Reducing Emissions at Land Border Crossings through Queue Reduction Expedited Security Processing

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ABSTRACT

Vehicle border crossings between Mexico and the United States generate significant amounts of air pollution, which can pose health threats to personnel at the ports of entry (POEs) as well as drivers, pedestrians, and local inhabitants. Although these health risks could be substantial, there is little previous work quantifying detailed emission profiles at POEs. Using the Mariposa POE in Nogales, Arizona as a case study, light-duty and heavy-duty vehicle emissions were analyzed with the objective of identifying effective emission reduction strategies such as inspection streamlining, physical infrastructure improvements, and fuel switching. Historical traffic information as well as field data were used to establish a simulation model of vehicle movement in VISSIM. Four simulation scenarios with varied congestion levels were considered to represent real-world seasonal changes in traffic volume. Four additional simulations captured varying levels of expedited processing procedures. The VISSIM output was analyzed using the EPA's MOVES emission simulation software for conventional air pollutants. For the highest congestion scenario, which includes a 200% increase in vehicle volume, total emissions increase by around 460% for PM_{2.5} and NO_x, and 540% for CO, SO₂, GHGs, and NMHC over uncongested conditions for a two-hour period. Expedited processing and queue reduction can reduce emissions in this highest congestion scenario by as much as 16% for PM_{2.5}, 18% for NO_x, 20% for NMHC, 7% for SO₂ and 15% for GHGs and CO. Other potential mitigation strategies examined include fleet upgrades, fuel switching, and fuel upgrades. Adoption of some or all of these changes would not only reduce emissions at the Mariposa POE, but would have air-quality benefits for nearby populations in both the US and Mexico. Fleet-level changes could have far-reaching improvements in air quality on both sides of the border.

Keywords: Port of entry, vehicle emissions, air quality, transportation logistics, border crossing

1.0 INTRODUCTION

In 2014, the 25 land border crossings from Mexico into the US processed 5.4 million heavy duty vehicles (HDVs), 2.1 billion buses, 6.96 million light duty vehicles (LDVs) and 41.2 million pedestrians (1). While these land ports of entry (POE) play a vital role in enhancing the economic relation between the two countries, their traffic can present noteworthy environmental and health challenges (2). Long queues of idling vehicles are a common sight at these ports. The emissions from idling traffic not only result in poor air quality in the vicinity of the port, but many of the vehicle emissions are also linked to adverse human health impacts (3-9). For example, particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) can cause respiratory issues, especially in young children and elderly individuals, leading to cardiovascular problems, as the particulates are small enough to traverse the membranes of the lungs (10). Further complicating the matter is the cross-jurisdictional nature of the pollution, impacting multiple states, provinces, and countries. Possibilities exist for reducing emissions through a combination of logistic improvements, technology changes, and fuel switching. Using the Mariposa POE at the Arizona-Mexico border, this study investigates the potential for emissions reductions at land ports.

The cities of Nogales, Arizona (AZ) and its Mexican counterpart Nogales, Sonora are home to three land POE's: Mariposa, Deconcini and Morley. Nogales, AZ has a population of approximately 20,000 and Nogales, Sonora has a population of nearly 213,000 (11, 12). With nearly a quarter of a million inhabitants in close proximity to the three POEs, accurately quantifying the drivers of air pollution and identifying reduction strategies is imperative. Another POE study at the International Bridge of the Americas between Juarez, Mexico and El Paso, Texas measured $PM_{2.5}$ and found that workers at the POE were exposed to considerably higher concentrations than the industrial occupational exposure standards (2). The high amount of HDV traffic at the Mariposa POE could lead to similar dangerous conditions for POE workers and local communities. We focus on the Mariposa POE, which is the main entry point for fresh produce and manufactured goods from Mexico to the Western US and the busiest land port in Arizona for LDVs (13). Currently, Mariposa POE staff process 1,300 HDVs and 10,000 LDVs on average each day (1). The facility underwent a major infrastructural upgrade (completed in 2015) which has significantly improved the processing capabilities for both LDVs and HDVs, yet major logistical challenges remain as multiple US and Mexican agencies oversee inspection processes. Northbound HDVs have to undergo a series of inspections by several agencies including Customs and Border Protection (CBP), United States Department of Agriculture (USDA), Food and Drug Administration (FDA), Federal Motor Carrier and Safety Administration (FMCSA) and Arizona Department of Transportation (ADOT) before they are cleared to enter the US. LDVs and passenger buses from Mexico are subjected to up to two inspections by CBP before they are allowed into the US.

The objective of this study is to assess emissions from northbound vehicles at the Mariposa POE and identify potential emission reduction strategies including information technology, inspection processes, physical infrastructure improvements, vehicle technology changes, and fuel switching. Northbound vehicle movements are the primary focus of this study as the existing border crossings are not designed for commercial inspection of vehicles entering Mexico. The southbound vehicle movements, therefore, are outside the scope of this project, and likely contribute less significantly to the total POE emission profile due to the lack of a HDV queue.

Historical information from the US Bureau of Transportation Statistics (BTS) as well as field data (including volume, service time and speed distributions) obtained from a two-day data collection at the port are used to establish a simulation model in the microscopic traffic simulation package VISSIM 7.0. The results from VISSIM are input to MOVES to analyze emissions.

There are no existing studies that evaluate emissions reductions at POEs with a combination of diverse logistic, technological, and fuel improvements. Furthermore, there are no studies to date that evaluate emissions specifically at the Mariposa POE, but a number of existing studies have focused on identifying bottlenecks in the vicinity of the port using traffic count, queue length and traffic delay information. Golob et.al (14) evaluated the intersections leading into and out of the port for possible bottlenecks but did not include operations inside the port. Villalobos et.al (15) used statistical methods like time series and multiple regression analyses to forecast traffic at the port based on historical traffic information and exogenous variables like GDP, fuel price, population etc. Villalobos et.al (16) used simulation techniques to determine the impact of the operation of a container terminal at the Port of Guaymas on the Mariposa POE. The simulation results from the former port were used as inputs to identify bottlenecks at the Mariposa POE. The solutions proposed by these studies to mitigate congestion include 1) geometric improvements like pavement restriping, modification of turn radii, lane widening and the addition of new lanes etc. and 2) operational changes including retiming existing and installing new traffic signals.

Outside of analyses at POEs, assessment of emissions using simulation software is well developed both at macro and micro levels. Motor Vehicle Emission Simulator (MOVES) is a state-of-the-art emission modeling software developed by the US Environmental Protection Agency (EPA), and multiple studies deploy MOVES at the link-level to study specific interventions, such as light signal timing and infrastructure design (17,18,19,20). Furthermore, MOVES has been shown to be effective at studying varying levels of vehicle congestion when linked to microscopic movement simulation (21, 22, 23), as is proposed for this project. Most recently, MOVES was used to investigate regional differences in metropolitan emission inventories due to differences in vehicle fleets and infrastructure (24). This software is well established in the literature for performing the emission simulation necessary for this study.

1.1 OBJECTIVES

The main objectives of this study are to i) assess vehicle movements near and within a POE with process-level detail using high fidelity vehicle trajectory information , ii) develop a robust emissions inventory, and iii) propose emissions reduction strategies through a variety of infrastructural, technological, and fuel change strategies. Combining VISSIM and MOVES has been shown to be an effective approach for analyzing POE emissions (25). Unlike the previous studies, queued vehicle movements are not classified as stop-and-go or creeping. Instead, sample trajectories are used as inputs to MOVES for higher resolution analysis. The emissions are analyzed for queued and non-queued traffic at different input volume conditions based on the field observations.

2.0 METHODOLOGY

Detailed vehicle movement and emissions simulations were created using field collected data from the Mariposa POE, VISSIM traffic simulations, and EPA MOVES software. Field data were processed to obtain volumes as well as average wait times and wait time distributions for each inspection process. These then informed the development of multiple congestion scenarios in VISSIM. Finally, VISSIM output on vehicle movement was input in MOVES to obtain vehicle emissions for each inspection phase.

2.1 Mariposa POE Overview

FIGURE 1 Vehicle Flow through the Mariposa POE. HDVs access the right half of the port which includes primary inspection, x-ray, secondary inspection and exit lanes managed by the CBP and the rapid and secondary inspection stations monitored by ADOT. Not all HDVs will go through all inspection processes. LDVs go through the primary inspection (and sometimes secondary inspection) stations managed by CBP on the left side of the port

Upon arriving at the POE, HDVs and LDVs undergo a series of inspections by various government agencies. The schematic of the flow inside the port is overlaid on an aerial image in Figure 1. Northbound HDVs that are enrolled in the Free and Secure Trade (FAST) program have a tag for identification while approaching the CBP Primary Inspection. Mexican customs and toll booths are located far away from the POE itself, and therefore are not included in the emission inventory of this study. The left most lane of the eight lanes is dedicated for primary inspection and reserved for those enrolled in the FAST program to expedite crossing for registered drivers, HDVs and cargo. Selected HDVs are then X-rayed. The X-ray station has two lanes, but only one was under operation as observed during the field visit. If further inspection is needed, HDVs proceed to the CBP secondary inspection. Once cleared by CBP and other agencies such as USDA, HDVs pass through one of the five CBP exit lanes, followed by one of the seven ADOT Rapid Inspection Lanes (RIL), where they may be sent to the ADOT secondary inspection area for weight limit, motor carrier license, or mechanical inspections. Not all HDVs go through every single inspection station. LDVs go through CBP primary inspection using one of the 12 inspection lanes, after which they are allowed to enter the US unless a secondary inspection is required. The secondary inspections involve a more comprehensive review of documentation along with a possible search of belongings in the vehicle to determine the actual purpose of the visit to the US. During our field visit, it was observed that not all the lanes of an inspection station are open at all times due to limited resources.

2.2 Data Collection

The overall data collection effort involved 10 hours of interviews with ADOT, CBP and EPA personnel and 20 hours of video recording over two days at Mariposa POE using four video cameras. Video recordings occurred March 5 and 6, 2015. The interviews with the relevant port authorities revealed that the morning and afternoon peak periods are usually between 9 – 11 AM and 2:30 – 4:30 PM. The LDV data were collected only for the morning peak but the HDV information was recorded for both peak periods. It was observed that HDVs spent a greater amount of time at the X-Ray station followed by the primary inspection station. Due to accessibility constraints, it was not possible to determine the time spent by the HDVs at the secondary inspection station. The number of LDVs requiring secondary inspection were found to be negligible.

2.3 Data Processing

The recorded videos were digitized to obtain the overall volumes and service/waiting time distribution at each of the inspection stations for both HDVs and LDVs. The observed volume data were comparable with those obtained from BTS. A total of 558 HDVs (in 6 hours) and 963 LDVs (in 4 hours) were observed during the data collection. The BTS data averaged 139 HDVs and 546 LDVs for 2 hours for the month of March in 2014 indicating the observed data is not atypical for the Mariposa POE. It was found that on average, 4% of HDVs go through the CBP secondary inspection and 14% go through the ADOT secondary inspection. The X-ray machine processes 5 to 7 vehicles at a time taking anywhere between 30 – 60 minutes, the majority of which is for administrative processing while the X-ray machine actually runs only for 5 minutes. During the 2-hour data collection, 10 vehicles were processed through the X-Ray in two cycles. The time distribution of HDVs at various inspection stations is shown in Table 1. On average, HDVs spend approximately 2 minutes and a maximum of 5.5 minutes at the primary inspection. Also, it takes an average of 24 seconds and a maximum of approximately one minute to go through the CBP exit lanes. The LDVs take an average of 69 seconds and a maximum of 4.4

minutes to go through primary inspection. The inspection times for HDVs at the primary station and CBP exit lanes follow approximately a Log-Logistic distribution whereas the LDVs at the primary inspection station follow a Log-Pearson distribution.

2.4 Traffic Simulation

The volume and inspection time distributions obtained from the processed data were used as inputs in the microscopic traffic simulation model in VISSIM. Figure 1 was a reference for building the traffic network. The simulation network consists of a nine mile section upstream of the Primary Inspection Station. This section is necessarily not always full of vehicles except during high volume conditions. Roads leading to the various inspection stations were modeled using links and connectors and the actual inspection stations were modeled as toll-booths which were assigned the waiting time distributions described in Section 2.3. All scenarios utilize the same wait distributions. Also, due to limited resources of the inspection agencies, the port is not being operated at full capacity at all times. It was observed that the primary inspection station had six open lanes for both HDVs and LDVs respectively. The CBP exit for HDVs had three lanes open, and five ADOT RIL lanes were open. The two lanes of the ADOT secondary inspection used for “Weight-In-Motion” and mechanical inspection respectively were both open. Traffic simulation models were developed for the following demand conditions. All simulations were developed for two-hour time intervals to match the periods of the field observations.

1. **Uncongested, Limited Lanes (UCL):** No queues were observed during the data collection at the POE, and hence the observed traffic conditions at the port could be classified as uncongested. The number of open lanes was set to that observed on site.
2. **Moderately Congested, Limited Lanes (MCL):** A 100% increase in the observed uncongested volume resulted in moderately congested conditions. The number of open stations was assumed to be the same as that during the field observations. This might be more representative of the actual vehicle traffic at the port and is an important benchmark. From the BTS reports, the two-hour volume at the port in 18 years (1995-2013) averaged to 121 HDVs and 1,178 LDVs, which is approximately double the observed vehicle volumes (*I*). The BTS reports also indicate highest traffic volumes in March, which are realistically represented by this scenario.
3. **Heavily Congested, Limited Lanes (HCL):** A 200% increase in the UCL volume was used in the heavily congested situation. This volume represents a 5% growth in vehicle volume over the next 20 years, and could thus represent future conditions at the POE (as estimated by the project technical advisory committee). The number of open stations is assumed to be the same as that during the field observations.
4. **HCL, 10% FAST Enrollment (HDV only):** FAST is an innovative trusted traveler/trusted shipper program that allows expedited processing for commercial carriers that have completed background checks and fulfilled certain eligibility requirements. The enrollment in this program is open only to truck drivers from the US, Canada and Mexico. The participation in this program requires that every link in the supply chain including the manufacturer, carrier, driver and importer is certified under the Customs-Trade Partnership Against Terrorism (C-TPAT) program. There is no historic information on the number of trucks enrolled in FAST at the POE. The simulation models were developed for the heavily congested limited lanes demand conditions with multiple FAST enrollment percentages. Based on POE observations, this scenario of 10% FAST enrollment is close to the current enrollment percentage.

5. **HCL, 20% FAST Enrollment (HDV only):** Increasing FAST enrollment to 20% would represent approximately doubling the participants enrolled in the program.
6. **HCL, 40% FAST Enrollment (HDV only):** The 40% FAST enrollment is an aggressive future scenario for increasing the FAST program
7. **HCL, 100% FAST Enrollment (HDV only):** Although 100% FAST enrollment does not necessarily represent a realistic scenario, we include this as a scenario to look at the potential congestion and emission benefits that would be associated with FAST-like processing times for all HDVs.
8. **Heavily Congested, All Lanes (HCA):** The traffic volume was held constant at a 200% increase over the uncongested scenario, but all the stations are open, in order to identify the impacts of flow on emissions.

2.5 Emissions Simulation

Emissions for the vehicle movement were simulated using the state-of-the-art MOVES model developed by the US EPA. The vehicle movement output from VISSIM for each of the congestion scenarios was input into MOVES along with data on the vehicle age distribution, fuel, weather, and vehicle class. In MOVES, the congestion scenarios are run separately for LDVs and HDVs. All the simulations retain information about the location of emissions throughout the port (i.e. queuing, CBP, X-Ray, etc.) so as to allow for comparison of the most influential processes to total emissions.

MOVES is designed to model emissions from US vehicles, so several modifications are made to improve the accuracy of LDVs and HDVs arriving from Mexico. A Mexico-specific emissions model exists called MOBILE 6.2 – Mexico, which is based upon MOVES' predecessor software. MOBILE 6.2 – Mexico utilizes an older emission calculation procedure which is more simplistic compared to the incorporation of vehicle-specific power in MOVES. The following modifications were made to MOVES to make it applicable for a Mexican simulation:

- Fuel – gasoline and diesel fuel formulations were developed based upon the most recent Mexico fuel quality standard as applicable to the US border area (26). Since all the vehicles in the simulation are northbound, it is reasonable to assume that they are using fuel from Mexico.
- Age distribution – for both HDVs and LDVs, the vehicle age distributions from MOBILE 6.2 – Mexico are employed. In general, the Mexican fleet is slightly older than the US fleet. The assumption that all vehicles entering the US follow the age distribution of Mexican fleet could result in slight overestimation of certain emissions if the northbound traffic also includes some US fleet.
- Type mix – for LDVs, the mix of cars and small amount of buses (technically HDVs, but processed through the same inspection process as LDVs) is available from field observations. For HDVs, the distribution between heavy-heavy duty (HHD) and medium-heavy duty (MHD) is unknown, so a base split of 80% HHD and 20% MHD was used. The importance of this assumption was tested through a sensitivity analysis by also including HHD/MHD percentage splits of 75/25 and 95/5.

The eight base scenarios of vehicle movement from VISSIM were augmented in MOVES to simulate different conditions in the vehicle fleet. All MOVES-only scenarios utilize the HCL (200% increase) vehicle volume with no FAST lanes.

9. **All New Vehicles:** The HCL scenario was analyzed for emissions with 2015 vintage vehicles which significantly contribute to reducing emissions. The fleet crossing the port is a combination of US and Mexican fleet and this case represents an extreme example of the benefits of incentivizing vehicle fleet turnover.
10. **Fuel Switching:** To capture potential future technology developments, a scenario was developed in which the fuel of all HDVs and buses was switched from diesel to compressed natural gas (CNG) and all LDVs were switched from gasoline engines to electric vehicles (EVs). This scenario is unlikely to fully occur in the near term, but it represents a theoretical maximum benefits of technology shifts. MOVES does not have the capability to model CNG freight vehicles, so CNG transit buses were used to approximate emissions.
11. **Fuel Sensitivity:** Not all of Mexico sells low sulfur diesel and gasoline in compliance with the latest Mexican fuel standards, so an alternate scenario including the higher sulfur fuels was developed to underscore the importance of moving towards the required fuel standards.
12. **Type Sensitivity:** The true split between HHD and MHD vehicles is unknown, so this scenario represents a lower percentage of HHD (75% HHD and 25% MHD) than what was assumed in the other models (80% HHD / 20% MHD).
13. **Type Sensitivity:** As a counterpart to scenario 12, this scenario modeled a higher percentage of HHD (90% HHD and 10% MHD) than what was assumed in the other models (80% HHD / 20% MHD).

The output from MOVES includes emissions inventories for Conventional Air Pollutants (CAPs): Nitrogen Oxides (NO_x), Particulate Matter less than 2.5 microns (PM_{2.5}), Sulfur Dioxide (SO₂), Carbon Monoxide (CO), and Non-Methane Hydrocarbons (NMHC), as well as greenhouse gas emissions (GHG). Many of these pollutants are regulated under the National Ambient Air Quality Standards because of their negative impacts on human and environmental health. GHG emissions include CO₂, CH₄, and N₂O. CH₄ and N₂O are normalized to CO₂-equivalence using a 100-year global warming potential.

3.0 RESULTS

Quantities of emissions at the Mariposa POE vary based on the vehicle types, fuel types, vehicle age, and the pollutant being considered. Emissions due to vehicle movement, sensitivity of simulation to fuel and type, and finally, reduction strategies including operational changes and fleet upgrades are discussed in this section.

3.1 Vehicle Movement and Congestion

Increasing traffic vehicle volume at the Mariposa POE causes non-linear increases in all emissions analyzed (PM_{2.5}, NO_x, NMHC, GHGs, SO₂, and CO). Volume increases of 100% resulted in between 190% and 270% increases in emissions, and volume increases of 200% resulted in emission increases between 429% and 650%. The absolute values of the emission changes are given in Figure 2.

FIGURE 2: Emission Changes from Increased Vehicle Volumes. Increasing vehicle volume through the POE results in non-linear increases in emissions across all pollutants for both HDVs and LDVs

Wait times to enter the POE also increased with vehicle volume increase. This increase in wait time was a driver of the higher emissions for the increasing volume. This can clearly be seen in the HDV and LDV process breakdowns (Figures 3 and 4).

FIGURE 3: Light-Duty Vehicle Congestion Emissions in the POE and Queue. Full emission profiles of LDVs for in-POE emissions (emissions occurring during inspection processes and movement through the POE) as well as queue emissions (emissions occurring during the nine-mile segment preceding primary inspection) as given for the three different levels of vehicle volumes. All scenarios represent total emissions occurring from all vehicles during a two-hour simulation.

For LDVs in the heavily congested scenario, compared to the baseline, there is a 560 - 700% increase in queue emissions for all pollutants. In the VISSIM simulation the queue includes the immediate line waiting for primary inspection as well as a nine-mile segment preceding the primary inspection station on which the vehicles traverse under relatively freeflow conditions until entering the queue at which point the vehicles operate under conditions of idling and stop and go traffic. LDVs and HDVs have separate entrance queues. Long queues of vehicles have been a significant concern for POE air quality in the past and was one of the precipitants of a POE reconfiguration which was completed in 2014. The uncongested scenario has almost no queue (with 1-minute and 2-minute wait times for HDV and LDV, respectively), so it represents only free-flow traffic and the minimum emissions that could occur for the nine-mile segment

preceding the POE. Queue emissions are the dominate contributor of many pollutants because of the amount of fuel needed to move the vehicle over the nine mile inspection approach area compared to moving the vehicle over the 0.25 – 0.5 mile distance within the POE itself. The changes in queuing dynamics and associated emissions are more significant than any changes in emissions occurring during other POE inspection processes, so queue length and wait time should be minimized in any operational emission reduction scenario.

FIGURE 4: Heavy-Duty Vehicle Congestion Emissions in the POE and Queue. Full emission profiles of HDVs for in-POE emissions (emissions occurring during inspection processes and movement through the POE) as well as queue emissions (emissions occurring during the nine-mile segment preceding primary inspection) as given for the three different levels of vehicle volumes. All scenarios represent total emissions occurring from all vehicles during a two-hour simulation.

3.2 Fuel and Vehicle Type Sensitivity

Although the majority of vehicles passing through the Mariposa POE are LDVs, HDVs are the major contributors across most pollutants due to weight, diesel-powered engines, and selective use of emission control devices due to the age of the fleet. In the HCL scenario, HDVs (including HHD, MHD, and buses) processed at the POE account for approximately 98% PM_{2.5}, 93% of NO_x, 65% of NMHC, 68% of GHGs, 34% of SO₂, and 24% of CO with the vast majority of these emissions coming from HHD vehicles. Since the actual ratio of HHD to MHD vehicles is unknown, a split of 80% HHD, and 20% MHD was assumed, and a sensitivity analysis was conducted to investigate its robustness using both a 90% HHD / 10% MHD and a 75% HHD / 25% MHD split. The HDV type sensitivity analysis found that the 90% HHD / 10% MHD scenario increased emissions up to 8% and the 75% HHD / 25% MHD scenario decreased emissions up to 16%. Some uncertainty still exists around the distribution of HDV types, but the sensitivity analysis shows that the difference is minimal compared to other factors in the study.

A second sensitivity assessment was conducted on the sulfur content of the fuel, as Mexico officially has comparable sulfur standards to the United States, but struggles to meet those standards in some parts of the country (27). Under the most recent Mexican fuel standard, gasoline and diesel contain on average 30 ppm and 15 ppm of sulfur, respectively (26). Major urban areas and Mexican states which border the U.S. (including Sonora) sell fuel which meets the standard, but other parts of Mexico are still using fuel with an average of 300 ppm and 500 ppm for gasoline and diesel, respectively (27). Vehicles arriving with partially-full tanks from other parts of Mexico could significantly impact the emission profile, as sulfur dioxide emissions correlate linearly with the presence of sulfur in the fuel, and sulfur can impede the efficiency of emission control devices for other pollutants. In the fuel sensitivity analysis, using higher sulfur fuel could increase non-sulfur emissions by 55% for LDV and up to 20% for HDV. SO₂ emissions under this scenario would increase 900% and 1960% for LDV and HDV, respectively.

3.3 FAST Enrollment

Increasing the number of HDVs enrolled in the FAST program was found to decrease queuing for all vehicles (including those not enrolled in FAST) due to the significantly faster processing times and avoidance of some secondary inspection processes, thus decreasing all emission categories (Figure 5). The 10% enrollment scenario approximates current enrollment conditions, but operates at a volume 200% of what was observed during the field observations, to illustrate the future emissions scenario with significant growth in HDV volume. The 20% enrollment scenario, which would approximately double the vehicles in the program, can achieve savings between 4-11% across pollutants. The 40% enrollment scenario, which represents an aggressive future enrollment target, can save between 15-20% in emissions. Both of these scenarios could achieve lower emissions and wait times for all HDVs without opening more lanes or increasing the personnel at the POE. The 100% enrollment scenario, which represents significant increases in vehicle processing time for all HDVs, could achieve between 31-36% savings in emissions, underscoring the potential for savings from improving primary inspection processing time.

FIGURE 5: Emissions Reductions from FAST program enrollment. Emissions are reported as total from all vehicles over a two-hour simulation period.

3.4 Reduction Strategies

For additional reduction strategies, three scenarios were developed: opening all primary inspection lanes, turning over the entire HDV and LDV fleet to the latest vintage, and switching the vehicle fuels to compressed natural gas and electricity (with battery storage), each of which yielded improvements in POE emissions. At the POE field visit, only six out of eight primary inspection lanes were open for HDVs. If all eight of the inspection lanes were utilized (the HCA scenario), savings of approximately 13% could be achieved from PM_{2.5}, NO_x, and NMHC, with savings of around 30% for GHGs, SO₂ and CO (FIGURE 6). This is a realistic POE management technique which could be implemented immediately, but it would require a larger number of CBP personnel. Much more dramatic increases could be achieved with a turnover of the fleet to newer vehicles. If all HDVs and LDVs entering the Mariposa POE were 2015 vintage, savings of around 95% could be achieved for PM_{2.5}, NO_x, and NMHC, savings of 81% for CO, and savings of around 15% for GHGs and SO₂. The savings for GHGs and SO₂ are more modest because these emissions are strongly correlated to the fuel consumption of the vehicle whereas the savings in some of the other categories are achieved through on-board emission control devices. The most dramatic emission reductions could be achieved through a switch towards

different fuels for LDVs and HDVs. If all LDVs were switched to EVs and all HDVs were switched to CNG, emissions could be reduced 93-99% across all pollutants at the POE. This would be a massive overhaul of not only the vehicle fleet, but also require supporting infrastructure on both sides of the border (especially for the distribution of CNG and EV charging). This case, however does demonstrate the potential benefits in exploring emerging technologies.

FIGURE 6: Reduction Strategies. The base case of 200% volume increase (HCL) was modified both for the vehicle fleet and operations to explore emission reduction potential. HCA opens all primary inspection lanes. HCL, All New, replaces the distributed age of the fleet with all 2015 vintage vehicles. HCL, EV/NG changes the fuels of LDV and HDV to EV and CNG, respectively. All scenarios maintain the same vehicle movement characteristics.

4.0 DISCUSSION

Various actors on both sides of the border could take action to reduce emissions at the Mariposa POE. The implications of improved air quality at the POE are likely to extend beyond the port enabling air quality improvements in other regions of the countries. This section provides an overview of the improvements that could be made in the port operation, vehicle technologies, and fuel changes. We divide the reduction strategies into three time horizons, short-term, mid-term, and long-term to frame the discussion.

Short-term reduction strategies can be implemented by the POE managing agencies and will reduce emissions in the Nogales border area, but these emission reductions might not have co-benefits in other areas. These strategies focus on improving the flow of traffic through the HDV

and LDV inspection processes to reduce queuing and idling. Increasing the participation in the FAST program for HDVs is one potential path to reducing primary inspection wait times and the associated vehicle idling. According to our results, increasing the FAST participation up to 40% while still only operating one FAST inspection lane would not cause additional congestion problems (with approximately 12% of vehicle traffic moving through each of the non-FAST lanes). If vehicle volumes were to double (as in the HCL scenario) and FAST enrollment were to exceed 40%, additional vehicle movement analysis would be required to determine the optimal number of FAST lanes that should be operated. In the short-term, FAST enrollment is an effective means to reduce vehicle wait times across all HDVs. If POE personnel and staffing allows, another easy-to-implement measure for reducing emissions is to operate the POE at full capacity. It is also possible to target peak operating times of the POE and only open additional inspection lanes at times of heavy usage. POE staff can also improve the temporal distribution of vehicle flow and avoid heavy peaks by utilizing information and communication technologies (ICT). As our results show, maintaining close to uncongested vehicle flow throughout the day could reduce emissions by up to 65% for both LDVs and HDVs, as the UCL scenario showed this improvement compared to the HCL scenario. The POE currently uses an online platform that gives current wait times. The capabilities of this could be extended with predictive capabilities to inform drivers of the best times to try to enter the POE, maybe even as a mobile phone application. This would have the impact of both reducing emissions by allowing closer to free flow conditions at the POE, and also giving drivers trying to cross the border shorter wait times and less inconvenience.

Mid-term reduction strategies will require state or national policy implementation which will take time to propagate, but the technologies for these strategies are well-developed and the emissions benefits will extend well-beyond the Mariposa POE. In the simulation, incentivizing turnover of vehicles can have substantial impacts in emissions. Younger vehicles (both HDVs and LDVs) have more advanced emission control technologies and higher fuel economy (LDVs), so incentivizing the turnover of the older fleet might substantially reduce POE emissions. Although it is unrealistic for various political and economic reasons to expect a fleet to be composed entirely of new vehicles, incentivizing more rapid turnover can move the POE closer to these potential emission reductions and related human health benefits. The funding through EPA's Diesel Emissions Reduction Act (DERA) could be explored for a potential fleet turnover at the POE's. The emissions from future vehicles can be expected to decrease even further with advancements in emission control technology. Policies supporting the advancement and deployment of emerging emission control technologies should be prioritized. Barring a complete fuel switch, there could also be fuel-related improvements through upgrading the existing Mexican diesel and gasoline mix throughout the country, especially for sulfur reduction. The current Mexican regulation that sets sulfur targets for premium and regular gasoline (referred to as "Premium" and "Magna" respectively) as well as diesel went fully into effect in 2009, but much of the country is still non-compliant with the standard (26). Continuing to lower and enforce the admissible amount of sulfur in fuels would reduce SO₂ emissions across Mexico, with a co-benefit of reductions in many other pollutants, as removal of sulfur from fuel allows for the more efficient operation of emission control technologies which target NO_x, PM, and NMHCs. One potential path towards this is through crude oil swaps through which dirtier Mexican crude oil is refined at U.S. refineries (28).

Long-term reduction strategies have technology hurdles or uncertainty which still need to be researched and will require more extensive and complex policies, but could fundamentally alter LDV and HDV traffic in North America. Exploring new fuels for HDVs and LDVs could reduce (CNG) or eliminate (EVs) emissions at the POE. In the cases of EVs and CNG vehicles, switching the vehicle fleet would require not only new engineering of a next generation of LDVs and HDVs (such as battery technology for EVs), but also supporting infrastructure, such as fuel distribution networks and refueling stations (29). This would require a large international effort and investment. As for any technology shift, the adoption would not be immediate, so the air quality benefits would be slowly incorporated over time. With EVs, additional research would be necessary on emission tradeoffs; although EVs would eliminate emissions at the POE, additional emissions would occur at an electric generation station. If the generation station is from renewable energy or located far from population centers, then human health benefits may be avoided.

Individually, logistics improvements, fleet upgrades, and fuel improvements or switches can have substantial reductions in emissions at the Mariposa POE, and further synergistic benefits could be achieved from advancing all of these strategies. This would require action by many different political actors, both in the U.S. and Mexico, but the air quality payoff would extend beyond the border region and could also be influential in reducing air pollution throughout the US and Mexican cities, particularly for some of the more aggressive strategies such as fuel-switching or fleet turnover. Both of these strategies would achieve emission savings on the order of 95% and upwards at the POE, but more significantly, the same emissions savings could be achieved throughout North America. This could yield human health and environmental benefits for the millions of people in both countries.

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