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EMISSIONS COMPARISON: ASPHALT PAVEMENT MIXTURE PLANTS AND SELECT SOURCE CATEGORIES

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APM	Asphalt Pavement Mixture
AQIA	Air Quality Impact Assessment
CHIEF	EPA Clearinghouse for Inventories and Emission Factors
CO	Carbon Monoxide
EPA	U.S. Environmental Protection Agency
NAPA	National Asphalt Pavement Association
NHEXAS	National Human Exposure Assessment Survey
NO_x	Nitrogen Oxides
NYSERDA	New York State Research and Development Authority
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
SO_x	Sulfur Oxides
THC	Total Hydrocarbons
VOC	Volatile Organic Compounds

1.0 INTRODUCTION AND SUMMARY

The purpose of this report is to evaluate emissions and air quality impacts from asphalt pavement mixture (APM) plants, providing comparisons to other sources of air pollutant emissions commonly found in both urban and rural areas. The report updates and expands preceding work. In September 2001, Clayton Group Services (Clayton) released a study sponsored by the National Asphalt Pavement Association (NAPA) that compared air emissions from a continuous drum APM plant (having an annual production of 200,000 tons) to air emissions emitted from seven common source categories: residential fireplaces, residential wood stoves, bakeries, gasoline filling stations, barbeque grills, lawn mowers, and fast-food restaurants. Following their study, Clayton summarized their findings in a document titled "Emission Comparison: Continuous Drum Asphalt Plant and Selected Source Categories" (The Clayton Report), which used available emission factors, combined with available activity data to calculate emission estimates from an APM plant and each source category. Using these emission estimates, Clayton quantified the impacts of an APM plant by comparing the APM plant emission estimations to the number of sources in each category that had comparable calculated emissions (*i.e*, 13 residential fireplaces, 12 gas filling stations, *etc.*).

To obtain emission factor data, Clayton conducted searches through the U.S. Environmental Protection Agency's (EPA) AP-42 emission factor data, as well as related references. Where U.S. EPA data did not exist, Clayton performed searches into peer reviewed literature, journal articles, and state-sponsored emission studies. Clayton recognized that sources outside of the U.S. EPA were potentially not as reliable; however, they were still useful to provide adequate data to perform emission estimation calculations and comparisons.

The Clayton Report was developed as a tool to help interpret the magnitude of emissions from a typical APM plant, with a goal of developing information to assist in community-based discussions on local environmental issues. As such, the document has been a reliable reference since its publication in 2001.

In September 2017, Sanborn, Head & Associates Inc. (Sanborn Head), at the request of NAPA, performed a review of the Clayton report. We reviewed the report for accuracy and provided any updates and/or corrections that had occurred since its original issuance in September 2001. Throughout our review, we found that some updated emission factor data had become available in the past 15 years as there had been a push to make sources "cleaner" and reduce pollutant emission rates from many sources. Additionally, since 2001, more source categories had been introduced into communities as interest had expanded into different consumer products. While most, if not all, of the source categories investigated in 2001 are still common sources, and are still useful in comparison studies, there are several "new" source categories that are of interest today. We found that with the addition of new source categories there came an increase of air emissions and possibly "new" pollutants that were not investigated in 2001. We compiled our information in 2017 and built upon the original Clayton report, updating previous data as appropriate and adding a new source category (breweries) for comparison. Table 1 provides a summary of the changes to emission factors and comparisons. We also added a section on air quality impacts from APM plants and exposure comparisons to key pollutants associated with APM plants. These new sections are

intended to provide better perspective on potential exposure to pollutants released from APM plants. This report thus serves as an update and expansion of the Clayton Report. The following sections will describe our review of the methodology of the Clayton Report and our approach to updating or improving assumptions and calculations.

2.0 EMISSION ESTIMATES

The emission comparison methodology involves several steps. First, emissions are evaluated from a "typical" APM plant. Other common candidate source categories that emit similar pollutants to APM plants are considered and literature searches conducted to identify emission factors and activity data. Finally, the emission factors and activity data for each category are used to determine annual emissions for comparison to emissions from a typical APM plant. In deriving annual emission estimates for each source category, an attempt is made to develop the number of the sources similar to the emission levels from a typical APM plant. That approach in essence showed the number of sources in each category that would have emissions comparable to emissions from an asphalt plant (for example: 20 residential fireplaces, two gas filling stations, three fast-food restaurants).

To acquire data for the analysis, information searches included the U.S. EPA's Clearinghouse for Inventories and Emission Factors (CHIEF) on the U.S. EPA Technology Transfer Network, U.S. EPA's home page information sources function, California South Coast Air Quality Management District home page information sources function, and the U.S. EPA Research Triangle Park library. Where possible, U.S. EPA references are used (such as AP-42 document sections, Locating & Estimating documents, and other laboratory research reports) to enhance the uniformity and credibility of the results. These references tend to base emission estimates on a larger data set than would a journal article or a government-sponsored emissions study.

Emission estimates were determined for each source category by combining emission factors with reasonably available activity data (throughput, consumption, *etc.*). With one exception, emission factors for the various source categories were obtained from U.S. EPA publications and were based on multiple source measurements. The one exception is the selected emission factor for fast food restaurants, which came from a peer-reviewed journal and was based on data from one source test.

In conducting the updated report, we found that most of the U.S. EPA's emission factors used in the Clayton Report remain valid, though the U.S. EPA has made minor updates to numerous emission factors for continuous drum APM plants. References cited by Clayton were investigated to evaluate any updates and/or additions that may have been made since 2001. We were able to find most of the original referenced documents and validate the data used in the Clayton Report, and noted that very few of the original documents had been updated. Therefore, we performed a further investigation to determine whether any additional literature reviews or government sponsored emission studies were available that published reliable emission factor information. Relevant data were found for fast food restaurants and auto refueling. All updates and/or changes are reflected in source-specific report sections and tables.

We expanded three parts of the original investigation: 1) we considered additional source categories not evaluated in the original report; 2) we considered additional pollutants that may not have been thoroughly investigated or compared against in the original report; and 3) we conducted a screening level air quality impact assessment to evaluate the potential exposure of pollutants from an APM plant relative to typical indoor and outdoor background air quality (see Section 4.0). As a result, we added breweries as a new source to investigate as they have recently become very popular in communities and are operated and frequented throughout all seasons. Of the additional pollutants we investigated, formaldehyde was of increased interest as it has recently garnered a lot of attention from the U.S. EPA and is now a common pollutant to investigate when performing air emission evaluations. PAHs were investigated to further understand any additional impacts that they may have in a community. With these additions, additional emission estimate calculations were performed and compared to the calculated emission estimates of an APM plant.

Asphalt Pavement Mixture Plants

The Clayton Report referenced a draft AP-42 Section 11.1 for APM plants, but U.S. EPA (2004) had finalized the section by the September 2001 report date. As such, the final Clayton Report did not account for some changes in the final AP-42 Section 11.1 for APM plants. Upon review, small adjustments were necessary in the overall emission table for APM plants, and these changes are reflected in Table 1 of this updated report. Also, in late 2000, the U.S. EPA published an *Emission Assessment Report* for Hot-Mix Asphalt Plants to help characterize the emissions from the production of APM. The report included emission factor tables for an oil-fired drum mix plant, and broke emissions into two categories; drier stack emissions and several types of fugitive emissions. While the Clayton Report did not reference the U.S. EPA's Assessment Report, there was an attempt to implement the U.S. EPA's method of including fugitive emissions in the calculations for the criteria pollutants. It appears only dryer stack emissions were considered in the calculations for all other pollutants listed in the report. Evaluating the information provided by the U.S. EPA and comparing it to the information from the Clayton Report, it is clear that in most situations, the addition of the fugitive emissions does not have a large impact on the overall calculated emissions. In some cases, however, the fugitive emissions play a greater role and increase the overall calculated emission by factors of two or more.

For simplicity and consistency, we adopted the emission estimates developed by the U.S. EPA (2000) in characterizing a typical APM plant. Table 2 provides the updated APM plant emissions, and also provides overall (stack plus fugitive) emission comparisons with the original Clayton Report. The ratios of U.S. EPA: Clayton emissions reflect the degree of similarity or difference between the two sources. Many of the ratios are near unity, indicating no significant difference or change between the finalized U.S. EPA *Emission Assessment Report* and the Clayton Report. Ratios for some pollutants, however, differ substantially from one another. For a few pollutants, notably particulate matter (PM) and benzene, ratios less than one indicate that emissions in the U.S. EPA *Emission Assessment Report* are lower than those assumed in the Clayton Report. For pollutants such as toluene and most PAHs, however, the Clayton Report assumed lower emissions than presented in the U.S. EPA *Emission Assessment Report*.

We conducted a similar review and update of emission estimates for the other source categories APM plants are compared against. The text and information presented in many of the following sections came directly from the original Clayton Report, but we edited or expanded based upon new information. Additionally, a section for breweries was added due to an increase of information and relevancy found in our research.

For simplicity, use of Clayton in the following sections refers to the work of the original 2001 emissions comparison report.

Residential Fireplaces

Clayton used the AP-42 emission factor for residential fireplaces to calculate emissions from residential fireplaces and assumed an average wood use per household from a U.S. EPA-sponsored wood stove study from November 1987. We reviewed the AP-42 emission factors referenced, and agree with both the emission factor, and the assumption made on wood use, as we found no updates since 2001. However, we did make one correction in the emission factor table issued by Clayton. The PM_{10} emissions for 13 households presented by Clayton were incorrect by a factor of ten. The calculated emissions are 0.485 tons/yr based on the emission factor used. Table 3 provides a compilation of the emission estimates for residential fireplaces. Using the most recent emission estimates for a typical APM plant, we found that the corrected emission estimation comparison between an APM plant and the number of households with fireplaces should be 20, based on the revised VOC emission total for an APM plant from the U.S. EPA *Emission Assessment Report*.

We added emission comparisons for two additional pollutants to Table 3 using information from the literature we identified in 2017, which supplements U.S. EPA AP-42 data. Li (2007) reports a formaldehyde emission factor of 1.94 lb/ton wood for wood stoves (which we judge equally applicable to fireplaces). Additionally, we use an arsenic mass fraction of 6.6 mg/kg measured in wood ash (NYSERDA, 2013) in combination with the PM emission factor of 34.6 lb/ton wood to derive an arsenic emission factor of 0.000228 lb/ton wood.

Residential Wood Stoves

Similar to the references and assumptions made for emissions from a fireplace, Clayton used the same wood use per household and the appropriate AP-42 emission factor to calculate emissions from residential wood stoves. We confirm and agree with the assumptions made as the emission factors have not been updated since 2001, and we were not able to find any additional research regarding annual household wood usage. We did, however, find discussion of the improvements made on wood stoves in the past 15 years. New residential wood stoves likely release substantially less particulate matter (and possibly other pollutants) than reflected in the current AP-42 emission factors.

Notwithstanding, there have been no recent updates to AP-42, and the use of emission factors from non-catalytic wood stoves to calculate emissions for criteria pollutants, PAHs, and metals, combined with the use of emission factors from conventional wood stoves to

calculate emissions from organic pollutants, is still relevant when comparing emissions from residential wood stoves to an APM plant. Table 4 summarizes the emission factors and calculations for residential wood stoves. We added an available TOC emission factor and set the number of households in Table 4 to 19 to match emissions of benzene to those of an APM plant.

We also performed additional research to enhance the credibility of results. For example, we found a 2007 Canadian study of five conventional wood stoves citing emission factors of particulate matter (PM) and carbon monoxide (CO) similar in magnitude to the published AP-42 values. Specifically, Li (2007) found average PM and CO emission factors of 17.8 lb/ton and 204.8 lb/ton, respectively, which are quite comparable to the AP-42 emission factors of 19.6 lb/ton (PM) and 140.8 lb/ton (CO). The mean benzene emission factor of 1.660 lb/ton measured by Li (2007) is also similar to the 1.938 lb/ton AP-42 emission factor.

Emission comparisons were added to Table 4 for two additional pollutants using information from the literature to supplement AP-42 data. Li (2007) reports a formaldehyde emission factor of 1.94 lb/ton wood. Additionally, we used an arsenic mass fraction of 6.6 mg/kg measured in wood ash (NYSERDA, 2013) in combination with the PM emission factor of 19.6 lb/ton wood to derive an arsenic emission factor of 0.000129 lb/ton wood.

One caveat on both the Li (2007) study and the AP-42 emission factors is that they reflect data from older vintage wood stoves. The average measured PM emission rate in the Li (2007) study of 21 g/hr is considerably greater than the 4.5 g/hr limit that U.S. EPA set for certification on stoves sold after May 15, 2015 (U.S. EPA, 2015). Even prior to this compliance date, most wood heaters on the market were capable of meeting the 4.5 g/hr limit, based on test certification data collected after U.S. EPA established initial New Source Performance Standards (NSPS) in 1988 (U.S EPA, 2017a).).

Examining the PM emission factors from AP-42 and the Li (2007) study in contrast with the NSPS and certification data, we believe that AP-42 emission factors for wood stoves may overestimate PM emissions for most wood stoves sold in the past few decades. We thus advise caution in the use of emissions comparisons between wood stoves and asphalt pavement mixture plants with respect to PM. We are not aware of emissions data on other pollutants that can be used to evaluate the relevancy of AP-42 emission factors to current and recent wood stove models, though conjecturally, one would expect trends for PM-associated pollutants such as PAHs and arsenic to be similarly lower than in AP-42, assuming that the composition of particles generated during combustion is similar in old and new stoves.

Bakeries

Clayton developed an emission estimation comparison between an APM plant and one medium sized commercial bakery (based on annual bread production). The annual production of bread used in the calculations was 17,308 tons of bread baked per year and the emission factor was obtained from an AP-42 support document. We confirm the accuracy of the approach that was taken in the bakery comparison and agree that the emission

calculation is a conservative estimation of the VOC emissions derived from bread baking at one medium sized bread bakery. Table 5 summarizes the calculations. We caution, though, that comparisons with bakery emissions be made with clarity. The medium-sized bakery considered in the calculations is sizable and representative of a commercial enterprise that produces about 95,000 pounds of bread per day, which is considerably larger than a typical neighborhood bakery.

Barbeque Grills

Clayton's TOC emission factor for barbeque grills was obtained from a non-U.S. EPA document that we reviewed and remains valid today. We performed additional investigation to find a more relevant emission factor, but nothing applicable was found. Table 6 summarizes the emission calculations for barbecue grilling, which are based on a grill cooking time of 30 minutes and use of the grill 20 times per year. Using these two assumptions, TOC emissions from an APM plant are comparable to 336 households using barbeque grills.

Lawn Mowers

The lawn mowers used in the Clayton emission estimation are 2-stroke, gasoline powered mowers. The emission factors were obtained from a document titled "Emission Study Report for Non-Road Engines and Vehicles" (U.S. EPA, 1991) and are expressed as gram of pollutant per horsepower-hour (g/hp-hr). We concur with the reasonableness of the assumptions made in the Clayton Report regarding approximate hours of operation per year (50 hours) and the use of horsepower rating at 30% load. Emission calculations are summarized in Table 7 and are presented for 211 lawnmowers to match the emissions of TOC from a typical APM plant. We added additional emission factors for CO, NO_x, and SO_x to Table 7 (also obtained from the U.S. EPA (1991) document).

However, an important caveat regarding the calculations for lawn mowers is the lessening relevance of the emission factors. The U.S. EPA developed stringent emission limits for nonroad engines that have been phased in over time such that new lawn mowers now release roughly 50 times lower hydrocarbons, two times lower CO, and 30–100 times lower PM than the models considered by Clayton at the time of the original report. Even allowing for the gradual replacement of old lawn mowers with new ones, aggregate emissions from lawn mowers have likely decreased substantially, making the emissions comparisons for TOC and PM much less relevant than in the past. As CO emissions have only dropped by a factor of 2, the Clayton Report's comparisons for aldehydes (another product of incomplete combustion) likely remain of greater contemporary relevance.

Auto Refueling

Upon review of the Clayton Report section on auto refueling, we identified more recent information from the U.S. EPA (2008) to update emission estimates. AP-42 section 5.2, issued in June 2008, provided estimates of VOC emissions from auto refueling in its Table 5.2-7. Assuming typical Stage 1 and Stage 2 controls, VOC emissions from (i) filling the

underground storage tank, (ii) breathing and emptying of the underground tank, (iii) vehicle refueling, and (iv) spillage total 372 mg/l. Assuming the same throughput of 50,000 gal/month, we added a total VOC emission estimate equal to:

$$\text{VOC emissions} = \left(\frac{372\text{ mg}}{\text{l}}\right)\left(\frac{3.7854\text{ l}}{\text{gal}}\right)\left(\frac{50000\text{ gal}}{\text{mo}}\right)\left(\frac{12\text{ mo}}{\text{yr}}\right)\left(\frac{\text{lb}}{453600\text{ mg}}\right)\left(\frac{\text{ton}}{2000\text{ lb}}\right) = 0.93\ \frac{\text{ton}}{\text{yr}}$$

AP-42 section 5.2 states that TOC emissions are essentially the same as VOC emissions.

Recent measurements of the composition of gasoline vapors (Chin & Batterman, 2012) indicate that gasoline vapors contain 5.4% benzene, 13.5% toluene, 2.7% ethylbenzene, and 12.0% xylenes (by mass). Multiplying these percentages by the total VOC emissions estimate yields annual emissions estimates of 0.05 tons benzene, 0.13 tons toluene, 0.025 tons ethylbenzene, and 0.11 tons xylenes from a typical filling station (summarized in Table 8a).

The original emission estimates for auto refueling (filling stations) are reproduced in Table 8b based on the methodologies in the Clayton (2001) report. Table 8a estimates have been labeled as revised based on the dependence on more recent data. However, the revised estimates also depend on two sources of data, introducing some additional uncertainty. Hence, the original emission estimates in Table 8b remain valuable for comparison in gauging the level of uncertainty.

Fast Food Restaurants

Clayton constructed emissions estimates for fast food restaurants based on a published paper on emissions from meat cooking (Rogge *et al*., 1991) and interviews of a local fast-food restaurant chain to determine an average annual meat consumption. In our review, we found emission factors from fast food restaurants were difficult to quantify as there were not a lot of available or consistent data on emission factors and emission estimation calculations. The restaurant chain Clayton contacted owned eight (8) franchise restaurants. The emission factors referenced were for TOC and various PAHs. As a result, Clayton calculated emission estimations based off an approximation of pounds of hamburger cooked in a week. We verified the calculations based on the assumptions made in this approach, and the calculations of emissions are summarized in Table 9a. We also did additional research into available fast food restaurant data. We found a document published by the U.S. EPA (Lee, 1999) that quantified emissions from Street Vendor Cooking Devices (charcoal grilling) in Mexico. The study measured levels of PM, VOCs, aldehydes, CO, NO_x, THC, and other pollutants. The study concluded that emissions of PM and organic pollutants were the result of cooking meat (charcoal did not contribute to the emissions). Using the emission factors listed in the Lee (1999) study we performed alternative calculations for comparison against the original Clayton estimates. Table 9b presents calculations based on the alternative emission factors. Despite originating from a study of charcoal cooking (in a less controlled cooking environment), the TOC and total PAH emission factors that overlap with Table 9a are within a factor of 2 of the original estimates (though 60–80% higher). Allowing for some potential overestimation by the alternative emission factor method in Table 9b, the new

estimates afford emission factors for additional pollutants not available in the original Table 9a estimates.

It is important to note that the estimations in Tables 9a and 9b may be inaccurate for at least three reasons: 1) only hamburger was considered when performing emission calculation estimations; 2) there were no control devices considered when performing these calculations; and 3) neither set of measurements from meat cooking was collected from fast food restaurant style cooking. Many restaurants may employ some sort of control (besides venting) as well as have additional food items listed on their menu. Also, the assumed amount of hamburger in the calculations may be overestimated, but this compensates for the lack of consideration of a diversified menu.[1] Based on these factors, we view the two sets of estimates as providing some information on the degree of uncertainty inherent in the calculations.

3.0 NEW EMISSION COMPARISONS

Clayton developed a comparison of air pollution emissions for various source categories based on specific pollutants or groups of pollutants. The pollutants that Clayton used for comparison include the following: TOCs, VOCs, PM, toluene, benzene, PAHs, benzo[*b*]fluoranthene, benzo[*a*]pyrene, fluoranthene, and pyrene. We added some additional pollutants to this list, as reflected in Tables 3 though 9b. We also developed an additional source category (breweries), described as follows.

Breweries

As beer brewing has become an increasingly popular endeavor, more literature and documentation have become available on emissions generated at both large- and small-scale brewing operations. In 1996, the U.S. EPA published VOC emission factors emitted during different parts of the beer brewing process. The U.S. EPA listed the numerous VOC emission sources during the beer brewing process, including but not limited to the following: mash tuns, cereal cookers, brew kettles, hot wort settling tanks, yeast storage, fermenters, grain holding tanks, and packaging operations. To obtain an overall VOC emission factor for comparison to APM plants, we added the emission factors for all the processes into one emission factor totaling 44.4 lb/1000 bbl for small-scale breweries (producing less than 60,000 barrels of beer (bbl) annually).[2] Using the VOC emission factor, we calculated emission estimations for small-scale breweries and compared those to the VOC emissions from an APM plant. We discovered that the annual VOCs from an APM plant are comparable to about four small-scale commercial breweries (assuming an annual production of 60,000 barrels of beer). In making a comparison, a small commercial brewery would emit about

[1] The Clayton Report assumes that a fast food restaurant cooks 146,692 lbs of meat (hamburger) per year. As another estimate on the amount of "meat" processed, there are reported to be 14,146 McDonald's restaurants in the U.S. (Statista, 2017)) and these restaurants use one billion lbs/yr of beef (Lubin & Badkar, 2011). So the amount of beef used by the average restaurant is 1,000,000,000 lbs / 14,146 = 70,691 lb/yr, which is about half the amount assumed in the Clayton Report. But there has been no accounting for the cooking of anything else on the menu, so the Clayton estimate might be reasonable for total food cooked.

[2] It should be noted that the definition of a "small" brewery varies widely among different trade groups, but the U.S. EPA threshold of 60,000 bbl is used in this report.

27% of the VOCs released by an APM plant (assuming the brewery produced 60,000 bbl/yr). Calculations for the brewery source category are included in Table 10.

Emissions Summary

Table 11 summarizes emission comparisons for various pollutants released from APM plants and the different selected source categories that were investigated. The table includes all the pollutants from the Clayton report and three that we added (arsenic, ethylbenzene, and toluene). As previously discussed, we have also included the "Fast Food Restaurant — Alternative" and "Gasoline Filling Stations — Revised" source categories that use different approaches to estimating emissions. In these cases, differences from the original estimates based on the Clayton (2001) methodologies are mostly thought to reflect uncertainty in the emission estimates.

4.0 EXPOSURE COMPARISONS FOR PARTICULATE MATTER, FORMALDEHYDE, PAHS AND BENZENE

Pollutant emissions that impact people to the greatest degree often occur indoors and outdoors near ground level. In both cases, dilution/dispersion processes are limited, and exposure levels can be elevated relative to other pollution sources. Several examples of typical, elevated exposures to pollutants are presented based on published measurements and information. Typical air pollutant concentrations that result under common conditions are compared to the concentrations of pollutants likely to result from emissions from a typical APM plant.

We extended emission comparisons to examine relative *exposures* to particulate matter, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and benzene, as these contaminants are commonly found in the indoor air of homes due to indoor emission sources. Particulate matter is released from many sources including household dust, cooking, and wood burning in fireplaces and wood stoves. Formaldehyde is a common component of resins used in building products such as pressed board, and off-gassing from new construction can lead to indoor air concentrations 10–100 times above typical outdoor levels. PAHs are a product of incomplete combustion and are emitted indoors through the use of wood burning stoves and cook stoves (gas or electric). Benzene is present in gasoline, and homes with attached garages have been found to have concentrations elevated above outdoor levels. All of these chemicals are also found in cigarette smoke and in the byproducts of combustion sources (such as cooking and heating sources, burning candles, *etc.*).

Screening Level Air Quality Impact Assessment

A screening-level air quality impact assessment (AQIA) was conducted to estimate worst-case air quality impacts of particulate matter, formaldehyde, PAHs, and benzene from a typical APM plant. Projected air quality impacts serve as a better estimate of air pollutant exposure than simple quantification of emissions. Although site-specific conditions for an individual APM plant may differ from the assumptions used in our analysis, the conservative assumptions built into screening-level methods tend to overestimate (bias high) projected

air quality impacts. Thus, the results are generally applicable as a conservative estimate of exposure to pollutants within close proximity to an APM plant.

Air toxics emissions data for APM plants are obtained from the U.S. EPA (2000) *Emission Assessment Report*. The emission estimates are based on a typical drum mix plant fired by natural gas producing 200,000 tons of APM per year. Emissions from loadout, yard activities, asphalt cement storage tank venting, and APM silo venting are combined as fugitive emissions. Fugitive emissions, by dint of elevated temperatures and distributed from various points, are assumed to be spread through volume source 40 feet in height and length and 150 feet in width, with an average release height of 20 feet.

Screening-level dispersion modeling using the U.S. EPA SCREEN3 model (as implemented in the Lakes Environmental (2017) SCREEN View freeware) is used to estimate worst-case 1-hour average impacts of these four air pollutants. Ground-level air quality impacts are estimated at a location 1,000 feet from the dryer stack, unless indicated otherwise. Drier stack emissions are modeled as a point source using the following parameters for a typical APM plant, as culled from stack test reports and communications with equipment vendors:

- A drier stack height of 30 feet, adjacent to a baghouse approximately 12 feet wide, 70 feet long, and 27 feet high; and
- A stack diameter of 4 feet, with effluent at a temperature of 240°F and velocity of 57 fps (feet per second).

Exposure Comparisons

Results of the air quality impact assessment were compared to average U.S. background concentrations predicted in the 2011 National Air Toxics Assessment (U.S. EPA, 2017b) and expected indoor air quality to determine the relative impact that emissions from an APM plant have on the surrounding community. The results for particulate matter, formaldehyde, PAHs, and benzene are presented below.

Particulate matter (PM) is regulated by U.S. EPA based on the particle size based on the knowledge that particles smaller than 10 µm aerodynamic diameter (PM_{10}) are "respirable" and penetrate deep into the respiratory tract, and particles smaller than 2.5 µm ($PM_{2.5}$) can reach the alveoli (air sacs) where oxygen and carbon dioxide exchange with the blood occurs. Various studies indicate greater concern over the potential adverse health effects of $PM_{2.5}$ in ambient air.

To evaluate the potential particulate matter impacts of APM plant emissions, we consider releases of PM_{10}, which both includes and overestimates $PM_{2.5}$. The screening-level air dispersion modeling predicts a PM increase of 0.3 µg/m^3 in ambient air due to APM plant emissions at a distance of 1,000 feet from the dryer stack. This represents a 4% increment to the average level of $PM_{2.5}$ of 8 µg/m^3 present in ambient air in the United States.[3] In the absence of indoor sources, PM levels in homes and offices tend to be lower than outdoor

[3] EPA's on-line air trends report (U.S. EPA, 2017c)indicates an average $PM_{2.5}$ concentration of 7.8 µg/m^3 in the U.S. in 2016 (which rounds to 8 µg/m^3).

levels. However, certain sources, such as cigarette smoking and cooking, lead to higher levels. As an example, a recent study of homes heated by wood stoves found an average $PM_{2.5}$ level of 29 µg/m³ in indoor air (Semmens *et al.*, 2015). Figure 1 compares these values.

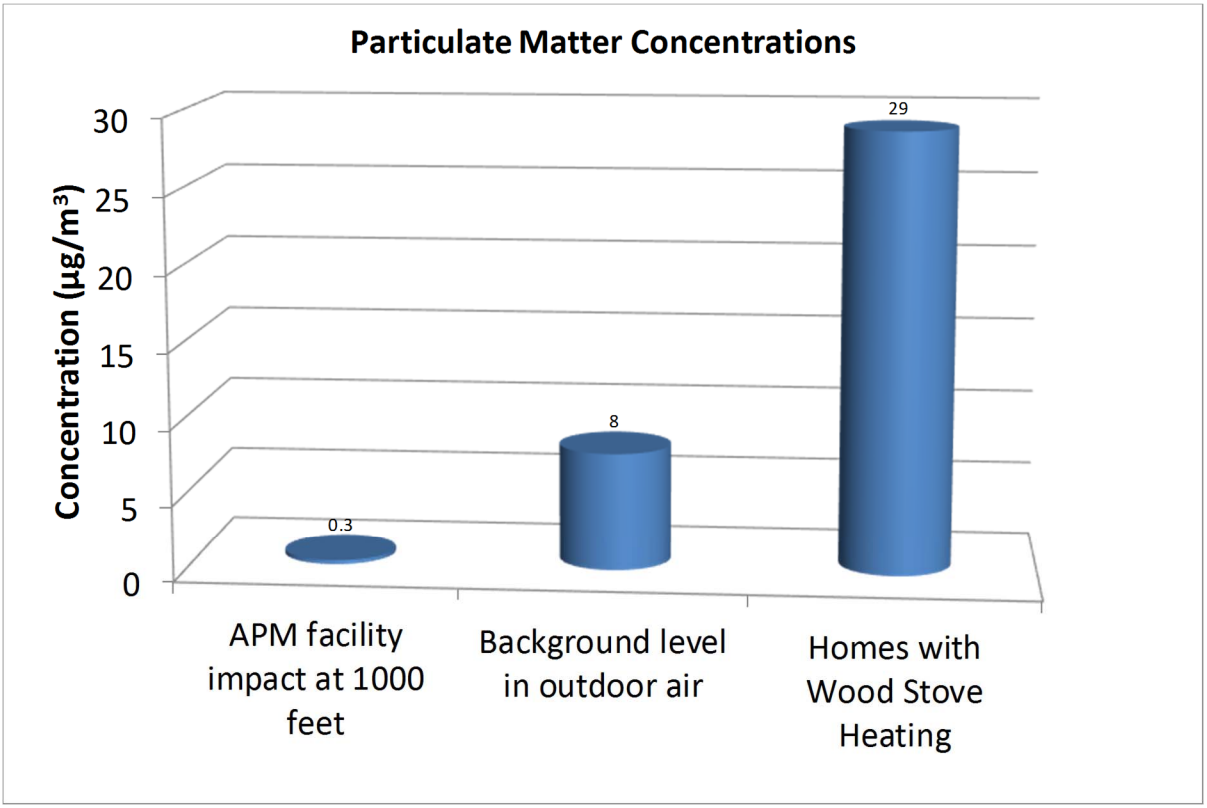

Figure 1 Comparison of sources of exposure to particulate matter

The subsequent chart (Figure 2) compares the formaldehyde concentrations that result from a typical APM facility, the background level in the United States, and the typical indoor concentration for conventional homes. The modeled formaldehyde impact at 1,000 feet from a 200,000 ton/year gas-fired drum mix APM plant (a typical size) is on the order of 0.1 µg/m³, while the typical background level measured in the United States is approximately 1.5 µg/m³. Based on a 2007 indoor air survey conducted in the United States, the 50th percentile formaldehyde concentration measured in the 234 homes was 20 µg/m³, which is approximately 200 times the impact from a typical APM (Liu *et al.*, 2007).

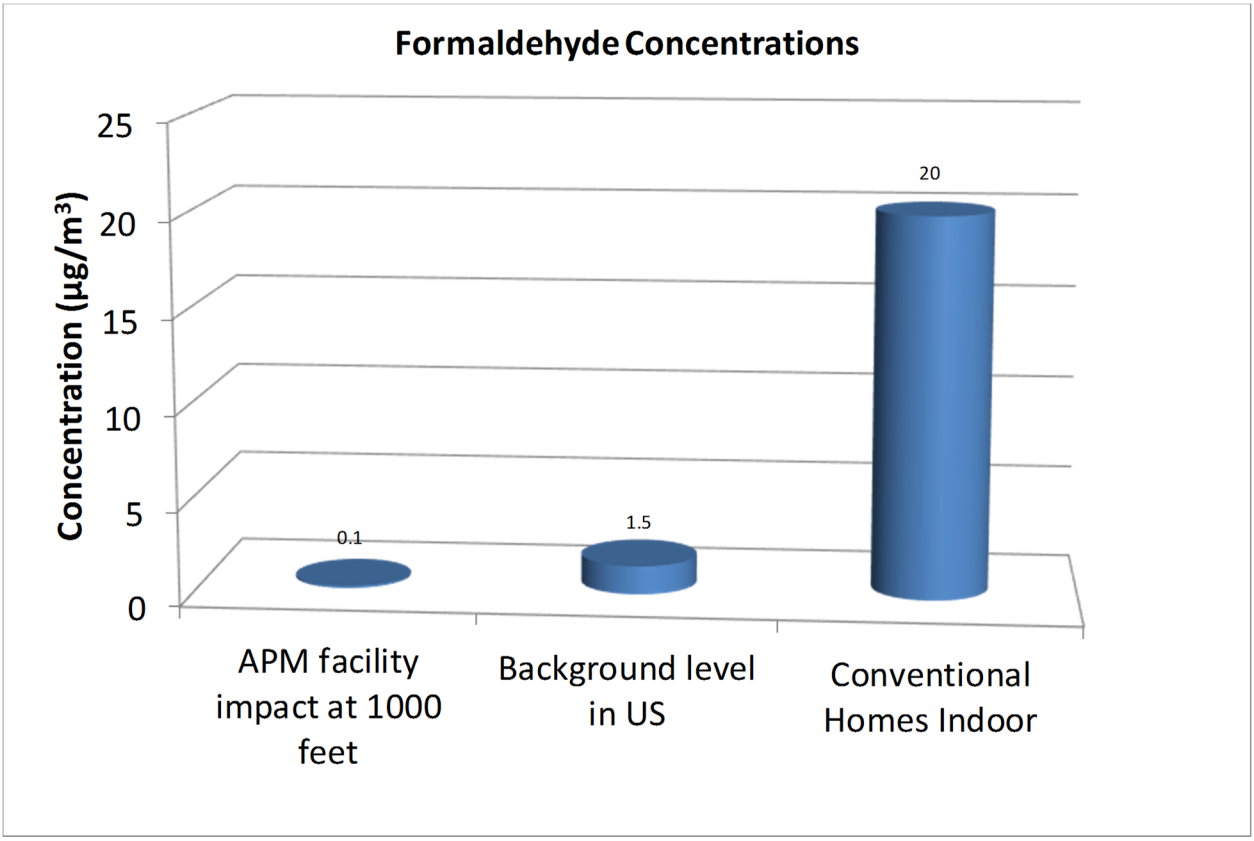

Figure 2 Comparison of sources of exposure to formaldehyde

Indoor air is also commonly contaminated by PAHs, which come not only from infiltration or intrusion of outdoor air but also from indoor emission sources such as cooking and domestic heating with fuel stoves and open fireplaces. Even in airtight stoves with a flue, elevated indoor levels of PAHs can result from intrusion of outdoor air and/or leakage from wood-burning appliances.

The following chart (Figure 3) compares the PAH concentrations from a typical APM facility to outdoor and indoor air concentrations in urban areas across the United States. Concentrations are expressed as benzo[*a*]pyrene equivalents. The modeled range of PAH impacts, 0.00009–0.0003 µg/m^3, represents distances of 250 and 3,000 feet from the typical 200,000 ton/year natural gas fired drum mix APM facility. Based on two studies that measured outdoor and indoor air quality at ten Chicago area homes and 55 residences in Los Angeles, California, Houston, Texas, and Elizabeth, New Jersey, the measured PAH concentrations ranged from 4 to 180 ng/m^3 in outdoor air and from 2 to 350 ng/m^3 in indoor air, which is approximately 10 to 2,000 times the impact from a typical APM (Li *et al.*, 2005; Naumova *et al.*, 2002).

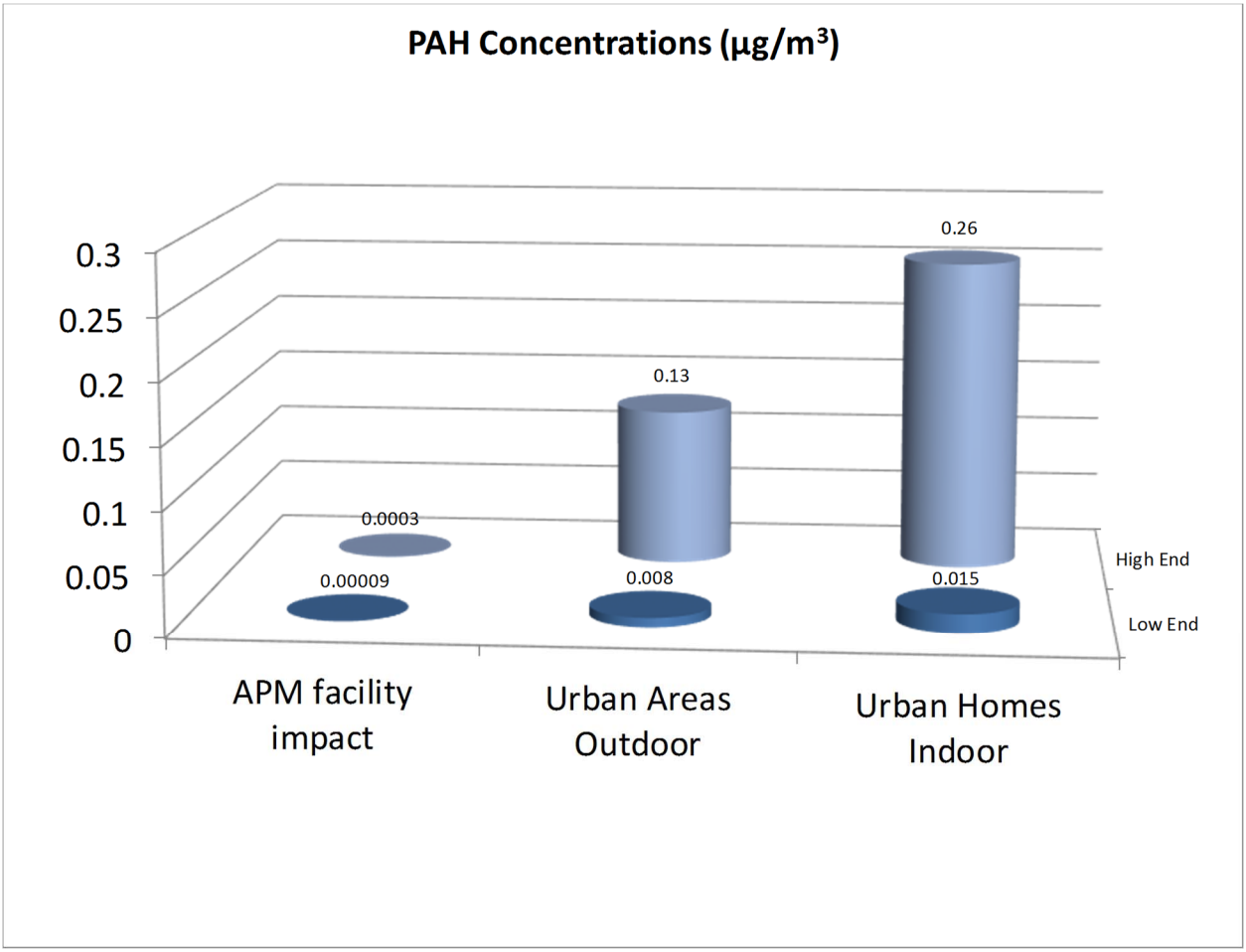

Figure 3 Comparison of sources of exposure to polycyclic aromatic hydrocarbons (PAHs)

The following chart (Figure 4) compares the benzene concentrations from a typical APM facility to outdoor and indoor air concentrations in areas across the United States. Concentrations are expressed as benzo[*a*]pyrene equivalents. The modeled range of PAH impacts, 0.005–0.02 µg/m³, represents distances of 250 and 3,000 feet from the typical 200,000 ton/year natural gas fired drum mix APM facility. The outdoor concentrations are the highest and lowest statewide averages from the U.S. EPA National Air Toxics Assessment (NATA) study, which range from 0.3 µg/m³ (Montana) to 1.4 µg/m³ (District of Columbia). Benzene concentrations in outdoor air vary with proximity to roads and traffic density — a study in New York City measured an average concentration of 0.6 µg/m³ in a low traffic area, and an average of 1.3 µg/m³ in a high traffic area (NYC Health, 2011) The National Human Exposure Assessment Survey (NHEXAS) found higher concentrations of benzene indoors than outdoor, with the median and 90th percentile indoor air concentrations measured at 1.7 µg/m³ and 18.1 µg/m³, respectively, in homes in Arizona (Robertson *et al.*, 1999) Concentrations of benzene encountered in specific microenvironments, such as gasoline filling stations, can be even higher.

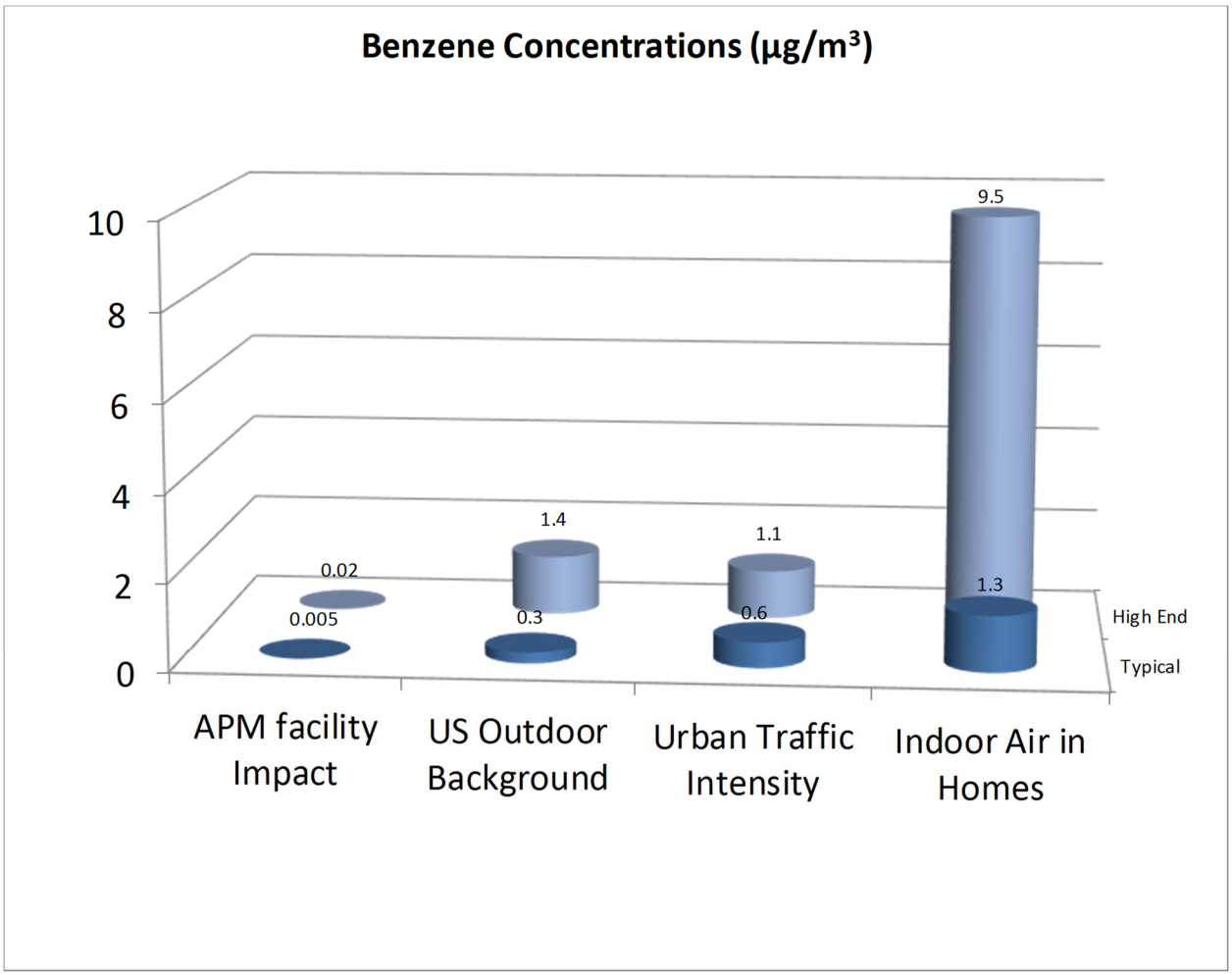

Figure 4 Comparison of sources of exposure to benzene

The overall commonalities of the comparisons of Figure 1 through Figure 4 are that the incremental concentrations of pollutants added by emissions of an APM facility are small compared to the levels typically present in outdoor air due to other sources, and that exposure levels indoors (where people spend the bulk of their time) can be many times greater and account for the majority of air pollutant exposure.

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TABLES

Table 1
Summary Update to Emission Estimates

Table # in Report	Emission Source Category	Changes and Updates from Original 2001 Clayton Report
2	Asphalt Pavement Mixture (APM) Plant	Emission factors updated for consistency with the U.S. EPA (2000) Emission Assessment Report, with most changes to fugitive emission estimates
3	Residential Fireplaces	PM10 emission estimate corrected and emission factor added for arsenic
4	Residential Wood Stoves	Emission factors developed for arsenic and formaldehyde
5	Bakeries	No updates to methodology
6	Barbeques	No updates to methodology
7	Lawn Mowers	Emission factors added for CO, NOx, and SO2
8	Auto Refueling	Methodology updated to 2008 changes to U.S. EPA AP42 emission factors and list of pollutants expanded
9a and 9b	Fast Food Restaurants	No changes to original calculations but second alternative method developed with expanded pollutant list
10	Breweries	New section/emission estimates
11	Emission Comparison Summary	Comparisons updated and expanded in response to emission updates within source categories

Table 2
Asphalt Pavement Mixture (APM) Plant
Emission Estimates and Comparison
with Previous Estimates

Pollutant	Previous Clayton 2001 Emission Estimates tons/yr	Revised APM Plant Emission Estimates			Ratio of Previous 2001 Clayton Emission Estimates to Revised Emission Estimates
		Drier Stack Emissions tons/yr	Fugitive Emissions tons/yr	Total (Drier Stack and Fugitive) tons/yr	
PM	3.4	2.3	0.1	2.4	0.72
CO	14	13	0.3	13	0.94
CO_2	3200	N/A	N/A	-	-
NOx	5.8	5.5	0	5.5	0.95
SO_2	1.1	1.1	0	1.1	1.0
TOC	4.9	4.4	1.7	6.1	1.2
CH_4	1.2	N/A	N/A	-	-
VOC	3.2	3.2	1.7	4.9	1.5
Isooctane	0.004	0.004	1.3E-05	0.0040	1.0
Benzene	0.051	0.039	6.7E-04	0.040	0.78
Ethylbenzene	0.024	0.024	0.0019	0.026	1.1
Formaldehyde	0.25	0.31	0.079	0.39	1.6
Toluene	0.015	0.29	0.0019	0.29	19
Xylenes	0.020	0.020	0.0056	0.026	1.3
2-Methylnaphthalene	0.0074	0.017	0.0022	0.019	2.6
Acenaphthene	1.4E-04	1.4E-04	2.1E-04	3.5E-04	2.5
Acenaphthylene	8.6E-04	0.0022	1.4E-05	0.0022	2.6
Anthracene	2.2E-05	3.1E-04	5.7E-05	3.7E-04	17
Benzo(a)anthracene	2.1E-05	2.1E-05	2.1E-05	4.2E-05	2.0
Benzo(a)pyrene	9.8E-07	1.0E-06	7.9E-07	1.8E-06	1.8
Benzo(b)fluoranthene	1.0E-05	1.0E-05	2.9E-06	1.3E-05	1.3
Benzo(g,h,i)perylene	1.1E-05	4.0E-06	6.5E-07	4.7E-06	0.42
Benzo(k)fluoranthene	4.1E-06	4.1E-06	7.5E-07	4.9E-06	1.2
Chrysene	1.8E-05	1.8E-05	9.0E-05	1.1E-04	6.0
Fluoranthene	6.1E-05	6.0E-05	5.5E-05	1.2E-04	1.9
Fluorene	3.8E-04	0.0011	5.2E-04	0.0016	4.3
Indeno(1,2,3-cd)pyrene	7.0E-07	7.0E-07	1.6E-07	8.6E-07	1.2
Naphthalene	0.0090	0.065	9.3E-04	0.066	7.3
Phenanthrene	7.6E-04	0.0023	7.4E-04	0.0030	4.0
Pyrene	5.4E-04	3.0E-04	1.6E-04	4.6E-04	0.85
Total PAHs	0.019	0.088	0.0050	0.093	4.9
Arsenic	5.60E-05	5.50E-05	N/A	5.5E-05	0.98
Barium	5.80E-04	N/A	N/A	-	-
Cadmium	4.10E-05	4.10E-05	N/A	4.1E-05	1.0
Chromium	5.50E-04	5.50E-04	N/A	5.5E-04	1.0
Hexavalent chromium	4.50E-05	4.50E-05	N/A	4.5E-05	1.0
Copper	3.10E-04	N/A	N/A	-	-
Lead	0.0015	0.0015	N/A	0.0015	1.0
Manganese	7.70E-04	7.50E-04	N/A	7.5E-04	0.97
Mercury	2.60E-04	2.60E-04	N/A	2.6E-04	1.0
Nickel	0.0063	0.0063	N/A	0.0063	1.0
Selenium	3.50E-05	3.50E-05	N/A	3.5E-05	1.0
Zinc	0.0061	N/A	N/A	-	-

Notes:

Emission estimates were made for an oil-fired drum-mix plant with a production of 200,000 tpy HMA.
Emission estimates based on U.S. EPA (2000) emssion assessment report.

N/A - indicates emission estimates not available in U.S. EPA (2000)

Table 3
Residential Fireplace Emission Estimates

Pollutant	Emission Factor	Units	Reference	Emissions per household (ton/yr)	Emissions for 20 households (ton/yr)
PM10	34.6	lb/ton	AP42 Section 1.9 (U.S. EPA, 1996a)	0.037	0.75
CO	252.6	lb/ton		0.27	5.5
CO_2	3400	lb/ton		3.7	73
NOx	2.6	lb/ton		0.0028	0.056
N_2O	0.3	lb/ton		3.2E-04	0.0065
SOx	0.4	lb/ton		4.3E-04	0.0086
VOC	**229**	**lb/ton**		**0.25**	**4.9**
POM	0.016	lb/ton		1.7E-05	3.5E-04
Aldehydes	2.4	lb/ton		0.0026	0.052
Arsenic	0.000228	lb/ton	NYSERDA (2013)	2.5E-07	4.9E-06

Calculations & Assumptions

Throughput of an average fireplace: Assume that the same amount of wood is burned in the average woodstove as in the average family fireplace, or approximately 1 cord of wood per year.

Arsenic emission factor based on the PM10 emission factor and an arsenic content in ash of 6.6 mg/kg (NYSERDA, 2013)

Reference: Equation from U.S. EPA (1987) is as follows:

1. Calculate an average wood use by calculating an average of the mean wood use values for all stove types using scale weighing and woodpile measurements.

Average wood use per household = (0.64+0.85+0.53+0.91+0.67+0.85+0.46+0.89)/8
Average wood use per household = 0.725 dry kg of wood/ heating degree day (HDD)

2. Convert wood use from dry kg/1000 HDD to tons dry wood use/year

(a) Convert from kg to tons dry kg/1000

0.725 HDD X 2.205 lb/kg X 1 ton/2000 lb
= 7.99E-04 dry ton wood X 2,700 HDD

(b) Convert from 1000 HDD to year

Assume that the Vermont and upstate New York region has three times as many HDD as the rest of the country. The reference reported 8,000 to 9,000 HDD/yr. Therefore, assume that there are 2,700 HDD/year.

7.99E-04 dry ton wood X 2,700 HDD

= 2.16 dry ton wood/yr

Boldface indicates pollutant with an emissions total equal to an APM plant

Table 4
Residential Wood Stove Emission Estimates

Pollutant	Emission Factor	Units	Reference	Emissions per household per year (tons/year)	Emissions for 19 households (ton/yr)
PM10	19.6	lb/ton	AP42 Section 1.10 (1996)	0.021	0.40
CO	140.8	lb/ton		0.15	2.9
SOx	0.4	lb/ton		4.3E-04	0.0082
TOC	28	lb/ton		0.030	0.57
TNMOC	12	lb/ton		0.013	0.25
CH_4	16	lb/ton		0.017	0.33
Ethane	1.47	lb/ton		0.0016	0.030
Ethylene	4.49	lb/ton		0.0048	0.092
Acetylene	1.124	lb/ton		0.0012	0.023
Propane	0.358	lb/ton		3.9E-04	0.0073
Propene	1.244	lb/ton		1.3E-03	0.026
i-Butane	0.028	lb/ton		3.0E-05	5.7E-04
n-Butane	0.056	lb/ton		6.0E-05	0.0011
Butenes	1.192	lb/ton		0.0013	0.024
Pentenes	0.616	lb/ton		6.6E-04	0.013
Benzene	**1.938**	**lb/ton**		**0.0021**	**0.040**
Furan	0.342	lb/ton		3.7E-04	0.0070
Furfural	0.486	lb/ton		5.2E-04	0.010
Methyl ethyl ketone	0.29	lb/ton		3.1E-04	0.0059
2-Methylfuran	0.656	lb/ton		7.1E-04	0.013
2,5-Dimethylfuran	0.162	lb/ton		1.7E-04	0.0033
Toluene	0.73	lb/ton		7.9E-04	0.015
o-Xylene	0.202	lb/ton		2.2E-04	0.0041
Acenaphthene	0.01	lb/ton		1.1E-05	2.1E-04
Acenaphthylene	0.032	lb/ton		3.5E-05	6.6E-04
Anthracene	0.009	lb/ton		9.7E-06	1.8E-04
Benzo(b)fluoranthene	0.004	lb/ton		4.3E-06	8.2E-05
Benzo(g,h,i)fluoranthene	0.028	lb/ton		3.0E-05	5.7E-04
Benzo(g,h,l)perylene	0.02	lb/ton		2.2E-05	4.1E-04
Benzo(a)Pyrene	0.006	lb/ton		6.5E-06	1.2E-04
Benzo(e)Pyrene	0.002	lb/ton		2.2E-06	4.1E-05
Biphenyl	0.022	lb/ton		2.4E-05	4.5E-04
Chrysene	0.01	lb/ton		1.1E-05	2.1E-04
Dibenzo(a,h)anthracene	0.004	lb/ton		4.3E-06	8.2E-05
7,12-Dimethylbenz(a)Anthracene	0.004	lb/ton		4.3E-06	8.2E-05
Fluoranthene	0.008	lb/ton		8.6E-06	1.6E-04
Fluorene	0.014	lb/ton		1.5E-05	2.9E-04
Indendo(1,2,3-cd)pyrene	0.02	lb/ton		2.2E-05	4.1E-04
9-Methylanthracene	0.004	lb/ton		4.3E-06	8.2E-05
12-Methylbenz(a)anthracene	0.002	lb/ton		2.2E-06	4.1E-05
1-Methylphenanthrene	0.03	lb/ton		3.2E-05	6.2E-04
Naphthalene	0.144	lb/ton		1.6E-04	0.0030
Perylene	0.002	lb/ton		2.2E-06	4.1E-05
Phenanthrene	0.118	lb/ton		1.3E-04	0.0024
Pyrene	0.008	lb/ton		8.6E-06	1.6E-04
Total PAHs	0.501	lb/ton	Sum from Acenapthene through Pyrene	5.4E-04	0.010
Cadmium	2.00E-05	lb/ton	AP42 Section 1.10 (U.S. EPA, 1996b)	2.2E-08	4.1E-07
Manganese	1.40E-04	lb/ton		1.5E-07	2.9E-06
Nickel	2.00E-05	lb/ton		2.2E-08	4.1E-07
Arsenic	1.29E-04	lb/ton	NYSERDA (2013)	1.4E-07	2.7E-06
Formaldehyde	1.94	lb/ton	Li (2007)	0.0021	0.040

Calculations & Assumptions:

Noncatalytic woodstove type assumed for criteria pollutants, PAHs and metals. Conventional stove type assumed for organic pollutants

Assume same wood use as calculated for fireplace calculations, which is 2.16 dry tons of wood/year

Arsenic emission factor based on the PM10 emission factor and an arsenic content in ash of 6.6 mg/kg (NYSERDA, 2013)

Boldface indicates pollutant with an emissions total equal to an APM plant

Table 5
Bakery Emission Estimates

Pollutant	Emission Factor	Units	Ref #	Emissions (ton/yr) (from equation)
VOC	6.9	lb/ton	AP42 Section 9.9.6 (1997)	60

Calculations & Assumptions:

Reference for values in equation and bread production: U.S. EPA (1992).

From the model ovens listed in the ACT, the one with medium-sized production and the largest emission factor was chosen, that is, model oven number 23. In addition to listing values for the variables in the emission factor equation, the ACT listed the emission factor and annual VOC emissions. These numbers were used.

AP-42 Equation:

VOC= 0.95Yi+0.195ti-0.51S-0.86ts+1.90

lb VOC per ton baked bread; Y i= initial baker's % of yeast; t i= total yeast action time in hours; S = final (spike) baker's % of yeast; ts = spiking time in hours

The variables for model oven no. 23 are: oven size=6X10^6 BTU/hr, Bread production = 17,308 tons /yr, Y=4.25, S=0, ti=5.15, ts=0, VOC emission factor (lbs/ton) = 6.9 and VOC Emissions (tons/yr) = 60

Emissions from bakery are 12 times greater than a typical asphalt plant

Table 6
Barbeque Emission Estimates

Pollutant	Emission Factor	Units	Ref #	Emissions per Household per year (tons/yr)	Emissions for Neighborhood of 336 Households (tons/yr)
TOC	0.0605	lb/min	Radian (1990)	0.018	6.1

Calculations & Assumptions:

Cooking time (min) on barbeque grill	30
Number of times per year using grill	20

Single household emissions

0.0605 lb/min * 30 min/event * 20 events/yr

= 36.3 lb/yr

= 0.01815 tons/yr

Table 7
Lawn Mower Emission Estimates

Pollutant	Emission Factor	Units	Reference	Emissions per Household per year (tons/yr)	Emissions for Neighborhood of 211 Households (tons/yr)
TOC	**437**	**g/hp-hr**	U.S. EPA (1991b)	**0.029**	**6.1**
PM	7.7	g/hp-hr		5.1E-04	0.11
Aldehydes	2	g/hp-hr		1.3E-04	0.028
CO	923.4	g/hp-hr		0.061	13
NOx	0.29	g/hp-hr		1.9E-05	0.0040
SO_2	0.54	g/hp-hr		3.6E-05	0.0075

Calculations & Assumptions:

Ave horsepower rating @ 30% load	1.2
Ave hours per year of operation	50

Calculation for TOC

(437 g/hp-hr * 1.2 hp * 50 hrs/yr) /(454 g/lb *2000 lb/ton)

= 0.02888 tons/yr

Boldface indicates pollutant with an emissions total equal to an APM plant

Table 8a
Auto Refueling Emission Estimates - Revised

Pollutant	Emission Factor	Units	Reference	Annual Emissions (tons/yr)
VOC	372	mg/l	AP42 Section 5.2 (U.S. EPA, 2008) with TOC = VOC	0.93
TOC	372			0.93
Benzene	5.4%	% of VOC emissions	Chin and Batterman (2012)	0.050
Toluene	13.5%			0.13
Ethylbenzene	2.7%			0.025
Xylene	12.0%			0.11

Calculations & Assumptions:

Throughput: Locating and Estimating document reported that the average filling station's throughput is 50,000 gallons per month.

$$\text{VOC emissions} = \left(\frac{372\ \text{mg}}{\text{l}}\right)\left(\frac{3.7854\ \text{l}}{\text{gal}}\right)\left(\frac{50000\ \text{gal}}{\text{mo}}\right)\left(\frac{12\ \text{mo}}{\text{yr}}\right)\left(\frac{\text{lb}}{453600\ \text{mg}}\right)\left(\frac{\text{ton}}{2000\ \text{lb}}\right) = 0.93\ \frac{\text{ton}}{\text{yr}}$$

Chin and Batterman (2012) report gasoline vapors contain 5.4% Benzene, 13.5% Toluene, 2.7% Ethylbenzene, and 12.0% Xylene

Benzene emissions = 5.4% * 0.93 tons/yr = 0.050 tons/yr

Toluene emissions = 13.5% * 0.93 tons/yr = 0.13 tons/yr

Ethylbenzene emissions = 2.7% * 0.93 tons/yr = 0.025 tons/yr

Xylene emissions = 12.0% * 0.93 tons/yr = 0.11 tons/yr

Table 8b
Auto Refueling Emission Estimates - Original

Pollutant	Emission Factor	Units	Reference	Annual Emissions (tons/yr)
Benzene	0.099	lb/1000 gal	U.S. EPA (1998a)	0.030
Toluene	139.9	mg/l	U.S. EPA (1994a)	0.35
Xylene	5.5	mg/l	U.S. EPA (1994b)	0.014
Total "VOC"			Sum of three compounds	0.39

Calculations & Assumptions:

Throughput: Locating and Estimating document reported that the average filling station's throughput is 50,000 gallons per month.

Benzene emissions = 0.099 lb/1000 gal * 50000 gal/mo * 12 mo/yr * 1 ton/2000lb

= 0.0297 tons/yr

Toluene emissions = 139.9 mg/l * 3.7854 l/gal * 50000 gal/mo * 12 mo/yr * 1 g/1000 mg * 1 lb/453.593g * 1 ton/2000 lb

= 0.350 tons/yr

Toluene emissions = 5.5 mg/l * 3.7854 l/gal * 50000 gal/mo * 12 mo/yr * 1 g/1000 mg * 1 lb/453.593g * 1 ton/2000 lb

= 0.0138 tons/yr

Table 9a
Fast-Food Restaurant Emission Estimates - Original

Pollutant	Emission Factor	Units	Reference	Emissions (tons/yr)
TOC	2,405	mg/kg	Rogge *et al* (1991)	0.18
2-Methylfuran	16.1	mg/kg		0.0012
Benzo(a)anthracene	0.29	mg/kg		2.1E-05
Benzo(b)fluoranthene	0.21	mg/kg		1.5E-05
Benzo(a)Pyrene	0.19	mg/kg		1.4E-05
Benzo(e)Pyrene	0.19	mg/kg		1.4E-05
Fluoranthene	0.35	mg/kg		2.6E-05
Pyrene	0.74	mg/kg		5.4E-05
Total PAHs				0.0013

Calculations & Assumptions:

To calculate throughput:

Clayton (2001) called Walker Holdings Group on 9/11/00. They own 8 Wendy's restaurants in the NC/southern VA area. Mr. Bert Walker reported that only data for their drive-thru sales were readily available.

Mr. Walker reported that the average (for 8 Wendy's) drive thru activity was 2,821 cars per week.

He added that the average check per car was $4.12.

Assumptions:

The same amount of sales occurred on foot (in the restaurant) as by the drive-thru.

The average sale consisted of one burger (plus fries and drink and other side dishes)

The average burger weighed 0.5 pound.

Throughput calculation:

Weekly number of sales = 2821*2 = 5642

Number of "half-pounders" sold = 5642

Weekly number of pounds of hamburger cooked = 5642 burgers/week * 0.5 lb/burger = 2821 lb/week

Annual mass of hamburger cooked at the average fast-food restaurant = weekly mass * 52

= 2821 lb/week * 52 weeks/year = 146692 lbs of hamburger cooked/yr

To calculate annual emissions:

TOC Emissions:

TOC Emissions = 2405 mg/kg * 0.4536 kg/lb * 146692 lb/yr * 1 g/1000mg * 1 lb/453.593g * 1 ton/2000lb

= 0.18 tons/year

Table 9b
Fast-Food Restaurant Emission Estimates - Alternative

Pollutant	Emission Factor	Units	Reference	Emissions (tons/yr)
TOC	4280	mg/kg	Lee (1999)	0.31
VOC	851	mg/kg		0.062
NOx	3140	mg/kg		0.23
PM10	8746	mg/kg		0.64
CO	162700	mg/kg		12
Aldehydes	874.6	mg/kg		0.064
Formaldehyde	394.1	mg/kg		0.029
Benzene	420.9	mg/kg		0.031
Toluene	160.9	mg/kg		0.012
Ethylbenzene	31.4	mg/kg		0.0023
Xylene	54.6	mg/kg		0.0040
Phenanthrene	1.12	mg/kg		8.2E-05
Fluoranthene	0.45	mg/kg		3.3E-05
Pyrene	0.34	mg/kg		2.5E-05
Naphthalene	21.1	mg/kg		0.0015
2-Methylnaphthalene	3.90	mg/kg		2.9E-04
Acenaphthylene	1.18	mg/kg		8.7E-05
Fluorene	0.43	mg/kg		3.2E-05
Total PAHs	28.5	mg/kg	Sum from Phenanthrene through Fluorene	0.0021

Calculations & Assumptions:

To calculate throughput:

Assume the same amount of meat coooked per year - 146692 lbs - estimated in the original analysis (see Table 9a)

To calculate annual emissions:

Use emission factors from grilling study by Lee (1999) as listed in table

Assume (as reported in Lee, 1999) THC = TOC, NO = NOx, and PM = PM10

TOC Emissions = 4280 mg/kg * 0.4536 kg/lb * 0 lb/yr * 1 g/1000mg * 1 lb/453.593g * 1 ton/2000lb

= 0.31 tons/year

Table 10
Brewery Emission Estimates

Pollutant	Emission Factor (lb/1000 bbl)	Units	References	Emissions (ton/yr) from a 60,000 bbl/year brewery
VOC	44.4	lb/bbl	AP42 Section 9.12.1 (U.S. EPA. 1996c); U.S. EPA (1996d); Radian (1992b)	1.3

Calculations & Assumptions:

VOC emissions from AP-42 Section 9.12.1 for Malt Beverages

Processes in Table 9.12.1-2 summed together for a sterilized bottle filling line

Volume of production (small brewery) = 60,000 barrels (bbl) per year based on AP-42 Section 9.12.1 background document (U.S. EPA, 1996d) estimate for the upper range of a small brewery

Table 11
Emission Comparison Table

Pollutant	Equivalent No. of a Selected Category	Selected Source Category
Arsenic	220	Residential Fireplaces
	390	Residential Woodstoves
Benzene	19	Residential Woodstoves
	1	Gasoline Filling Stations - Original
	1	Gasoline Filling Stations - Revised
	1	Fast Food Restaurant - Alternative
Ethylbenzene	1	Gasoline Filling Stations - Revised
	6	Fast Food Restaurant - Alternative
Formaldehyde	150	Residential Fireplaces
	190	Residential Woodstoves
	2900	Lawnmowers
	7	Fast Food Restaurant - Alternative
PM	65	Residential Fireplaces
	110	Residential Woodstoves
	4700	Lawnmowers
	2	Fast Food Restaurant - Alternative
TOC	470	Residential Woodstoves
	340	Barbecue Grills
	210	Lawnmowers
	35	Fast Food Restaurant - Original
	10	Fast Food Restaurant - Alternative
Total PAHs/POMs	5400	Residential Fireplaces
	180	Residential Woodstoves
	70	Fast Food Restaurant - Original
	21	Fast Food Restaurant - Alternative
Toluene	1700	Residential Woodstoves
	1	Gasoline Filling Stations - Original
	2	Gasoline Filling Stations - Revised
	12	Fast Food Restaurant - Alternative
VOC	20	Residential Fireplaces
	1/12	Bakery
	4	Breweries
	13	Gasoline Filling Stations - Original
	5	Gasoline Filling Stations - Revised
	39	Fast Food Restaurant - Alternative
Xylenes	120	Residential Woodstoves
	2	Gasoline Filling Stations - Original
	1/4	Gasoline Filling Stations - Revised
	3	Fast Food Restaurant - Alternative

Notes:
1. Typical emissions from an asphalt plant in tons/year (from the US EPA (2000) Emission Assessment Report):
TOC: 6.1
VOC: 4.9
PM: 2.4
Benzene: 0.03967
Toluene: 0.29187
Ethylbenzene: 0.025937
Xylenes: 0.025648
Total PAHs: 9.34E-02
Formaldehyde: 0.38896
Arsenic: 5.50E-05