 tons reduced = $48,000/ton

**Based on EPA estimates for entire span of program

NA – not available

CONCLUSIONS

TNRCC expects an estimated 21 and 13 percent emission reduction from the construction industry through the proposed equipment ban in the HGA and DFW area, respectively. This reduction will come at a cost to TxDOT and other government agencies as well as to private business. TxDOT may pay $400,000 to $500,000 per ton of NOx reduction as a result of this rule. In comparison, emission control devices cost four to ten times less. The table summaries presented herein indicate that implementing after-treatment emission controls would range from $24,000 to $55,000 per ton of NOx reduction across the entire fleet, and $80,000 to $120,000 per ton of NOx reduction if controls are only partially implemented. In addition:

- The use of diesel engine emission control devices targeted to reduce NOx emissions are more cost effective than the construction shift when measured in dollars per ton of NOx reduced.

- The cost of using diesel engine emission control technology (after-treatments and retrofits) is generally less than the cost of the construction shift and provides greater NOx emission reductions.

- The NOx reduction potential is greatest when diesel engine emission control devices are combined with the use of low-sulfur diesel fuel.

- Engine emission control and accelerated purchase are more cost effective than construction shifts. Even using conservative assumptions, NOx reductions using emission control after-treatment devices range from $25,000 to $55,000 per ton.

- The cost estimate for TxDOT by TNRCC on the impact of a construction shift is of the same order of magnitude as that developed by TTI. Both estimates indicate the cost per ton of NOx reduction to be more than $400,000 per ton.

- The cost effectiveness of the LED Program appears to be greater than that of the construction shift strategies.