Regional Inventory of Air Pollutant Emissions Associated with Removal of Waste Concrete and Supply of Road Base Aggregate

Matthew P. Fraser, Ph.D.
Associate Professor of Civil and Environmental Engineering
Rice University

HPP

Good for the Environment
Great for your Bottom Line

Table of Contents

As a member of the faculty of the Civil and Environmental Engineering Department at Rice University, Professor Matt Fraser directs several air quality research projects. Most of Dr. Fraser's research focuses on using organic speciation and receptor modeling to apportion ambient pollutants to their original source. To tackle this complex problem, Dr. Fraser's research group has been involved in field monitoring programs, source characterization studies, emission inventory preparation, and analytical method and instrument development projects. Dr. Fraser's research is focused on being directly relevant to environmental policy. Dr. Fraser serves in several roles to bring scientific understanding of air pollution into the regulatory process including the Science Coordinating Committee of the Texas Commission on Environmental Quality. Dr. Fraser teaches courses on air pollution control and atmospheric chemistry.

Executive Summary

Landfill vs. Recycling

Hauling waste concrete from construction sites and supply of road base aggregate to sites are necessary functions in construction industry. Several approaches can be used to fill this need. Recycling of concrete material at local recycling depots removes waste pavement material while supplying base aggregate for ground stabilization. Another approach is hauling waste material to distant landfills for permanent disposal and supply of virgin aggregate material from remote locations. The regional emissions associated with materials hauling from these two disparate approaches have not been assessed or used in conjunction with air quality improvement plans. This study is a first attempt to quantify the regional impacts associated with these two alternatives for removal of waste pavement and supply of base aggregate.

Emissions associated with materials hauling from the recycling option were calculated using the operation of Southern Crushed Concrete as an example. Emissions for materials hauling were calculated for three representative construction projects for recycling material plus three competing alternatives for waste removal and aggregate supply. In all cases, emissions were calculated for nitrogen oxides (NOx) emissions inside the Houston Galveston Ozone Nonattainment Area (HGONA) as these emissions lead to the formation of ground-level ozone.

Study Protocol

Using the three representative concrete recycling projects, the NOx emissions associated with removal of waste pavement to a recyling depot totaled 8.3 grams of NOx per ton of material removed. Hauling material from the construction site to the nearest available landfill would result in emissions of 17.3 grams NOx per ton material removed. The lower emission rate for recycling of materials is due entirely to lower trucking distances between construction sites and recycling depots than between construction sites and remote landfill locations.

Annual NOx Emissions Reduction = 157.8 Tons

For supply of road base aggregate, the recycling option resulted in the emissions of 8.3 grams NOx per ton supplied, while the competitive alternate supplier with the lowest emissions resulted in emissions of 30.8 grams NOx per ton supplied. The lower emission rate associated with the use of recycled material for aggregate supply is a combined effect of lower trucking distances between depots and construction sites and the emissions associated with transport of virgin aggregate by ship or train to local depots from distant sources.

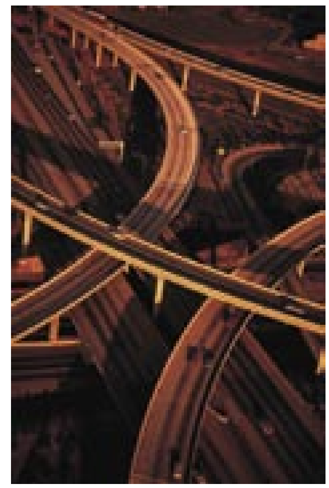
Based on the volume of material removed and supplied by Southern Crushed Concrete, the recycling option resulted in a reduction of regional NOx emissions of 157.8 tons per year. By comparison, the new light-rail line from Downtown Houston to Reliant Park is expected to reduce regional NOx emission by 95.0 tons per year. This reduction in emissions through local recycling of material as opposed to removal to remote landfills and supply of virgin aggregate from distant sources is not included in any local Houston-Galveston air pollution planning process. However, if emissions from material hauling were to increase due to decreased use of the recycling option, additional emissions cuts from existing NOx sources would be required to off-set increased emissions.

1. Introduction

Regional and Local Issues

The technical information supplied to and reviewed by the Texas Commission on Environmental Quality (TCEQ) for a new source operating permit ensures no detrimental effect on air quality in the local vicinity of any new industrial facility. However, in those reviews, no consideration is given to how a proposed facility will impact regional air quality beyond the immediate surrounding neighborhood. Without a calculation of the regional emissions associated with proposed facilities, it is impossible to gauge the relative advantage of competing alternatives for industrial expansion within a region. For an accurate evaluation of proposed facilities, a thorough evaluation of all local and regional emissions associated with a particular strategy should be considered.

NOx Emissions and Regional Air Quality



For example, in the 8-county Houston-Galveston Ozone Non-Attainment Area (HGONA), emissions from on-road and off-road mobile sources contribute 25% and 20%, respectively, of the nitrogen oxide (NOx) pollution. These NOx levels result in increased formation of ground-level ozone. Since the HGONA routinely violates the health-based air quality standard for ground-level ozone, any reduction in the emissions of NOx from on-road and off-road mobile sources will lead to lower regional ozone formation and improved regional air quality. Often strategies to reduce NOx emissions from mobile sources focus on improved vehicle technology and fuel formulations to reduce the quantity of pollutants emitted per distance traveled. An equally valid approach to reduce NOx emissions from mobile sources is to reduce the distance travelled. This approach is currently being used in the HGONA area with programs that encourage mass-transit ridership, telecommuting and vanpooling.

Reducing Regional Traffic

One approach for reducing mobile source NOx emissions by reducing vehicle travel distances is to use locally recycled crushed concrete to supply construction projects rather than hauling virgin aggregate from distant sources. In the process of collecting waste concrete from road reconstruction projects and refurbishing into aggregate in local depots, haulage distance is reduced for both the supply of aggregate and the removal of what would otherwise be a waste product to a distant landfill.

2.0 Approach

2.1 Project Selection

Three Representative Projects

To quantify the emissions associated with alternate approaches to the removal of waste concrete from construction sites and supply of road base aggregate, three types of projects were chosen to be representative of Southern Crushed Concrete's business. The representative projects are: highway expansion projects, surface road reconstruction projects and industrial site construction. For a highway expansion project, the recent expansion of US 59 in Montgomery County was selected. The surface road reconstruction project selected was the METRO reconstruction of downtown streets. As being representative of industrial site construction, the apron eeconfiguration of Terminals A & B at Houston Intercontinental Airport was chosen.

For each project, specifics of the concrete removal and aggregate supply were obtained from the bidding documents released by the contracting authority. For the US 59 expansion, the contracting authority was the Texas Department of Transportation. For the downtown street reconstruction, the contracting authority was the Metropolitan Transit Authority. For the IAH reconfiguration, the contracting authority was Dannenbaum Engineering for the City of Houston.

US 59 Expansion, Montgomery County

For the US 59 expansion project, the project location was Highway 59 in Montgomery County from Northpark Dr. to the Harris County Line (Bid date 9/10/04).[9] For the IAH reconfiguration, the project location was the Terminal A and B ramps at Intercontinental Airport (Bid date 6/26/03). For the Metro street reconstruction, the specific project investigated included several components including the (A) reconstruction of Fannin Street from Pierce to Commerce (Bid date 12/21/00), (B) reconstruction of Fannin Street from Wheeler to Holman (Bid date 5/18/00), (C) reconstruction of Louisiana Street from West Gray to Lamar (Bid date 5/23/00), and (D) the Preston Street Cotswold Phase 1C project (Bid date 8/8/00).

Emissions associated with materials haulage were calculated for bid items including removal of waste concrete and asphalt overlay. For the US 59 expansion, emissions associated with materials hauling were calculated for bid items 305-0591, 305-0547, 305-0518, 305-0516, 305-0515, 305-0503, 276-0526, 105-0502, 105-0511, 104-0503, and 104-0501. These items are for removal of waste asphalt overlay, supply of cement treated stabilized base and removal of concrete pavement, rip-rap and stabilized base. These items included the removal of 149,788 tons of asphalt material, 38,865 tons of concrete, and 34,685 tons of stabilized base and supply of 105,000 tons of concrete treated stabilized base.

IAH Terminal Apron Reconfiguration

For the IAH ramp widening project, emissions associated with materials hauling for items 02221-01, 02221-02, 02221-03, 02221-04, 02221-05, 02221-21, 02221-22, 02708-01, and 02714-01 were calculated. These items are for removal of concrete pavement, asphalt overlay and supply of cement stabilized crushed concrete and flexible base course. These bid items totaled a removal of 63,282 tons of material and supply of 58,200 tons of material.

Metro Downtown Street Reconstruction

For the Metro street reconstruction, emissions associated with materials hauling for the Fannin reconstruction from (A) Pierce to Commerce were calculated for bid items A7, A8, A14, A25 and A26. These items detail removal of concrete pavement and supply of crushed rock. The removal totaled 38,883 tons of material and supply totaled 21,820 tons. For the reconstruction of Fannin from (B) Wheeler to Holman, emissions associated with materials haulage from bid items A4, A5, A6, A7 and A14 were calculated. These items include removal of concrete pavement and asphalt overlay and supply of crushed concrete base material. Removal quantities totaled 14,805 tons and supply totaled 9,800 tons. For (C) the reconstruction of Louisiana from West Gray to Lamar, emissions associated with haulage of materials from bid items A4, A5, A6, A7 and A15 were calculated. These include removal of concrete pavement with asphalt overlay and supply of crushed concrete stabilized base. A total of 20,997 tons of material removed and 11,800 tons of material supplied are included in the emission calculation for this project. For (D) the Cotswold Phase 1C project on Preston, emissions associated with removal bid item 9 and demolition bid items 8, 9, 10 and 17 were calculated. These items detail removal of concrete pavement. For this project, no materials supply was used in preparation of the inventory as no supply of material was included in the bid. For the Cotswold project, removal hauling totaled 28,318 tons of material.

In sum, the three projects included in the inventory (including the four components of the Metro downtown street reconstruction) included removal of 389,623 tons of material and supply of 206,620 tons of material.

2.2 Competing Alternatives

Alternatives to Concrete Recycling

To provide a basis of comparison for alternative approaches to remove construction waste pavement and supply base material, four competing approaches were included in the emission inventory calculations. First is the use of distributed recycling depots for removal of waste to and supply of material from was included. The basis for this scenario is based on the business practices of Southern Crushed Concrete (SCC), and will be labeled the 'Recycling scenario'. For this scenario, emissions haulage of waste material from the project site to the nearest SCC depot and supply of material from the nearest SCC depot to the project site are included in the inventory.

Alternate Waste Disposal

Based on current business practices, emissions associated with haulage of waste from the project site to one of three landfills was deemed the competing alternative to the 'Recycling scenario'. The three landfill locations used for preparing the inventory were: the BFI McCarty Landfill (5757 Oats Road), the Waste Management Fairbanks Landfill (8205 Fairbanks North Houston Road) and the BFI Fresno Landfill 2200 FM 521). For each project, emissions from haulage of waste material to each of the three landfills was calculated. Comparisons between the Recycling scenario are made with haulage to the nearest landfill to each project location as only one landfill would be selected as an alternative to the Recycling scenario.

Alternate Aggregate Supply

As alternative supply sources of base material, based on current business practices, three alternatives to the Recycling scenario were selected and are based on current operations at an on-going business interest. One alternative, labeled Competitor A, involves bringing aggregate to a local depot on the Houston Ship Channel by ship with material then trucked to construction sites. Emissions associated with haulage by shipping and by truck are restricted only to emissions inside the 8-county HGONA (i.e. only shipping within Galveston Bay and the Houston Ship Channel). The second and third alternatives involves rail supply to one of two local depots and truck supply from the depots to construction sites. Supply of stabilizing base material from each of these depots will be labeled Competitor B and Competitor C. For these two competing alternatives, only emissions within the 8-county HGONA are calculated (i.e. rail emissions outside this region are not included in the inventory).

2.3 Emissions Calculations

NOx Emissions Calculations

Emissions associated with haulage of waste and supply materials were calculated for nitrogen oxides (NOx), a key ingredient in the formation of ground-level ozone. Currently, the ground-level ozone standard is the only National Ambient Air Quality Standard which is violated in the Houston area. For this reason, emissions reductions of NOx are a key focus of the State Implementation Plan for the HGONA which consists of Harris, Galveston, Brazoria, Fort Bend, Waller, Montgomery, Liberty and Chambers counties.

Emissions of NOx from hauling material were determined based on emission factors and level of activity. For level of activity, each truck was assumed to transport 22 tons and have a fuel consumption rate of 0.16 gallons fuel per mile transport. For train haulage, a train of 100 cars was assumed to carry 10,000 tons of material and have a fuel consumption rate of 19 gallons per mile. For ship haulage, a ship was assumed to carry 60,000 tons of material and have a fuel consumption rate of 30 gallons per mile.

Emission factors for each mode of transport were determined only within the 8-county HGONA. The emission rate of NOx from heavy-duty diesel trucks was based on recent research which studied the emissions of 21 in-use heavy duty diesel vehicles[1] and determined an average NOx emission rate of 23.3 grams of NOx per mile traveled. Locomotive emissions were based on an emission factor from AP-42[2] which details emissions of 81 kg NOx per ton of fuel consumed. Emissions from shipping were based on an emission factor from Lloyd's Marine Exhaust Emission Programme[3] which found an average emission rate of 87 kg NOx per ton fuel burned for slow speed marine engines.

(Footnotes)

[1] "Chassis dynamometer study of emissions from 21 in-use heavy duty diesel vehicles" by J. Yanowitz, M. Graboski, L. Ryan, T. Alleman and R. McCormick; Environ. Sci. Technology (1999) volume 33, issue 2, pages 209-216.

[2] "Compilation of emission factors – AP 42, 5th Edition" prepared by the Clearinghouse for Inventories and Emission Factors, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina.

[3] "Marine Exhaust Emissions Research Programme" by J. Carlton et al. (1995) published by Lloyd's Register Engineering Services, London.

3.0 Results

3.1 Vehicle Travel on Regional Roads for Waste Removal

Truck Traffic and Regional Roads

Since emissions inventories for truck haulage of material is dependant on vehicle-miles-traveled, the first step in determining regional NOx emissions is to determine vehicle traffic as a result of materials hauling for construction projects. For debris removal from the US 59 expansion project, hauling to a local recycling depot would result in 142,124 truck miles on regional roads. Alternative waste hauling options would result in 211,157 truck miles on regional roads if hauled to BFI McCarty; 219,278 truck miles if hauled to Waste Management Fairbanks; and 357,342 truck miles if hauled to BFI Fresno. For the IAH project, the truck mileage on regional roads for waste removal would be 31,131 truck miles for hauling to a recycling depot; 63,282 truck miles for hauling to BFI McCarty; 52,064 truck miles for hauling to Waste Management Fairbanks; and 102,977 truck miles for hauling to BFI Fresno.
For the downtown street reconstruction, the vehicle mileage for waste removal would be 23,131 truck miles for hauling to a local recycling depot; 48,224 truck miles to haul to BFI McCarty; 74,911 truck miles to haul to BFI Fresno; and 83,339 truck miles to haul to Waste Management Fairbanks. These results are summarized in Table 1.

Proximity to Construction Sites Reduces Truck Traffic

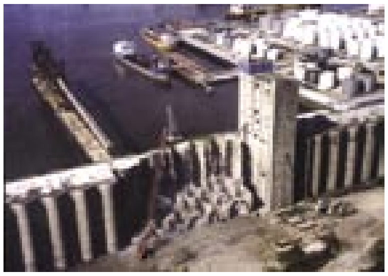
Project	Recycling Scenario	BFI McCarty Landfill	Waste Management Fairbanks Landfill	BFI Fresno Landfill
US 59 Widening	142,124	211,157	219,278	357,342
IAH Apron Reconfiguration	31,131	63,282	52,064	102,977
Downtown Street Reconstruction	23,131	48,224	83,339	74,911

Table 1: Truck traffic (in miles) on regional roads associated with waste removal of waste material from representative construction projects.

3.2 Emissions Quantification for Debris Removal

NOx Emission from Waste Concrete Removal

Emissions of nitrogen oxides within the HGONA calculated for the four alternative waste removal options are detailed in Figure 1. The emissions for waste haulage associated with each of the representative constructions projects studied are calculated for four alternative approaches: localized recycling of waste pavement, removal to BFI McCarty Landfill, removal to Waste Management Fairbanks Landfill and removal to the BFI Fresno Landfill. These emissions were quantified based on volume of material removed,



distances to either the nearest recycling depot or a specific landfill, and the average emission rate for heavy-duty diesel vehicles. The emissions were then normalized by mass of material transported to give an emission rate for each alternative in grams of NOx per ton of material supplied. This allowed a representative comparison between alternative approaches for the various projects studied.

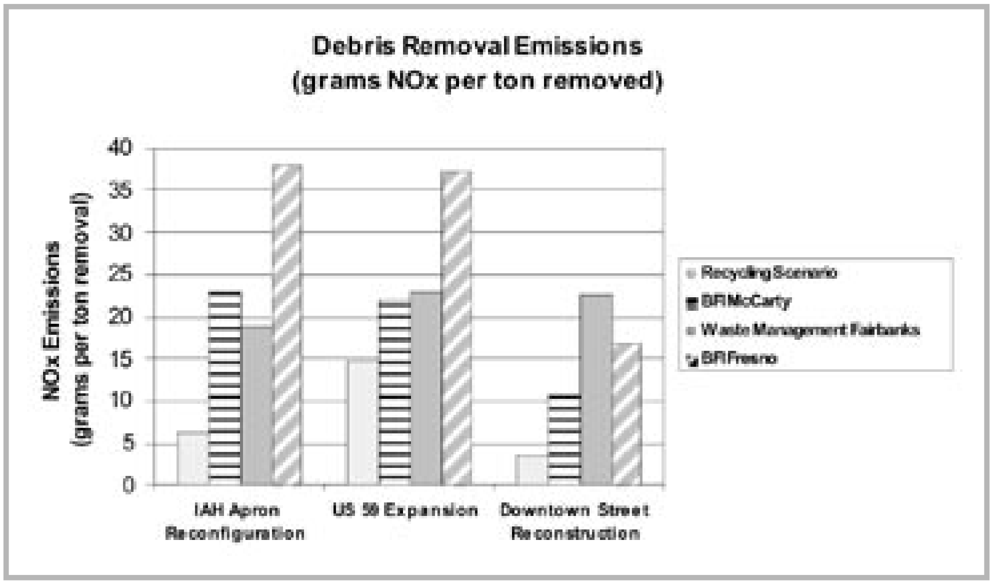


Figure 1: Regional NOx for the 8-county Houston Galveston Ozone Nonattainment Area for hauling waste debris from three representative construction projects in grams NOx per ton removed. Emissions were calculated based on methodology detailed in text.

As can be seen in Figure 1, localized recycling of waste pavement from construction projects results in significantly lower regional NOx emissions per ton of removal than competing alternatives for all projects studied. This result is primarily because localized recycling depots require less distance to be traveled by haulage trucks. For example, for the downtown street reconstruction, local recycling results in emissions that are 66% lower than the next competitive solution. That occurs because a recycling depot is located near a construction site but there is no nearby landfill. For representative projects where the nearest recycling depot and the nearest landfill are a similar distance (i.e. US 59 expansion in Montgomery County), the emissions benefits of local recycling are still present but not as significant.

3.3 Emission Quantification for Material Supply

Recycling Provides Local Source of Base Aggregate

In addition to removal of waste pavement, construction projects often require supply of aggregate for base stabilization. Three alternative supply routes in addition to local recycling of material are used for supply of road base aggregate. The three construction project case studies used required a total supply of 206,620 tons of material and NOx emissions associated with supply haulage for each of the four alternatives have been calculated.

For the Recycling scenario, which relies on trucking material from local depots to construction sites, regional NOx emissions are entirely associated with trucking. For Alternative A, shipping material to a depot along the Houston Ship Channel and then trucking to the site, emissions of NOx in the HGONA are from both shipping and trucking. For Alternatives B and C, rail transport of aggregate material to one of two local depots and then trucking to construction sites, emissions are quantified for both rail and trucking of material. For Alternatives A, B and C, only emissions within the 8-county HGONA are included.

For the US 59 widening project in Montgomery county, a total of 105,000 tons of cement stabilized base material were required. For the four competing alternatives, the relative emissions per ton supplied is summarized in Figure 2.

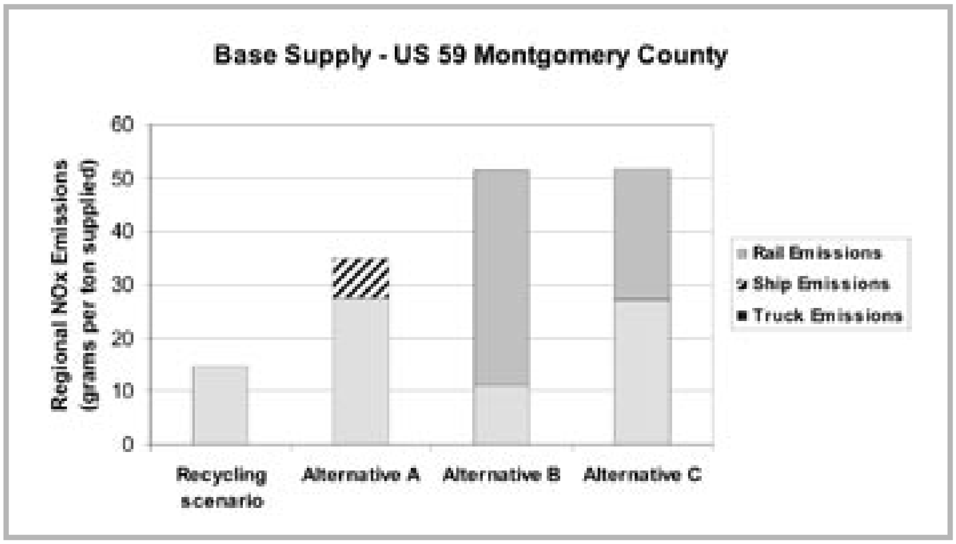


Figure 2: Emissions of NOx in the 8-county Houston Galveston Ozone Nonattainment Area for four alternatives for road base aggregate supply for the US 59 expansion project in Montgomery County. Emissions are quantified in grams NOx per ton supplied for each of the four competing approaches for materials supply.

Emissions for Virgin Aggregate Higher Than for Local Recycling

The data presented in Figure 2 show that localized recycling can result in higher emissions from trucking than competitive alternatives. This can occur when there is no local recycling depot near a construction site. In the case of the US 59 expansion project in Montgomery County, one alternative material supplier is located closer to the construction site than the nearest recycling depot. As a result, that supplier has lower associated trucking distance and thus lower associated trucking emissions. However, emissions associated with rail emissions for that supplier to bring the aggregate from remote locations to the local materials depot far exceed any reduction in emissions from shorter trucking distances.

For the IAH ramp realignment project at Terminals A and B, a total of 58,200 tons of material were required including 56,600 tons of cement stabilized crushed rock and 1,600 tons of flex crushed concrete base. For the four competing alternatives to supply this material, the expected regional emissions of NOx are summarized in Figure 3.

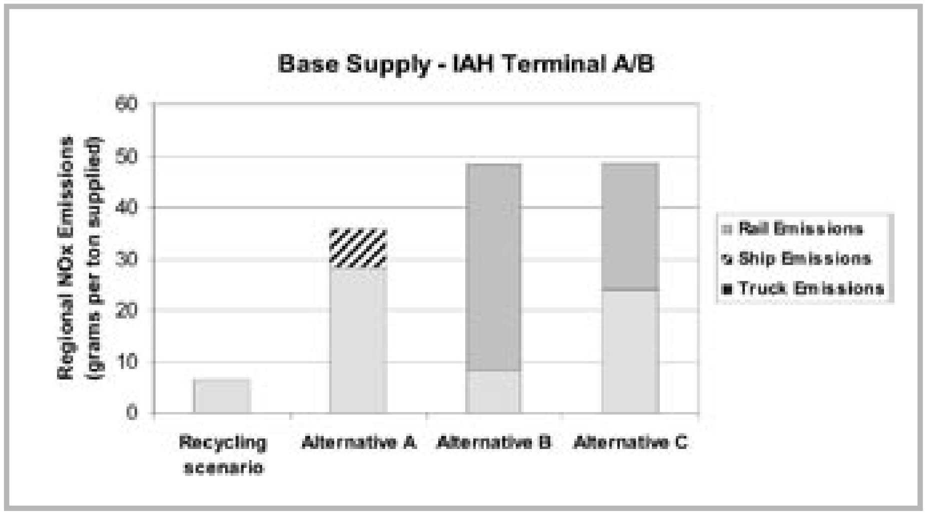
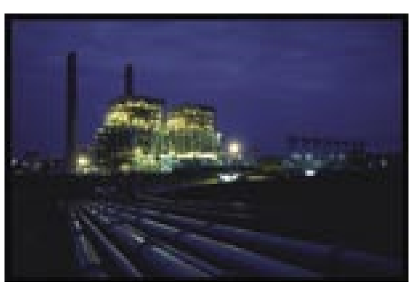


Figure 3: Emissions of NOx in the 8-county Houston Galveston Ozone Nonattainment Area for four competing alternatives for road base aggregate supply for the IAH Terminal A/B ramp realignment project. Emissions are quantified in grams NOx per ton supplied for each of the four competing approaches for materials supply.

Virgin Aggregate Transport Results in Trucking and Rail Emissions

The data presented in Figure 3 show a clear advantage for localized recycling of material to supply base stabilizing aggregate, with the recycling alternative resulting in less than 20% of the expected emissions from the next alternative (Alternative A). While some alternatives have similar emissions from trucking as the recycling alternative (i.e. Alternative B), the emissions associated with rail transport to the local depot for Alternative B far exceed any trucking emissions.

For the four individual components considered together as the downtown street reconstruction project, a total stabilizing base aggregate supply of 43,420 tons was required. For the four competing alternatives to supply this material, expected emissions were calculated and are presented in Figure 4.



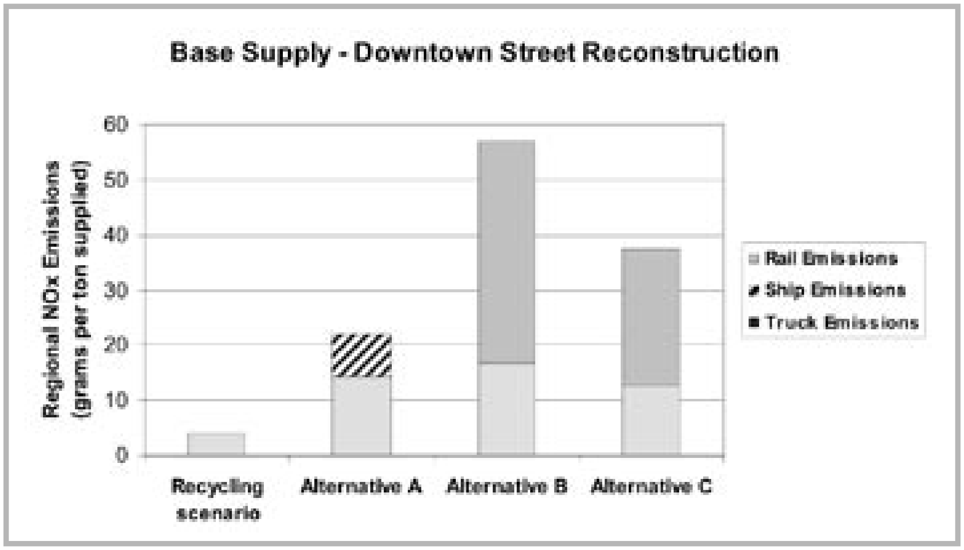


Figure 4: Emissions of NOx in the 8-county Houston Galveston Ozone Nonattainment Area for four competing alternatives for road base aggregate supply for the downtown street reconstruction project. Emissions are quantified in grams NOx per ton supplied for each of the four competing approaches for materials supply.

For this project, local recycling clearly results in reduced NOx emissions primarily because of the proximity of the local recycling depot to the project. This is similar to the results associated with waste debris hauling for the downtown street reconstruction project. Since there is no landfill or alternative supply depot nearby, emissions associated with hauling from supply depots or to landfills far exceed emissions if recycling is used.

3.4 Overall Regional Inventory

Conclusion: Local Recycling Reduces Regional NOx Emissions

Up to this point, emissions have been determined for alternatives based on quantity of material supplied. The overall air quality impact of local concrete recycling can be quantified by preparing a regional inventory of NOx emissions for the Recycling scenario and the three competing alternatives. This can be performed by scaling the average emissions per ton for recycling and the closest alternative by the volume of concrete currently being recycled in the community. This requires the assumption that the projects selected for investigation are truly representative of the business practice of concrete recycling.

Taking these projects as representative of the business practice of Southern Crushed Concrete, the average regional NOx emissions for hauling waste debris from construction sites is 8.3 grams NOx per ton removed. For the next best alternative as measured by regional NOx emissions, the emission of NOx for debris removal is 17.3 grams NOx per ton removed. The emission rate for localized concrete recycling is approximately half that of the next best alternative as measured by NOx emissions.

Annual Regional NOx Emissions 157.8 Tons Lower with Recycling

A greater advantage for local recycling of concrete is seen in the comparative emission rates for supply of road base aggregate to construction sites. For material supply, the regional NOx emissions for hauling material from a local concrete recycling depot is 8.3 grams per ton supplied. For supply of virgin aggregate, the expected NOx emissions per ton of material supplied is 30.8 grams NOx per ton supplied for the competing alternative with the lowest NOx emissions in the HGONA per ton material supplied. For the other competing alternatives, the emissions are much greater. The regional NOx emissions for supplying material from a recycled source is less than 30% the regional emissions for virgin aggregate supply. In addition, these estimates are low as the calculations only include NOx emissions inside the 8-county HGONA and do not include emissions from outside this specific area.

The volume of material processed each year by Southern Crushed Concrete is roughly 3 million tons. This quantity is both the volume of debris removed from construction sites and material supplied as stabilizing aggregate to local construction projects. If the three projects selected for investigation in this study are representative of the business as a whole, it is expected that 3 million tons or recycled material will result in roughly 24.9 tons per year of NOx emissions from vehicle haulage of debris material and 24.9 tons per year of NOx emissions associated with supplying material to construction sites. While these emissions are significant, the expected emissions if alternative methods are used for removal and supply of this material are far greater. The competing alternative with the lowest emissions other than recycling would result in the annual regional NOx emissions of 51.9 tons NOx in the process of removing debris and 155.7 tons NOx in the process of material supply.

4.0 Impact of NOx Emissions on Ozone

The chemistry of ground-level ozone formation involves a complicated pathway of chemical reactions interlinking emissions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). For that reason, it is difficult to summarize the impact of reduced NOx emissions from local recycling of concrete versus disposal and supply of virgin aggregate on ozone levels. However, any alternative for material removal and supply that has significantly lower NOx emissions will lead to a reduction in ozone formation and lower ozone concentrations. For this reason, significant NOx emission reductions from existing sources are called for in the current air quality improvement plans for Houston. If alternatives with NOx emissions greater than the local recycling of concrete are employed, the NOx emissions reductions that will be required from existing sources to meet our clean air goals will need to be greater.

Emissions Reductions from Recycling Greater Impact Than Light Rail

Using concrete recycling at a rate of 3 million tons per year the current volume of business at Southern Crushed Concrete, the 8-county HGNOA has annual NOx emissions that are 157.8 tons lower than if recycling of crushed concrete was not available. This includes 27.0 tons per year of lower emissions in the process of debris removal and 130.8 tons per year of lower emissions in the process of materials supply. These reduced emissions from employing local recycling of crushed concrete are 0.43 tons of NOx per day. To put these emissions savings in perspective, the new light-rail line from Downtown Houston to Reliant Park is expected to reduce regional NOx emissions by 95 tons per year or 0.26 tons per day.[4]

780 Tons Less Ozone Per Year

In a recent study of ozone formation in Houston, Ryerson et al.[5] found that the formation of ozone from NOx emissions in Houston is very dependant on the co-emitted volatile organic compounds (VOCs). In the urban core of Houston, the oxidation of 1 gram of NOx emissions resulted in the formation of approximately 5 grams of ozone. As a result of these measurements, it is possible to estimate the impact reduced emissions on ozone formation. As shown above, it is expected that localized recycling of concrete reduces NOx emissions by more than 157 tons of NOx per year. With an estimation of the chemistry as described above, this reduction in emissions from materials hauling through the Recycling scenario results in decreased ozone formation of over 780 tons of ozone each year. While it is not possible to determine an absolute concentration associated with this decreased ozone formation, it is illustrative of the magnitude of the benefit of reduced emissions through local recycling of concrete as opposed to removal to remote locations and supply of virgin aggregate.

[4] "State Implementation Plan for the Houston-Galveston Ozone Nonattainment Area" prepared by the Texas Commission on Environmental Quality, December 2000, Austin, TX.

[5] "Effect of petrochemical industrial emissions of reactive alkenes and NOx on tropospheric ozone formation in Houston, Texas" T. Ryerson et al (2003), J. eophysal Research, volume 108(D8), article no. 4249.

5.0 Conclusions

Emissions associated with materials hauling from concrete recycling were calculated using the operations of Southern Crushed Concrete as an example. For comparison, emissions for materials hauling were calculated for three representative construction projects for both the recycling option plus three competing alternatives for waste removal and aggregate supply. In all cases, emissions were calculated for nitrogen oxides (NOx) emissions as these emissions lead to the formation of ground-level ozone.

Debris Removal 8.3 Grams NOx Per Ton for Recycling vs. 17.3 Grams Per Ton Landfilling

Using three projects selected as representative of the concrete recycling option, the NOx emissions associated with removal of waste pavement to a recyling depot totaled 8.3 grams of NOx ton removed. Hauling material from the construction site to the nearest available landfill would result in emissions of 17.3 grams NOx per ton material removed. The lower emission rate for recycling of materials is due to decreased trucking distances between construction sites and recycling depots compared to remote landfill locations.

Aggregae Supply 8.3 Grams NOx for Recycling vs. 30.8 Grams Per Ton Virgin Supply

For supply of road base aggregate, the recycling option resulted in the emissions of 8.3 grams NOx per ton supplied, while the competing alternate supplier with the lowest emissions resulted in emissions of 30.8 grams NOx per ton supplied. The lower emission rate associated with the use of recycled material for aggregate supply is a combined effect of lower trucking distances between depots and construction sites and the emissions associated with transport of virgin aggregate to local depots from distance sources by either ship or train.

Based on the volume of material removed and supplied by Southern Crushed Concrete, the recycling option resulted in a reduction of regional NOx emissions of 157.8 tons per year. By comparison, the new light-rail line from Downtown Houston to Reliant Park is expected to reduce regional NOx emission by 95.0 tons per year. This reduction in emissions through local recycling of material as opposed to removal to remote landfills and supply of virgin aggregate from distant sources is not included in any air pollution planning process. However, if emissions from material hauling were to increase due to decreased use of the recycling option, additional emissions cuts from existing NOx sources would be required to off-set increased emissions.