METHODS FOR DEVELOPING A NATIONAL EMISSION INVENTORY FOR COMMERCIAL COOKING PROCESSES:

TECHNICAL MEMORANDUM

PECHAN

5528-B Hempstead Way
Springfield, VA 22151

703-813-6700 telephone
703-813-6729 facsimile

3622 Lyckan Parkway
Suite 2002
Durham, NC 27707

919-493-3144 telephone
919-493-3182 facsimile

P.O. Box 1345
El Dorado, CA 95623

530-295-2995, ext. 200 telephone
530-295-2999 facsimile

Prepared for:

Emission Factor and Inventory Group
Emissions Monitoring and Analysis Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Prepared by:

Steve Roe
E.H. Pechan & Associates, Inc.
P.O. Box 1345
El Dorado, CA 95623

December 22, 2003

Contract No. 68-D-02-063
Work Assignment No. 2-09

[This page intentionally left blank]

CONTENTS

Page

TABLES iv

FIGURES iv

I. INTRODUCTION 1
A. POLLUTANTS 1
B. COMMERCIAL COOKING PROCESSES (SOURCE CATEGORIES) 2

II. LITERATURE REVIEW 3
A. EMISSION FACTORS 3
B. ACTIVITY DATA 13

III. METHODOLOGY 17
A. ACTIVITY DATA 17
B. SAMPLE CALCULATION 23
C. CONTROLS 24

IV. RESULTS 26

V. NIF 3.0 CONVERSION 27

VI. RESPONSE TO COMMENTS 27

VII. REFERENCES 33

TABLES

1A. Summary of Commercial Cooking Test Results: Criteria Pollutants (g/kg) 5
1B. Summary of Commercial Cooking Test Results: Criteria Pollutants (lb/ton) 6
2A. Summary of Commercial Cooking Test Results: Hazardous Air Pollutants (g/kg) 7
2B. Summary of Commercial Cooking Test Results: Hazardous Air Pollutants (lb/ton) 10
3. Emission Factor Sources 13
4. Restaurant Classification System Used for the SCAQMD Survey 18
5. Restaurant Classifications Used in the PRI Study for CARB 18
6. Recommended Source Categories for Commercial Cooking 19
7. Percent of Restaurants with Each Type of Cooking Equipment 20
8. Average Number of Equipment Pieces by Restaurant Type[1] 20
9. Average Pounds of Meat Cooked on Each Type of Equipment Per Week 20
10. Mapping of Criteria Pollutant EFs to Activity Data 21
11. Mapping of HAP EFs to Activity Data 22
12. HAP Pollutants and CE 25
13. 2002 National Criteria and Hazardous Air Pollutant Emissions for Commercial Cooking . 26

FIGURES

1. $PM_{2.5}$ Emissions by Commercial Cooking Source Category 29
2. Comparison of Commercial Cooking $PM_{2.5}$ Emissions to NEI 2001 $PM_{2.5}$ Emissions 30
3. Total Polycyclic Aromatic Hydrocarbon (PAH) Emissions by Commercial Cooking Source Category 31
4. Comparison of Commercial Cooking PAH Emissions to NEI 1999 PAH Emissions 32

I. INTRODUCTION

The Emission Factor and Inventory Group (EFIG) produces the National Emission Inventory (NEI) for criteria and hazardous air pollutants (HAPS) and ammonia (NH_3). These data are needed by EPA and State agencies to evaluate emission trends and as a basis for various EPA modeling and regulatory analyses. Since the early 1990's, there have been several investigations and tests conducted to determine emissions from commercial cooking activities. Commercial cooking activities were believed to be capable of producing significant amounts of criteria pollutants (especially fine particulate matter) and HAPS.

Emissions from commercial cooking may contribute to exceedances of the Federal $PM_{2.5}$ air quality standards in certain regions. Commercial cooking processes are important contributors of secondary organic aerosols (SOA) and organic carbon (OC) and elemental carbon (EC). SOA is formed from the condensation of gaseous organic emissions at ambient temperatures, sometimes following photo-chemical processes. Estimated contributions of various source categories, including meat charbroiling, to carbonaceous PM in Pittsburgh, Pennsylvania are described by Cabada et al. (2002).

This technical memorandum contains data and methods for quantifying these emissions on a national level to determine the impact of commercial cooking activities on national air quality. The approach for producing an emissions inventory (EI) of criteria pollutants and HAPS from commercial cooking for the calendar year 2002 are described (note that no emission factors for NH_3 were identified). The most challenging aspect of the work was to identify appropriate activity data for the existing emission factors. This memorandum provides information on emission factors developed from recent test programs for commercial cooking followed by a discussion of the activity data that were used to construct the national inventory.

A. POLLUTANTS

Based on previous tests conducted by EPA and State and local environmental agencies, the focus of the emissions inventory is commercial cooking of meat, which is the greatest source of commercial cooking emissions. In particular, emissions of particulate matter (PM) and volatile organic compounds (VOCs) are the most significant. Of the commercial cooking processes that have been studied, charbroiling is the most important air pollutant emissions contributor. Commercial cooking processes are described in more detail below.

Particulate matter is the general term used for a mixture of solid particles and liquid droplets suspended in air. EPA defines PM_{10} as particle matter having a nominal aerodynamic diameter of 10 micrometer (μm) or less. $PM_{2.5}$ is defined as PM that is less than or equal to 2.5μm in aerodynamic diameter. The Federal Government has established emission standards for PM_{10}. In 1997, new standards for $PM_{2.5}$ were proposed by EPA due to the negative impact of $PM_{2.5}$ on human health and visibility in the United States.

VOCs contribute to the formation of ozone and SOA in some cases. Ozone is not directly emitted from stationary or mobile sources, but is formed through photo-chemical reactions in the atmosphere with other air pollutants (e.g., nitrogen oxides or NO_x). Commercial charbroiling

processes also produce HAP emissions. Notable among these are emissions of polycyclic aromatic hydrocarbons (PAHs).

B. COMMERCIAL COOKING PROCESSES (SOURCE CATEGORIES)

Pechan categorized the commercial cooking EI into five source categories based on equipment type. For the purposes of this EI, commercial cooking processes and source categories are synonymous. Source categories comprise emissions from all meat types for a particular equipment type. The following types of meat are included: hamburger, steak, fish, pork, and chicken. The five equipment types have been adopted from work carried out by the South Coast Air Quality Management District (SCAQMD, 1997):

- Chain-driven (conveyorized) charbroilers: this type of broiler has conveyor belts to carry the meat through the flame area. It also may have a belt to carry buns through the appliance. Typically, flames broil the meat on the top and bottom simultaneously. Most chain-driven charbroilers burn natural gas. This appliance normally produces lower PM and VOC emissions than under-fired charbroilers;

- Under-fired charbroilers: these appliances consist of three main components - a heating source, a high-temperature radiant surface, and a slotted grill. The grill holds the meat, or other food, while exposing it to the radiant heat. When grease from the meat falls onto the high-temperature radiant surface, both PM and VOC emissions occur. Most under-fired charbroilers burn natural gas; however, solid fuels, such as charcoal or wood, with or without the addition of ceramic stones, are sometimes used. This category includes broilers, grill charbroilers, flame broilers, and direct-fired barbecues. This category contributes the bulk of emissions for the commercial cooking sector;

- Deep Fat Fryers: fryers use an exposed hot metal surface to heat cooking oil, which is then used to cook the food. Typically, the food is totally immersed in hot melted shortening at about 177°C (350˚F). The fryers may be either gas-fired or electric with fuel type not affecting PM or VOC emissions. Most of the raw food products have a water content in the range of 10% to 75% by weight prior to deep fat frying. Most of the water at the surface of the product vaporizes during the cooking process causing a carry-over of oil mist and oil distillation, resulting in VOC and PM emissions. Practically all fast-food establishments utilize deep fat fryers to prepare food in batches;

- Griddles: these appliances consist of an exposed metal plate used to cook food. The temperatures on the hot surface are typically lower than those encountered in broiling. Unlike deep fat frying, the food is not immersed in shortening, rather the process is similar to sautéing, and the emissions include light oil particulates and odors. Some griddles are grooved in order to give a “broiled” appearance to the food. Most griddles are gas-fired, although electric griddles are also used. Fuel type does not affect emissions of PM or VOC; and

- Clam Shell Griddles: a newer griddle type, which employs a two-sided cooking configuration, lowering an upper hot plate on top of the food product to cook that side

while a lower plate cooks the bottom of the product. This reduces cooking time and decreases emissions.

The studies reviewed by Pechan indicate that the type of fuel used by each cooking equipment category was not important to estimating emissions of PM or VOC. However, the testing programs were often designed to measure VOC, PM, and their components, and did not focus on other combustion products, such as NO_x, carbon monoxide (CO), or sulfur dioxide (SO_2), which may be more strongly associated with fuel combustion.

II. LITERATURE REVIEW

A. EMISSION FACTORS

Pechan reviewed an EPA report entitled "Emissions from Street Vendor Cooking Devices (Charcoal Grilling)" that was prepared by the Office of Air Quality Planning and Standards (OAQPS) (EPA, 1999). This report discusses tests that were conducted by EPA to quantify emissions due to charcoal grilling of meat by street vendors in Mexicali, Mexico. The emissions of interest included PM, VOC, semi-volatile compounds (SVOC), aldehydes, carbon monoxide (CO), carbon dioxide (CO_2), NO_x, total hydrocarbons (THC), and sulfur dioxide (SO_2). Emissions were tested for charcoal grilling of both beef and chicken, including marinated and non-marinated meat. Test results are summarized in Tables 1A, 1B, 2A, and 2B. In Tables 1A and 2A, the emission factors are expressed in grams per kilogram (g/kg); whereas, in Tables 1B and 2B, they are expressed in pounds per ton (lb/ton).

For the street vendor charcoal grilling test program, EPA (1999) noted that charcoal did not contribute significantly to total PM, VOC or SVOC emission levels. Marinated meat had higher VOC and total PM emissions than non-marinated meat. No significant differences were seen in emission rates between chicken and beef (chicken was whole chicken with skin). Emissions of CO and nitric oxide (NO) appeared to be primarily from the charcoal fire and not the cooking of meat. THC emissions were almost all from the initial burning of charcoal (e.g., first half hour), however there appears to be some contribution from meat cooking. Emission rates for SO_2 were not reported due to problems with the analyzer. The emission factors reported in Tables 1A and 1B were developed as the average of two test results. When one test result was a non-detect, the emission factor from the detected result is reported as the emission factor. This was done since the report did not list the detection limits for each pollutant.

Emission tests supporting rule development in the SCAQMD were conducted by the University of California, Riverside Bourns College of Engineering - Center for Environmental Research and Technology [(CE-CERT); Norbeck 1997]. These tests focused on PM and VOC (see Tables 1A and 1B). McDonald et al. (2003) used additional test data from CE-CERT to develop emission estimates for the Colorado Front Range Study. These data include emission factors for CO and some HAPs (mainly PAHs; see Tables 1A, 1B, 2A, and 2B).

Cabada et al. (2002) used organic carbon (OC) emission factors for meat frying and charbroiling in their development of a carbonaceous PM inventory for Pittsburgh. The source of their data was a 1991 study.

Table 1A. Summary of Commercial Cooking Test Results: Criteria Pollutants (g/kg)

Equipment Type (fuel)	Meat/Food	Emission Factor[1] (g/kg meat)							Notes
		PM	PM_{10}	$PM_{2.5}$	CO	NO_x	VOC	SO_2	
Under fired-Charbroiler (charcoal)	Beef	8.1	7.5	7.1	163.5	2.4	4.7	n/a	Source: EPA, 1999. Beef was flank steak. Chicken was thigh meat. SO_2 analyzer malfunctioned, so no emissions data reported. CO and NO_x emissions appear to be mainly from charcoal burning. VOC was measured as total hydrocarbons (THC). Some of the VOC is attributed to the burning of charcoal (most of which burns off after the first 30 minutes of light-off).
	Beef (marinated)	9.5	9.2	8.7	167.6	3.6	5.8	n/a	
	Chicken (marinated)	9.8	9.4	9.1	157.9	4.2	4.5	n/a	
Under-fired Charbroiler (natural gas)	Hamburger (25% fat)	**32.7**	**32.7**	**31.9**	**13.72**	n/a	**3.94**	n/a	Source: Norbeck, 1997. VOC measured as reactive organic gases (ROG). CO taken from McDonald et al., 2003.
	Steak	**17.2**	**17.2**	**16.8**	**4.97**	n/a	**0.86**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Chicken (whole)	**10.5**	**10.5**	**9.9**	**4.84**	n/a	**1.82**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Seafood	**3.3**	**3.3**	**3.2**	n/a	n/a	**0.38**	n/a	Source: Norbeck, 1997. Seafood - Atlantic salmon.
Deep fat fryer (natural gas)	Shoestring potatoes	n/d	n/a	n/a	n/a	n/a	**0.21**	n/a	Source: Norbeck, 1997. EF is in g/kg potatoes
	Breaded chicken	n/d	n/a	n/a	n/a	n/a	**0.12**	n/a	Source: Norbeck, 1997.
	Breaded fish	n/d	n/a	n/a	n/a	n/a	**0.14**	n/a	Source: Norbeck, 1997.
Griddle (electric)	Hamburger (24% fat)	**5.0**	**5.0**	**3.8**	**0.38**	n/a	**0.07**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Chicken (boneless breast)	n/d	n/a	n/a	**0.45**	n/a	**0.4**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Seafood	n/d	n/a	n/a	n/a	n/a	**0.11**	n/a	Source: Norbeck, 1997. Seafood - cod fillets.
Conveyorized Charbroiler (natural gas)	Hamburger (21% fat)	**7.4**	**7.4**	**7.3**	**8.29**	n/a	**2.27**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
Double-sided (clamshell) Griddle (electric)	Hamburger (24% fat)	**0.85**	**0.85**	**0.72**	n/a	n/a	**0.01**	n/a	Source: Norbeck, 1997.

[1]n/d - not detected; n/a - not analyzed. Emission factors in **bold** were used in this project. For PM, all testing was performed using dilution sampling techniques. Hence, both filterable and condensible fractions are represented.

Table 1B. Summary of Commercial Cooking Test Results: Criteria Pollutants (lb/ton)

Equipment Type (fuel)	Meat/Food	Emission Factor[1] (lb/ton meat)							Notes
		PM	PM_{10}	$PM_{2.5}$	CO	NO_x	VOC	SO_2	
Under fired-Charbroiler (charcoal)	Beef	16.2	15.0	14.2	327	4.8	9.4	n/a	Source: EPA, 1999. Beef was flank steak. Chicken was thigh meat. SO_2 analyzer malfunctioned, so no emissions data reported. CO and NO_x emissions appear to be mainly from charcoal burning. VOC was measured as total hydrocarbons (THC). Some of the VOC is attributed to the burning of charcoal (most of which burns off after the first 30 minutes of light-off).
	Beef (marinated)	19.0	18.4	17.4	335.2	7.2	11.6	n/a	
	Chicken (marinated)	19.6	18.8	18.2	315.8	8.4	9.0	n/a	
Under-fired Charbroiler (natural gas)	Hamburger (25% fat)	**65.4**	**65.4**	**63.8**	**27.44**	n/a	**7.88**	n/a	Source: Norbeck, 1997. VOC measured as reactive organic gases (ROG). CO taken from McDonald et al., 2003.
	Steak	**34.4**	**34.4**	**33.6**	**9.94**	n/a	**1.72**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Chicken (whole)	**21.0**	**21.0**	**19.8**	**9.68**	n/a	**3.64**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Seafood	**6.6**	**6.6**	**6.4**	n/a	n/a	**0.76**	n/a	Source: Norbeck, 1997. Seafood - Atlantic salmon.
Deep fat fryer (natural gas)	Shoestring potatoes	n/d	n/a	n/a	n/a	n/a	**0.42**	n/a	Source: Norbeck, 1997. EF is in g/kg potatoes
	Breaded chicken	n/d	n/a	n/a	n/a	n/a	**0.24**	n/a	Source: Norbeck, 1997.
	Breaded fish	n/d	n/a	n/a	n/a	n/a	**0.28**	n/a	Source: Norbeck, 1997.
Griddle (electric)	Hamburger (24% fat)	**10.0**	**10.0**	**7.6**	**0.76**	n/a	**0.14**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Chicken (boneless breast)	n/d	n/a	n/a	**0.9**	n/a	**0.8**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Seafood	n/d	n/a	n/a	n/a	n/a	**0.22**	n/a	Source: Norbeck, 1997. Seafood - cod fillets.
Conveyorized Charbroiler (natural gas)	Hamburger (21% fat)	**14.8**	**14.8**	**14.6**	**16.58**	n/a	**4.54**	n/a	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
Double-sided (clamshell) Griddle (electric)	Hamburger (24% fat)	**1.70**	**1.70**	**1.44**	n/a	n/a	**0.02**	n/a	Source: Norbeck, 1997.

[1]n/d - not detected; n/a - not analyzed. Emission factors in **bold** were used in this project. For PM, all testing was performed using dilution sampling techniques. Hence, both filterable and condensible fractions are represented.

Table 2A. Summary of Commercial Cooking Test Results: Hazardous Air Pollutants (g/kg)

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)												Notes
		Ben	Tol	EBen	o-xyl	m,p-xyl	Sty	Form	Acet	Prop	EdCl	MeCl	Phen	
Under fired-Charbroiler (charcoal)	Beef	0.392	0.154	0.026	0.023	0.023	0.151	0.337	0.251	0.068	0.017	0.012	0.016	Source: EPA, 1999. Beef was flank steak. Chicken was thigh meat. Where 2 test runs were performed, the listed value is the average (non-detects were not averaged into the emission factor due to lack of data on detection limits). Fat content: beef = 7%; chicken = 18%; marinated beef = 19%.
	Beef (marinated)	0.502	0.184	0.038	0.030	0.025	0.218	0.526	0.329	0.084	0.015	0.010	0.021	
	Chicken (marinated)	0.504	0.200	0.040	0.033	0.028	0.190	0.393	0.282	0.076	0.014	0.012	0.023	

[1]Ben = benzene; Tol = toluene; Eben = ethyl benzene; Sty = styrene; Form = formaldehyde; Acet = acetaldehyde; Prop = propionaldehyde; EdCl = ethylene dichloride; MeCl = methylene chloride; Phen = phenol. Emissions of MeCl appear to come mainly from the burning of charcoal; all other emission factors were used in this project.

Table 2A (continued)

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)												Notes
		AcPh	o-Cre	p-Cre	Nap	BaP	Ace	Flu	Phn	Fla	Pyr	dnBP	4nPh	
Under fired-Charbroiler (charcoal)	Beef	**1.83 E-03**	**9.18 E-04**	**1.77 E-03**	2.15 E-02	n/a	0.00	n/d	2.14 E-03	6.51 E-04	6.51 E-04	**1.03 E-03**	n/d	Source: EPA, 1999. Beef was flank steak. Chicken was thigh meat. Where 2 test runs were performed, the listed value is the average (non-detects were not averaged into the emission factor due to lack of data). Fat content: beef = 7%; chicken = 18%; marinated beef = 19%. Charcoal contributed to emissions for about half of these HAPs.
	Beef (marinated)	**2.73 E-03**	**1.28 E-03**	**2.16 E-03**	2.54 E-02	n/a	1.42 E-03	6.81 E-04	3.17 E-03	5.39 E-04	7.04 E-04	n/d	n/d	
	Chicken (marinated)	**2.43 E-03**	**1.68 E-03**	**3.43 E-03**	2.29 E-02	n/a	1.57 E-03	8.25 E-04	3.56 E-03	7.14 E-04	5.00 E-04	**1.92 E-03**	**6.60 E-03**	
Conveyorized Charbroiler (natural gas)	Hamburger	n/a	n/a	n/a	**2.30 E-02**	**1.70 E-04**	**4.89 E-03**	**1.09 E-03**	**4.88 E-03**	**8.80 E-04**	**1.15 E-03**	n/a	n/a	Source: McDonald et al., 2003.
Under-fired Charbroiler (natural gas)	Hamburger	n/a	n/a	n/a	**1.90 E-02**	**1.50 E-04**	**4.24 E-03**	**1.26 E-03**	**4.88 E-03**	**1.40 E-03**	**1.90 E-03**	n/a	n/a	
	Steak	n/a	n/a	n/a	**1.50 E-02**	**7.00 E-05**	**4.28 E-03**	**1.17 E-03**	**5.31 E-03**	**1.28 E-03**	**1.56 E-03**	n/a	n/a	
	Chicken	n/a	n/a	n/a	**8.75 E-03**	**1.00 E-04**	**2.06 E-03**	**7.20 E-04**	**3.46 E-03**	**1.28 E-03**	**1.80 E-03**	n/a	n/a	
Griddle (electric)	Hamburger	n/a	n/a	n/a	**6.10 E-03**	**2.00 E-05**	**1.60 E-04**	**2.10 E-04**	**2.07 E-03**	**8.60 E-04**	**1.15 E-03**	n/a	n/a	
	Chicken	n/a	n/a	n/a	**1.00 E-03**	**1.00 E-05**	**1.30 E-04**	**1.80 E-04**	**1.87 E-03**	**6.20 E-04**	**8.20 E-04**	n/a	n/a	

[1]n/d = not detected; AcPh = acetophenone; o-Cre = ortho-cresol; p-Cre = para-cresol; Nap = naphthalene; BaP = benzo[a]pyrene; Ace = acenaphthylene; Flu = fluorene; Phn = phenanthrene; Fla = fluoranthene; Pyr = pyrene; dnBP = di-n-butyl phthalate; 4nPh = 4-nitrophenol. The emission factors in **bold** were used for this project.

Table 2A (continued)

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)											Notes
		BbFl	BkFl	BaA	Chr	dBa,hA	InP	Acn	An	BghiP	PAHt	BiP	
Conveyorized Charbroiler (natural gas)	Hamburger	n/a	n/a	2.20 E-04	n/a	n/a	1.00 E-04	2.80 E-04	9.10 E-04	1.60 E-04	0.05	2.43 E-03	Source: McDonald et al., 2003. Most PAH species were analyzed; however some were grouped with other species (e.g., benzo[b+j+k]fluoranthene). Hence, species specific emission factors were not available.
Under-fired Charbroiler (natural gas)	Hamburger	n/a	n/a	2.20 E-04	n/a	n/a	9.00 E-05	1.50 E-04	9.40 E-04	1.70 E-04	0.05	1.72 E-03	
	Steak	n/a	n/a	1.10 E-04	n/a	n/a	5.00 E-05	1.50 E-04	1.03 E-03	9.00 E-05	0.04	1.54 E-03	
	Chicken	n/a	n/a	3.40 E-04	n/a	n/a	6.00 E-05	1.00 E-04	8.80 E-04	9.00 E-05	0.03	9.10 E-04	
Griddle (electric)	Hamburger	n/a	n/a	7.00 E-05	n/a	n/a	n/d	2.00 E-05	1.70 E-04	n/d	7.96 E-03	6.00 E-05	
	Chicken	n/a	n/a	1.20 E-04	n/a	n/a	n/d	5.00 E-05	4.40 E-04	n/d	9.51 E-03	1.30 E-04	

[1]n/d = not detected; n/a = not analyzed; BbFl = benzo[b]fluoranthene; BkFl = benzo[k]fluoranthene; BaA = benz[a]anthracene; Chr = chrysene; dBa,hA = dibenzo[a,h]anthracene; InP = indeno[1,2,3-c,d]pyrene; Acn = acenaphthene; An = anthracene; BghiP = Benzo[g,h,i,]perylene; PAHt = total PAH; BiP = Biphenyl. All emission factors were used in this project.

Table 2B. Summary of Commercial Cooking Test Results: Hazardous Air Pollutants (lb/ton)

Equipment Type (fuel)	Meat	Emission Factor[1] (lb/ton meat)												Notes
		Ben	Tol	EBen	o-xyl	m,p-xyl	Sty	Form	Acet	Prop	EdCl	MeCl	Phen	
Under fired-Charbroiler (charcoal)	Beef	0.784	0.308	0.052	0.046	0.046	0.302	0.674	0.502	0.136	0.034	0.024	0.032	Source: EPA, 1999. Beef was flank steak. Chicken was thigh meat. Where 2 test runs were performed, the listed value is the average (non-detects were not averaged into the emission factor due to lack of data on detection limits). Fat content: beef = 7%; chicken = 18%; marinated beef = 19%.
	Beef (marinated)	1.004	0.368	0.076	0.060	0.050	0.436	1.052	0.658	0.168	0.030	0.020	0.042	
	Chicken (marinated)	1.008	0.400	0.080	0.066	0.056	0.380	0.786	0.564	0.152	0.028	0.024	0.046	

[1]Ben = benzene; Tol = toluene; Eben = ethyl benzene; Sty = styrene; Form = formaldehyde; Acet = acetaldehyde; Prop = propionaldehyde; EdCl = ethylene dichloride; MeCl = methylene chloride; Phen = phenol. Emissions of MeCl appear to come mainly from the burning of charcoal; all other emission factors were used in this project.

Table 2B (continued)

Equipment Type (fuel)	Meat	Emission Factor[1] (lb/ton meat)												Notes
		AcPh	o-Cre	p-Cre	Nap	BaP	Ace	Flu	Phn	Fla	Pyr	dnBP	4nPh	
Under fired-Charbroiler (charcoal)	Beef	**3.66 E-03**	**1.84 E-03**	**3.54 E-03**	4.30 E-02	n/a	0.00	n/d	4.28 E-03	1.30 E-03	1.30 E-03	**2.06 E-03**	n/d	Source: EPA, 1999. Beef was flank steak. Chicken was thigh meat. Where 2 test runs were performed, the listed value is the average (non-detects were not averaged into the emission factor due to lack of data). Fat content: beef = 7%; chicken = 18%; marinated beef = 19%. Charcoal contributed to emissions for about half of these HAPs.
	Beef (marinated)	**5.46 E-03**	**2.56 E-03**	**4.32 E-03**	5.08 E-02	n/a	2.84 E-03	1.36 E-03	6.34 E-03	1.08 E-03	1.41 E-03	n/d	n/d	
	Chicken (marinated)	**4.86 E-03**	**3.36 E-03**	**6.86 E-03**	4.60 E-02	n/a	3.14 E-03	1.65 E-03	7.12 E-03	1.43 E-03	1.00 E-03	**3.84 E-03**	**1.32 E-02**	
Conveyorized Charbroiler (natural gas)	Hamburger	n/a	n/a	n/a	**4.60 E-02**	**3.40 E-04**	**9.78 E-03**	**2.18 E-03**	**9.76 E-03**	**1.76 E-03**	**2.30 E-03**	n/a	n/a	Source: McDonald et al., 2003.
Under-fired Charbroiler (natural gas)	Hamburger	n/a	n/a	n/a	**3.80 E-02**	**3.00 E-04**	**8.48 E-03**	**2.52 E-03**	**9.76 E-03**	**2.80 E-03**	**3.80 E-03**	n/a	n/a	
	Steak	n/a	n/a	n/a	**3.00 E-02**	**1.40 E-04**	**8.56 E-03**	**2.34 E-03**	**1.06 E-02**	**2.56 E-03**	**3.12 E-03**	n/a	n/a	
	Chicken	n/a	n/a	n/a	**1.75 E-02**	**2.00 E-04**	**4.12 E-03**	**1.44 E-03**	**6.92 E-03**	**2.56 E-03**	**3.60 E-03**	n/a	n/a	
Griddle (electric)	Hamburger	n/a	n/a	n/a	**1.22 E-02**	**4.00 E-05**	**3.20 E-04**	**4.20 E-04**	**4.14 E-03**	**1.72 E-03**	**2.30 E-03**	n/a	n/a	
	Chicken	n/a	n/a	n/a	**2.00 E-03**	**2.00 E-05**	**2.60 E-04**	**3.60 E-04**	**3.74 E-03**	**1.24 E-03**	**1.64 E-03**	n/a	n/a	

[1]n/d = not detected; AcPh = acetophenone; o-Cre = ortho-cresol; p-Cre = para-cresol; Nap = naphthalene; BaP = benzo[a]pyrene; Ace = acenaphthylene; Flu = fluorene; Phn = phenanthrene; Fla = fluoranthene; Pyr = pyrene; dnBP = di-n-butyl phthalate; 4nPh = 4-nitrophenol. The emission factors in **bold** were used for this project.

Table 2B(continued)

Equipment Type (fuel)	Meat	Emission Factor[1] (lb/ton meat)											Notes
		BbFl	BkFl	BaA	Chr	dBa,hA	InP	Acn	An	BghiP	PAHt	BiP	
Conveyorized Charbroiler (natural gas)	Hamburger	n/a	n/a	4.40 E-04	n/a	n/a	2.00 E-04	5.60 E-04	1.82 E-03	3.20 E-04	0.10	4.86 E-03	Source: McDonald et al., 2003. Most PAH species were analyzed; however some were grouped with other species (e.g., benzo[b+j+k]fluoranthene). Hence, species specific emission factors were not available.
Under-fired Charbroiler (natural gas)	Hamburger	n/a	n/a	4.40 E-04	n/a	n/a	1.80 E-04	3.00 E-04	1.88 E-03	3.40 E-04	0.10	3.44 E-03	
	Steak	n/a	n/a	2.20 E-04	n/a	n/a	1.00 E-04	3.00 E-04	2.06 E-03	1.80 E-04	0.08	3.08 E-03	
	Chicken	n/a	n/a	6.80 E-04	n/a	n/a	1.20 E-04	2.00 E-04	1.76 E-03	1.80 E-04	0.06	1.82 E-03	
Griddle (electric)	Hamburger	n/a	n/a	1.40 E-04	n/a	n/a	n/d	4.00 E-05	3.40 E-04	n/d	1.59 E-02	1.20 E-04	
	Chicken	n/a	n/a	2.40 E-04	n/a	n/a	n/d	1.00 E-04	8.80 E-04	n/d	1.90 E-02	2.60 E-04	

[1]n/d = not detected; n/a = not analyzed; BbFl = benzo[b]fluoranthene; BkFl = benzo[k]fluoranthene; BaA = benz[a]anthracene; Chr = chrysene; dBa,hA = dibenzo[a,h]anthracene; InP = indeno[1,2,3-c,d]pyrene; Acn = acenaphthene; An = anthracene; BghiP = Benzo[g,h,i,]perylene; PAHt = total PAH; BiP = Biphenyl. All emission factors were used in this project.

In constructing the national inventory, Table 3 provides the sources for emission factors (i.e., the emission factors shown in Tables 1A, 1B, 2A, and 2B). The emission factors from Norbeck (1997) and McDonald et al. (2003) were generally favored since they are based on common commercial cooking operations. The EPA (1999) study was performed to characterize emissions from street vendors in Mexico (e.g., using charcoal-fired charbroilers and marinated meat). Several HAP emission factors from the EPA study were used where these factors were not available from the other studies and where the emissions do not appear to be mainly from the burning of charcoal.

Table 3. Emission Factor Sources

Pollutants	Emission Factor Source
Criteria Pollutants: PM_{10}, $PM_{2.5}$, VOC	Norbeck (1997)
CO, PAHs, Biphenyl	McDonald (2003)
ethylene dichloride, benzene, toluene, ethyl benzene, xylenes, styrene, formaldehyde, acetaldehyde, propionaldehyde, acetophenone, o-cresol, p-cresol	EPA (1999); emissions that appeared to be associated with the burning of charcoal were excluded.

B. ACTIVITY DATA

The emission factors are specific both to meat type and type of cooking equipment. Pechan performed a literature search for activity data including the amount of meat cooked at various types of commercial facilities and number of restaurants/other commercial cooking facilities which perform these activities. This involved a review of U.S. Census Bureau data and reports, U.S. Department of Agriculture data, the scientific literature, industry journals, and reports on commercial cooking emissions from State and local environmental agencies.

U.S. Census Data

In the Statistical Abstract of the United States, the U.S. Census Bureau presents per capita expenditures on food consumed both at home and away from home (BOC, 2002). At-home food expenditures are broken down into categories, such as meat, and subcategories, such as, beef, pork, other meats, poultry, fish and seafood, and eggs. However, expenditures on food consumed away from home is not tracked by food category.

Pechan also examined the U.S. Census Bureau sector report on food wholesaling. According to the sector report on wholesaling, food service outlets buy over 20% of wholesale grocery and related products. The food service industry includes a broad range of business types. Data specific to commercial cooking facilities such as restaurants and cafeterias were not available.

The U.S. Census Bureau provides basic data on “eating and drinking places” including sales, earnings, number of establishments, number of employees, and payroll. The sales data are broken down into various types of eating and drinking places. These data are also provided by the National Restaurant Association (NRA, 2002).

Lastly, the Statistical Abstract of the United States contains both producer price indexes and consumer price indexes for food, including meat by type and cut (i.e., ground beef, ham, whole chicken, etc.). The consumer price index data are based on information for retail sales of food such as sales at grocery stores.

The U.S. Bureau of Census' County Business Patterns provides facility counts by county and North American Industry Classification System (NAICS) code. While these data provide detailed resolution of restaurant categories, the available survey data described below are categorized by Standard Industrial Classification (SIC) code instead of NAICS code.

U.S. Department of Agriculture

Pechan contacted Judy Putnam of the U.S. Department of Agriculture (USDA) regarding food consumption data. Ms. Putnam stated that USDA does not track food away from home consumption or sales data which are specific to meat or meat cuts. She said panel and individual survey data on food consumption was available which contains the amount of food consumed away from home. However, these data may not specify the meat cut or how the meat was cooked. The surveys were generally conducted for 2 week periods.

Scientific and Industry Literature

Pechan researched the scientific and industry literature to obtain information on the consumption and expenditures of meat products in the "away from home" market and sales of meat to restaurants and other food service facilities. The business, hospitality, and agriculture literature was reviewed. Several reports were obtained for expenditures in the "away from home" market and sales of meat, however, no information was obtained that was usable as activity data. The available agriculture data focused on the cost and sales of meat at the wholesale level, which as stated previously, does not distinguish between different types of food service suppliers, such as restaurants versus grocery stores. The hospitality literature focused on total sales of food by restaurant type and trends in the food and type of restaurants such as fast-food and national chains. The business literature focused on sales information by type of restaurant. There was limited information on sales at specific franchises and regional/national chains and types of meat such as hamburger.

Pechan reviewed one article which mentioned estimating emissions from meat cooking (Cabada, et al., 2002). The work was part of an effort to estimate atmospheric carbonaceous PM for a number of source categories in the Pittsburgh, PA metropolitan area. The emissions estimate for meat cooking was developed using the total population of the Pittsburgh area and the annual per capita consumption of meat in the United States from the U.S. Census Bureau State and Metropolitan Data Book. The estimate assumed that 90% of the meat consumed was fried and 10% was charbroiled. Meat cooking operations were assumed to remain constant during the year. In addition, no distinction was made between in home consumption and "away from home" consumption.

Meat and Food Service Industry Associations and Consultants

Pechan contacted the following industry groups to request information on the sales, consumption and expenditures of meat products in restaurants and the food service industry:

- National Restaurant Association;
- The Food Institute;
- . The Food Marketing Institute;
- American Meat Institute;
- National Cattleman's Association; and
- International Food Service Manufacturers Association.

None of these associations or institutions reported having data available on sales, consumption or expenditures of meat at restaurants or other commercial cooking facilities. The food consumption, sales and expenditure data that are readily-available are generally provided at a higher level than that desired for activity data. This included the National Restaurant Association report entitled *Restaurant Industry Operations Report* (NRA, 2002). The report is based on an annual survey that provides information on typical operational costs in a restaurant, including the percentage of sales allocated to employee benefits, food-and-drink purchases, services and more. The report only distinguishes between food and beverages, not by type of food.

Pechan also contacted Sterling Marketing, the current publishers of the American Meat Institute report *Meat & Poultry Facts* (Appel, 2003). Pechan reviewed the Table of Contents for the report. This report contained similar data to that provided in the Statistical Abstract of the United States such as per capita consumption and consumer/producer price indices, therefore, Pechan did not obtain a copy.

Several of the associations suggested contacting food service consultants. Pechan contacted two such companies. Pechan spoke with Tracy Ethridge of Technomic. Ms. Ethride stated that data on the amount of meat cooked or meat sales specific to the restaurant industry were not readily available. She stated that the data could be developed by their company. Pechan also spoke with Harry Balzer of the ND&P Group. Mr. Balzer stated that their CREST-Restaurant Purchases database contained data on food purchases at commercial restaurants by type of food. CREST collects data from a sample of 13,000 households reporting on 33,000 individuals. The data would include restaurant name and type of food purchased, but would not indicate the cooking method. The estimated cost for providing these data was on the order of $50,000.

Dun & Bradstreet

The Dun & Bradstreet Marketplace data provide facility counts by county and 8-digit SIC code (Dun & Bradstreet, 2002). These data also include facility counts by revenue class, which may be useful in future inventory development (e.g., at regional/local levels, if relationships are established between revenue and the amount of meat processed).

Environmental Agency Reports

EPA's Emission Inventory Improvement Program (EIIP) Area Source Method Abstract on charbroiling provides an average ground beef throughput per restaurant with a charbroiler of 1,160 pounds (lbs) cooked per week (EPA, 2000). This estimate was based on Whopper® and hamburger sales as posted on the Burger King® website (www.burgerking.com), and assumes an average hamburger weight of 0.25 lb.

Pechan contacted the Massachusetts Department of Environmental Protection (MADEP) to gather underlying information for their emission estimates for this source category (Santal, 2003). MADEP estimated VOC emissions from commercial charbroilers and commercial deep fat fryers using emission factors obtained from a 1992 EPA report (EPA, 1992). The EPA report provided equipment fractions (e.g., 9% of restaurants have charbroilers) and VOC emission factors to apply to facility counts (e.g., number of restaurants from the County Business Patterns). These VOC emission factors were 1,000 lb VOC/restaurant-yr for charbroiling and 101 lb/restaurant-yr for deep fat fryers.

Pechan reviewed documents pertaining to the SCAQMD Rule 1138 development process. This includes a staff report for the proposed Rule 1138 (SCAQMD, 1997) and a survey of commercial cooking operations in the SCAQMD conducted by PES (1999). In the staff report on the proposed rule, the average daily amount of hamburger cooked on a chain-driven charbroiler was estimated to be 233 lb. This value was based on confidential data provided by affected restaurants. No other meat types were discussed in the report. For comparison, Pechan calculated a value of 154 lb/day based on information provided on Burger King's web-site (Burger King, 2003). This estimate assumes one chain-driven charbroiler per facility, each hamburger patty weighs 0.25 lb prior to cooking, and 365 days of operation per year.

The study conducted by PES was to obtain accurate estimates of the total number of restaurants in the SCAQMD, to classify restaurants using a scheme that is relevant to meat cooking operations, and to obtain the distribution in the SCAQMD of the following:

- Types of cooking equipment;
- Types and amount of meats cooked for each equipment;
- Fuels used by cooking equipment;
- Fat content of hamburger cooked;
- Days per year of operation;
- Ventilation hoods and stacks; and
- Percentage of small businesses.

The total number of restaurants was obtained by reviewing lists of facilities regulated by the county health departments in the District. This total was adjusted to account for restaurants which had gone out of business. The remaining information was obtained by a detailed survey of restaurants.

CARB began work on estimating emissions from charbroiling activities at restaurants in the State of California. A detailed survey of restaurants was conducted by the Public Research Institute of San Francisco State University (PRI). The draft report was submitted in June of 2001

(PRI, 2001). Pechan contacted CARB regarding further development of an emission inventory from charbroiling activity but was told that there were no plans for developing an inventory.

The PRI survey was similar to the PES survey, with a few key differences. First, PRI surveyed restaurants using computer-assisted telephone interviews instead of a self-administered (mail-out) questionnaire. Second, PRI used a more detailed restaurant classification scheme, and not all restaurant categories were surveyed. PRI surveyed a subset of restaurants most likely to employ charbroilers. Third, PRI surveyed fewer types of cooking devices.

In 2002, the San Joaquin Valley Unified Air Pollution Control District promulgated a rule regarding commercial charbroiling (SJVUAPCD, 2002). The Final Draft of the Staff report for Rule 4692 utilized the average pounds of meat cooked per day that SCAQMD utilized in its staff report for the proposed Rule 1138 (SCAQMD, 1997). The number of restaurants was determined from health department records on permitted restaurants.

III. METHODOLOGY

A. ACTIVITY DATA

After reviewing the literature; Pechan developed activity data based on data provided by the PRI survey (PRI, 2001). The PRI survey data were chosen over the PES survey data for several reasons:

- The PRI survey sample size and geographic area were larger than in the PES survey;.
- The PRI survey used a more detailed classification of restaurants that focused on restaurant types most likely to use charbroilers (the most important emissions process); and
- National restaurant facility counts are available for the same restaurant classifications used by PRI.

From the 4,518 surveys sent to restaurants in the SCAQMD, PES obtained 543 usable responses. The PRI survey included a slightly larger sample, with 655 completed interviews. The PRI survey sample included restaurants from all over the State of California. Although the sample size of the PRI survey was only slightly larger than the PES survey, the PRI survey covered the entire State of California. This broader geographic coverage makes for a better fit with the national scope of this project.

PES categorized restaurants into 9 different types, as shown in Table 4. The categorization used a 6-digit SIC categorization approach. This type of approach does not fully resolve the types of restaurants that are thought to contribute the most emissions. For example, fast food chains were associated with a more generic group of establishments called “restaurants” rather than breaking out the type of restaurant into “limited service”and “full-service” restaurants. As shown in the table, neither the 6-digit SIC code used by PES nor the associated NAICS code allow for the identification of establishments of most interest (e.g., fast food chains).

The CARB study conducted by PRI did not survey all types of restaurants. Instead, this study focused on a subset of restaurants most likely to employ charbroilers. These restaurant

categories, shown in Table 5, were classified using a system developed by Dun & Bradstreet (a 2-digit extension of the 4-digit SIC code). Survey data from this study can be directly applied to national, county-level facility counts available from Dun & Bradstreet.

Table 4. Restaurant Classification System Used for the SCAQMD Survey

Restaurant Type	Primary 6-Digit SIC Code	Associated NAICS Code	# Facilities in SCAQMD
Banquet Rooms	5812-23	72211	305
Barbecue	5812-24	72211	16
Cafes	5812-14	72211	32
Cafeterias	5812-13	722212	52
Foods-Carry Out & Foods Delivered	5812-06, 5812-30	72221	2,140
Caterers	5812-12	72232	912
Coffee Shops	5812-28	722213	255
Delicatessens	5812-09	72221	708
Pizza	5812-22	72211, 72221	1,120
Restaurants	5812-08	72211, 72221	19,361
Sandwich Shops	5812-19	72221	352
	Total		**25,253**

Table 5. Restaurant Classifications Used in the PRI Study for CARB

Restaurant Type	Dun & Bradstreet Code
Ethnic food	5812-01
Fast food	5812-03
Family	5812-05
Seafood	5812-07
Steak & Barbecue	5812-08

Table 6 provides the recommended source categories for the commercial cooking and charbroiling inventory. Note that the following sources/pollutants will not be included in the inventory: residential or special-event cooking and charbroiling (e.g., county fairs, other public gatherings); cooking processes at institutional facilities (e.g., school or prison cafeterias); commercial cooking processes at facilities that do not fall within the surveyed facility categories; and most criteria pollutant emissions associated with fuel combustion (e.g., natural gas or propane used to fire a charbroiler). Criteria pollutant emissions associated with fuel combustion

(e.g., NO_x, CO) in cooking equipment are included in the commercial fuel combustion emissions sector of the NEI. Pechan recommends no changes to these emission estimates. NO_x emissions were typically not measured for the test programs reviewed during this project. Also, most of the measured CO emissions from the available studies appear to be from the cooking of meat, not fuel combustion.

Table 6. Recommended Source Categories for Commercial Cooking

SCC	Descriptor 1	Descriptor 2	Descriptor 3
2302002000	Industrial Processes	Food and Kindred Spirits: SIC 20	Commercial Cooking - Charbroiling; Charbroiling Total
2302002100	Industrial Processes	Food and Kindred Spirits: SIC 20	Commercial Cooking - Charbroiling; Conveyorized Charbroiling
2302002200	Industrial Processes	Food and Kindred Spirits: SIC 20	Commercial Cooking - Charbroiling; Under-fired Charbroiling
2302003000	Industrial Processes	Food and Kindred Spirits: SIC 20	Commercial Cooking - Frying; Deep Fat Frying
2302003100	Industrial Processes	Food and Kindred Spirits: SIC 20	Commercial Cooking - Frying; Flat Griddle Frying
2302003200	Industrial Processes	Food and Kindred Spirits: SIC 20	Commercial Cooking - Frying; Clamshell Griddle Frying

Tables 7 - 9 provide data from the PRI survey that were used to construct the activity data for each source category (i.e., pounds of meat/year). There are no emission factors for pork; therefore, Pechan used emission factors for chicken to estimate emissions from cooking of pork. Pechan used steak emission factors for the "other" category; which includes lamb, veal, and venison. Tables 10 and 11 provide a map of the criteria pollutant and HAP emission factors to the national activity data (i.e., average pounds of meat cooked by each equipment type per week).

Pechan also estimated emissions from deep fat frying of french fries. The mass of frozen potatoes sold by food services in 2001 (6,736,530 lbs) was obtained from American Frozen Food Institute, USDA (USDA, 2001). French fries sold by fast food restaurants account for 91 percent (6,130,242 lbs) of frozen potatoes sold (Lucier, 2003). 9,338 lbs of french fries was assumed to be sold by the other restaurant types. The activity data for deep fat frying of french fries were the 2002 number of fast food and all other restaurants from D&B.

Note that emissions from residential charbroiling were not included in this inventory effort. Also, note that commercial cooking operations that take place outside of the source sector universe described above are not included (e.g., restaurants not classified into one of the SIC codes listed in Table 5). While Pechan anticipates that the bulk of emissions occur within the universe defined in Table 5, it is not possible with existing information to estimate the amount of commercial activity that is being missed. Other related sources include institutional cooking processes (e.g., schools and prisons) and episodic commercial processes, such as county or state fairs.

Table 7. Percent of Restaurants with Each Type of Cooking Equipment

Restaurant Category	Chain-Driven Charbroilers	Underfired Charbroilers	Deep-Fat Fryers	Flat Griddles	Clamshell Griddles
Ethnic	3.5	47.5	81.9	62.7	4
Family	10.1	60.9	91.4	82.9	1.4
Fast Food	18.6	30.8	96.8	51.9	14.7
Seafood	0	52.6	100	36.8	10.5
Steak & BBQ	6.9	55.2	82.8	89.7	0

Table 8. Average Number of Equipment Pieces by Restaurant Type[1]

Restaurant Category	Chain-Driven Charbroilers	Underfired Charbroilers	Deep-Fat Fryers	Flat Griddles	Clamshell Griddles
Ethnic	1.62	1.54	1.63	1.88	1.8
Family	1.71	1.29	2.34	2.03	–[1]
Fast Food	1.07	1.58	3.1	1.43	2.09
Seafood	--	1.1	2.47	1.11	1.5
Steak & BBQ	–[2,3]	1.63	2.42	1.35	--

[1] Average number of equipment pieces only for the segment of restaurants estimated as having such equipment.
[2] Not clear why the number of pieces of equipment was not reported for this category.
[3] Steak and BBQ restaurants are not likely to employ chain-driven charbroilers.

Table 9. Average Pounds of Meat Cooked on Each Type of Equipment Per Week

Type of Meat	Chain-Driven Charbroilers	Underfired Charbroilers	Deep-Fat Fryers	Flat Griddles	Clamshell Griddles
Steak	236	180	181	166	94
Hamburger	798	270	274	362	1314
Poultry, With Skin	147	144	365	88	113
Poultry, Skinless	266	179	208	111	108
Pork	57.6	148	58.6	112	118
Seafood	119	143	159	92.1	632
Other	--	41.5	274	57.5	–

Table 10. Mapping of Criteria Pollutant EFs to Activity Data

Type of Meat	Chain-Driven Charbroilers	Underfired Charbroilers	Deep-Fat Fryers	Flat Griddles	Clamshell Griddles
Steak	Hamburger EF	Steak EF	No EFs	Hamburger EF	Hamburger EF
Hamburger	Hamburger EF	Hamburger EF	No EFs	Hamburger EF	Hamburger EF
Poultry, with skin	Chicken (whole) EF	Chicken (whole) EF	Breaded Chicken EF	Chicken (boneless breast) EF	Flat Griddle Chicken (boneless breast) EF reduced by % VOC Hamburger EF
Poultry, skinless	Chicken (whole) EF	Chicken (whole) EF	Breaded Chicken EF	Chicken (boneless breast) EF	Flat Griddle Chicken (boneless breast) EF reduced by % VOC Hamburger EF
Pork	Chicken (whole) EF	Chicken (whole) EF	Breaded Chicken EF	Chicken (boneless breast) EF	Flat Griddle Chicken (boneless breast) EF reduced by % VOC Hamburger EF
Seafood	Seafood EF	Seafood EF	Breaded Fish EF	Seafood EF	Flat Griddle Seafood EF reduced by % VOC Hamburger EF
Other Meat	No Activity	Steak EF	No EFs	Hamburger EF	No Activity

Notes:

Chain-Driven Charbroilers:

Hamburger emission factors used for "Steak".

Underfired Charbroilers Chicken (whole) emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

Underfired Charbroilers Seafood emission factors used for "Seafood".

Underfired Charbroilers:

Chicken (whole) emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

Steak emission factors used for "Other Meat".

Deep-Fat Fryers:

Did not estimate "Steak", "Hamburger", and "Other Meat" emissions due to lack of emission factor data.

Breaded Chicken emission factors used for both "Poultry, with skin" and "Poultry, skinless".

Breaded Fish emission factors used for "Seafood".

VOC emissions for cooking french fries estimated with the EF of 0.21 g/kg potatoes cooked.

Flat Griddles:

Hamburger emission factors used for "Steak" and "Other Meat".

Chicken (boneless breast) emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

Clamshell Griddles:

Hamburger emission factors used for "Steak".

To develop a VOC emission factor for Chicken, estimated the percent VOC of the Hamburger EFs (Flat Griddle/Clamshell Griddle) and reduced the Flat Griddle Chicken (boneless breast) VOC EF by this percent. This Chicken VOC emission factor was applied to "Poultry, with skin", "Poultry, skinless", and "Pork".

To develop a VOC emission factor for Seafood, estimated the percent VOC of the Hamburger EFs (Flat Griddle/Clamshell Griddle) and reduced the Flat Griddle Seafood VOC EF by this percent.

Table 11. Mapping of HAP EFs to Activity Data

Type of Meat	Chain-Driven Charbroilers	Underfired Charbroilers	Deep-Fat Fryers	Flat Griddles	Clamshell Griddles
Steak	Hamburger EF	Steak EF, Beef EF	No EFs	Hamburger EF	No EFs
Hamburger	Hamburger EF	Hamburger EF	No EFs	Hamburger EF	No EFs
Poultry, with skin	Chicken EF, Chicken (Marinated) EF	Chicken EF, Chicken (Marinated) EF	No EFs	Chicken EF	No EFs
Poultry, skinless	Chicken EF, Chicken (Marinated) EF	Chicken EF, Chicken (Marinated) EF	No EFs	Chicken EF	No EFs
Pork	Chicken EF, Chicken (Marinated) EF	Chicken EF, Chicken (Marinated) EF	No EFs	Chicken EF	No EFs
Seafood	No EFs	No EFs	No EFs	No EFs	No EFs
Other Meat	No Activity	Steak EF, Beef EF	No EFs	Hamburger EF	No Activity

Notes:

Chain-Driven Charbroilers:

Hamburger emission factors used for "Steak".

For certain HAPs, Underfired Charbroilers Chicken emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

For certain HAPs, Underfired Charbroilers Chicken (marinated) emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

Underfired Charbroilers:

For certain HAPs, Chicken emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

For certain HAPs, Chicken (Marinated) emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

For certain HAPs, Steak emission factors used for "Other Meat".

For certain HAPs, Beef emission factors used for "Steak" and "Other Meat".

Deep-Fat Fryers:

Did not estimate HAP emissions for Deep-Fat Fryers due to lack of emission factor data.

Flat Griddles:

Hamburger emission factors used for "Steak" and "Other Meat".

For Flat Griddles, Chicken emission factors used for "Poultry, with skin", "Poultry, skinless", and "Pork".

Clamshell Griddles:

Did not estimate HAP emissions for Clamshell Griddles due to lack of emission factor data.

B. SAMPLE CALCULATION

The following sample calculation illustrates how activity data (pounds of meat) were estimated for SCC 2302002200, under-fired charbroiling, for one county. The facility counts for each type of restaurant in the county were used with the survey data in Tables 6-9 to estimate activity. The steps in this process are:

Step 1. Multiply county-level facility counts by the fraction of each restaurant type with each type of cooking equipment (Table 6):

$$N_{ethnic} * f_{ethnic,\ ufc} = N_{ethnic,\ ufc}$$

where: N_{ethnic} = Number of ethnic food restaurants in county;
$f_{ethnic,\ ufc}$ = fraction of ethnic food rest. with under-fired charbroilers; and
$N_{ethnic,\ ufc}$ = Number of ethnic food rest. with under-fired charbroilers.

538 restaurants x 0.475 = 256 ethnic food rest. with under-fired charbroilers

Step 2. Multiply number of restaurants with each type of cooking equipment by number of pieces of equipment (Table 7):

$$N_{ethnic,\ ufc} * e_{ethnic,\ ufc} = E_{ethnic,\ ufc}$$

where: $N_{ethnic,\ ufc}$ = Number of ethnic food rest. with under-fired charbroilers;
$e_{ethnic,\ ufc}$ = Number of under-fired charbroilers at ethnic food restaurants with at least one under-fired charbroiler;
$E_{ethnic,\ ufc}$ = Total number of under-fired charbroilers at ethnic food restaurants.

256 ethnic food rest. with under-fired charbroilers * 1.54 *under-fired charbroilers*
= 394 under-fired charbroilers *at ethnic food restaurants*

Step 3. Sum number of pieces of cooking equipment across restaurant types:

$$E_{ethnic,ufc} + E_{family,ufc} + E_{fast,ufc} + E_{seafood,ufc} + E_{S\&B,ufc} = E_{all,ufc}$$

where: $E_{ethnic,ufc}$ = Total number of under-fired charbroilers at ethnic food restaurants;
$E_{family,ufc}$ = Total number of under-fired charbroilers at family restaurants;
$E_{fast,ufc}$ = Total number of under-fired charbroilers at fast food restaurants;
$E_{seafood,ufc}$ = Total number of under-fired charbroilers at seafood restaurants;
$E_{S\&B,ufc}$ = Total number of under-fired charbroilers at steak & barbecue restaurants; and
$E_{all,ufc}$ = Total number of under-fired charbroilers at all restaurants.

394 ethnic + 238 family + 62 fast food + 14 seafood + 32 steak & barbecue
= 737 under-fired charbroilers at all restaurants

Step 4. Multiply total number of under-fired charbroilers by average pounds of meat cooked on each type of equipment per week (Table 9):

$$E_{all,ufc} * m_{steak,ufc} = M_{steak,ufc}$$

where: $E_{all,ufc}$ = Total number of under-fired charbroilers at all restaurants
$m_{steak,ufc}$ = Average pounds per week of steak cooked on one under-fired charbroiler
$M_{steak,ufc}$ = Total pounds per week of steak cooked on all under-fired charbroilers in the county

(737 under-fired charbroilers x 180.06 lbs/week) / (2000 lbs/ton)
= 66.4 tons of steak per week

The mass of meat was then multiplied by the appropriate emission factor. Emissions for all meat types were summed at the equipment level and reported by SCC.

C. CONTROLS

The only known area with controls in place with regards to commercial charbroiling is the South Coast Air Quality Management District (SCAQMD) in California. Controls consistent with the requirements of Rule 1138 currently only affect chain-driven charbroilers (SCAQMD, 1997). Pechan applied an 86% control efficiency (CE) for VOC and an 83% CE for PM to uncontrolled chain-driven charbroiler emissions in the following SCAQMD counties: Los Angeles, Orange, Riverside, and San Bernardino. For uncontrolled HAP emissions in these counties, Pechan applied either the CE that was used to estimate controlled VOC emissions or the CE used to estimate controlled PM emissions. Rule effectiveness for these four counties was set to 100%. Los Angeles and Orange counties are assumed to have 100% rule penetration. San Bernardino and Riverside counties were assumed to have 80% rule penetration, since about 80% of the population of these counties resides within the SCAQMD.

For HAPs, Table 12 lists the pollutant and the CE used to estimate controlled emissions. Controlled emissions of volatile organic HAP species were estimated by using the VOC CE, while those associated with PM were estimated using the PM_{10} CE.

Table 12. HAP Pollutants and CE

Pollutant	Pollutant Code	CE Used
4-Nitrophenol	100027	PM_{10}
Acenaphthene	83329	PM_{10}
Acenaphthylene	208968	PM_{10}
Acetaldehyde	75070	VOC
Acetophenone	98862	VOC
Anthracene	120127	PM_{10}
Benz[a]Anthracene	56553	PM_{10}
Benzene	71432	VOC
Benzo[a]Pyrene	50328	PM_{10}
Benzo[g,h,i,]Perylene	191242	PM_{10}
Biphenyl	92524	PM_{10}
Dibutyl Phthalate	84742	PM_{10}
Ethyl Benzene	100414	VOC
Ethylene Dichloride	107062	VOC
Fluoranthene	206440	PM_{10}
Fluorene	86737	PM_{10}
Formaldehyde	50000	VOC
Indeno[1,2,3-c,d]Pyrene	193395	PM_{10}
m,p-xylenes	1330207	VOC
Naphthalene	91203	VOC
o-Cresol	95487	VOC
o-Xylene	95476	VOC
p-Cresol	106445	VOC
Phenanthrene	85018	PM_{10}
Phenol	108952	VOC
Propionaldehyde	123386	VOC
Pyrene	129000	PM_{10}
Styrene	100425	VOC
Toluene	108883	VOC
Total PAH	234	PM_{10}

IV. RESULTS

2002 National criteria pollutant and hazardous air pollutant (HAP) emissions are summarized in Table 13 by SCC and pollutant type. Emissions are expressed in tons per year (tpy).

Table 13. 2002 National Criteria and Hazardous Air Pollutant Emissions for Commercial Cooking

Pollutants	Source Classification Code (SCC)					
	2302002000 (tpy)	2302002100 (tpy)	2302002200 (tpy)	2302002300 (tpy)	2302002400 (tpy)	2302002500 (tpy)
VOC	11,499	2,113	7,234	940	39	1,173
CO	33,004	7,401	23,662	1,941		
PM	85,515	8,460	60,304	15,679	1,073	
PM_{10}	85,515	8,460	60,304	15,679	1,073	
$PM_{2.5}$	79,320	8,201	58,295	11,916	909	
NAPHTHALENE	80.9	18.1	42.0	20.8		
BENZO[A]PYRENE	0.57	0.15	0.34	0.08		
ACENAPHTHYLENE	14.9	3.93	10.2	0.72		
FLUORENE	5.05	0.95	3.13	0.96		
PHENANTHRENE	27.7	4.35	13.8	9.61		
FLUORANTHENE	8.94	0.99	4.22	3.73		
PYRENE	12.00	1.33	5.70	4.97		
BENZ[A]ANTHRACENE	1.49	0.25	0.81	0.42		
INDENO[1,2,3-C,D]PYRENE	0.30	0.09	0.21			
ACENAPHTHENE	0.77	0.22	0.40	0.15		
ANTHRACENE	5.14	0.88	2.99	1.27		
BENZO[G,H,I,]PERYLENE	0.50	0.14	0.36			
PAH, TOTAL	205.6	42.9	121.9	40.8		
BIPHENYL	6.44	1.92	4.12	0.40		
BENZENE	1,237	154.3	1,083			
TOLUENE	489.7	61.2	428.5			
ETHYL BENZENE	94.4	12.2	82.2			
O-XYLENE	79.0	10.1	68.9			
XYLENES (MIXTURE OF O, M, AND P ISOMERS)	69.6	8.57	61.1			
STYRENE	468.7	58.2	410.6			
FORMALDEHYDE	987.8	120.3	867.5			
ACETALDEHYDE	715.6	86.3	629.3			
PROPIONALDEHYDE	193.1	23.3	169.9			
ETHYLENE DICHLORIDE	38.9	4.28	34.6			
PHENOL	55.1	7.04	48.0			
ACETOPHENONE	5.92	0.74	5.18			
O-CRESOL	3.84	0.51	3.32			
P-CRESOL	7.75	1.05	6.70			
DIBUTYL PHTHALATE	4.37	0.59	3.78			
4-NITROPHENOL	12.4	2.02	10.4			

Pechan reviewed the percent contribution of $PM_{2.5}$ emissions by source category to the total $PM_{2.5}$ commercial cooking emissions. The percentages are summarized in Figure 1. The total $PM_{2.5}$ commercial cooking emissions were also compared to various source category $PM_{2.5}$

emissions obtained from EPA's 2001 NEI (EPA, 2003a). Percent contributions, by source category, to the total 2001 area source NEI $PM_{2.5}$ emissions are summarized in Figure 2.

Pechan reviewed the percent contribution of total polycyclic aromatic hydrocarbon (PAH) emissions by source category to the total PAH commercial cooking emissions. The percentages are summarized in Figure 3. The total PAH commercial cooking emissions were compared to various source category PAH emissions obtained from EPA's 1999 NEI (EPA, 2003b). In the NEI, PAH emissions are expressed as total PAH, 16-PAH, 7-PAH, and by PAH species. For the comparison, Pechan used all available PAH emissions from the NEI. Percent contributions, by source category, to the total 1999 area source NEI PAH emissions are summarized in Figure 4.

V. NIF 3.0 CONVERSION

Pechan prepared the 2002 data for the five commercial cooking source categories for incorporation into the NEI. Activity data, emission factors and emissions for four criteria pollutants and 30 HAPs were converted into NEI Input Format (NIF) Version 3.0 in an Access 2000 database. Seasonal throughputs, material codes and control efficiencies were also compiled into the relational NIF tables, as well as transmittal record information and other applicable NIF 3.0 codes.

The NEI data base format allows only one entry for activity data and emission factors. Due to this limitation, county-level composite activity data was calculated by first summing the activity to get county-level tons of all food cooked on each type of equipment per week. Tons of food cooked was then converted to $tons^2$/lb by multiplying by 52 weeks/year and 1 ton/2000 lb. Weighted composite emission factors, in lb/ton, were calculated by dividing emissions by the activity data.

After preparing the data in NIF 3.0, Pechan ran EPA's NIF QA program on the inventory to ensure that there were no format or data errors and that referential integrity was maintained.

VI. RESPONSE TO COMMENTS

Pechan received two comments with regards to this technical memorandum and emission estimates for commercial cooking. One commenter suggested using English units (lb pollutant/ton food cooked) for the emission factors instead of metric units (grams pollutant/kg food cooked). The commenter felt that emission factors in lb/ton would save time in the preparation of emission inventories and provide less chance for error. Pechan incorporated the commenter's suggestion into the report by including emission factors (Tables 2A and 2B) expressed in lb pollutant/ton food cooked.

Another commenter suggested that Pechan compare the 2002 commercial charbroiling emission estimates with existing state-level inventories. Pechan incorporated the commenter's suggestion by reviewing the percent contribution of $PM_{2.5}$ and total PAH emissions by source category to the total $PM_{2.5}$ and total PAH commercial cooking emissions. Results of the review are presented in Figures 1-4.

Figure 1. $PM_{2.5}$ Emissions by Commercial Cooking Source Category

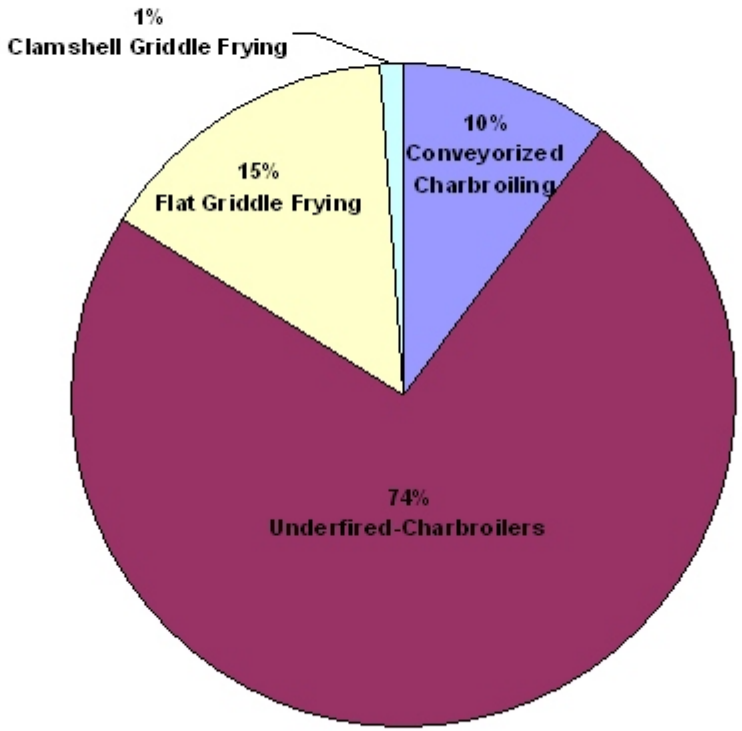
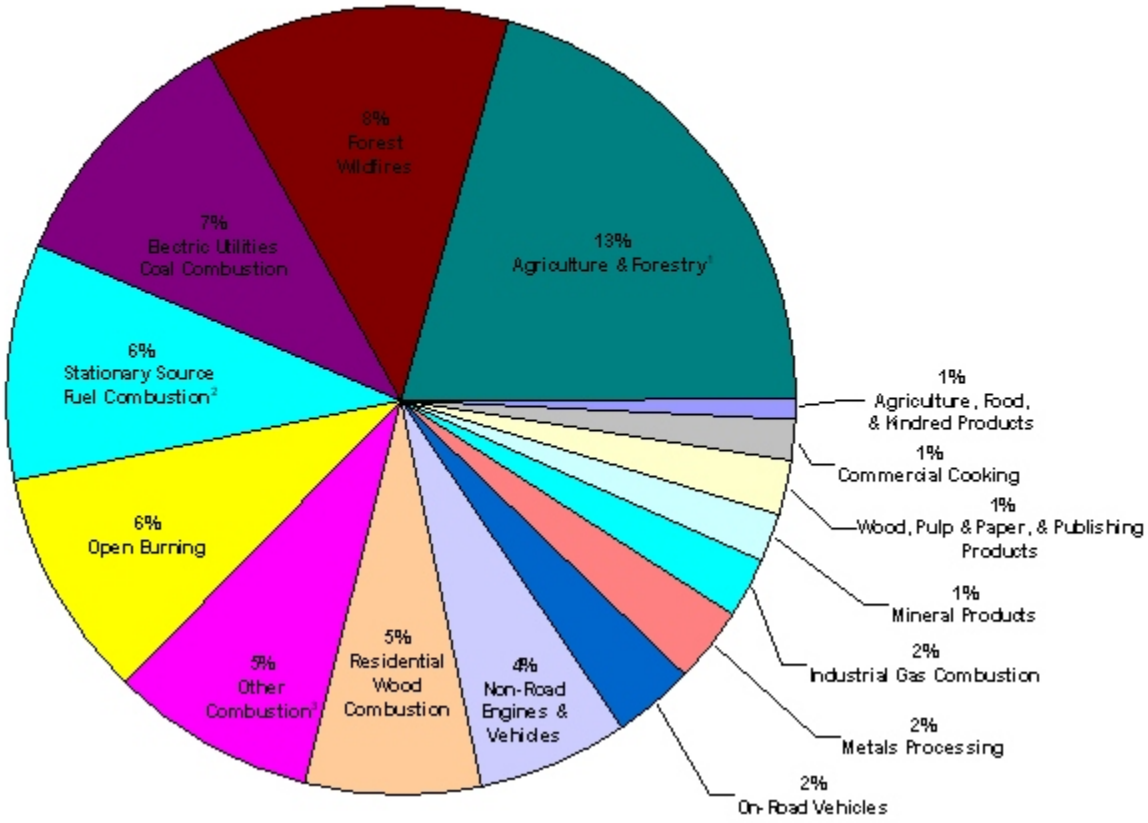


Figure 2. Comparison of Commercial Cooking PM2.5 Emissions to NEI 2001 PM2.5 Emissions



1. Agriculture & Forestry consists of agricultural crops and agricultural livestock.
2. Stationary Source Fuel Combustion consists of electric utilities oil, gas, other, and internal combustion; industrial coal, oil, other, and internal combustion; commercial/institutional coal, oil, and gas combustion; miscellaneous fuel combustion (except residential), and residential other fuel combustion.
3. Other Combustion consists of structural fires, agricultural fires, slash/prescribed burning, and other miscellaneous area source combustion.

Figure 3. Total Polycyclic Aromatic Hydrocarbon (PAH) Emissions by Commercial Cooking Source Category

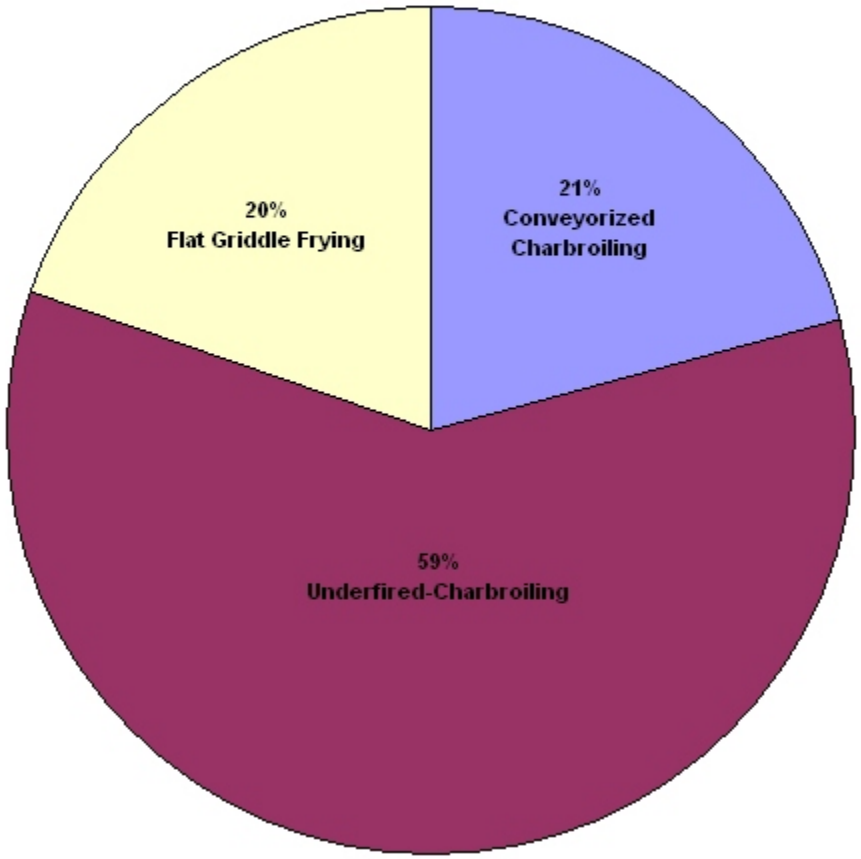
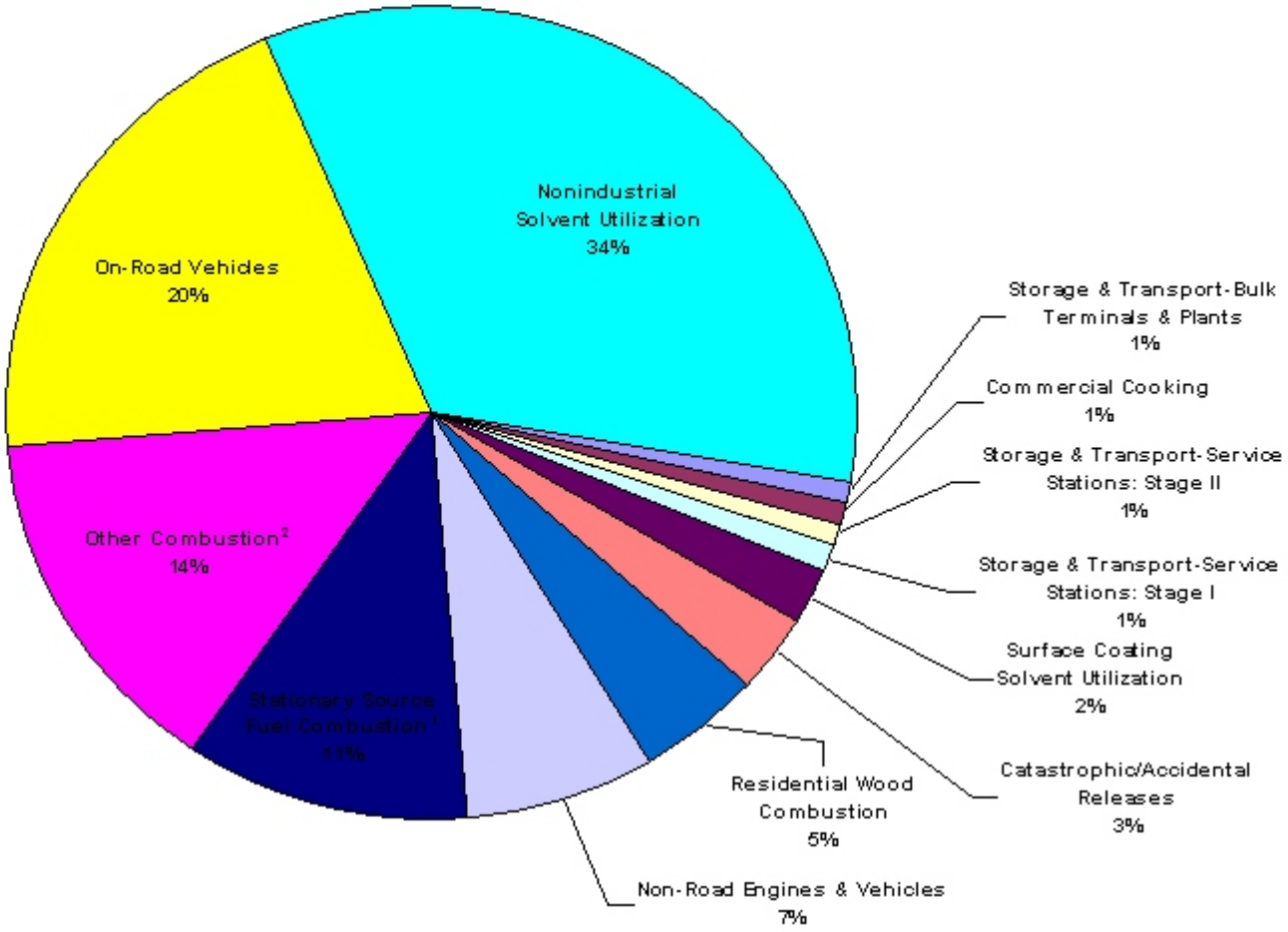


Figure 4. Comparison of Commercial Cooking PAH Emissions to NEI 1999 PAH Emissions



1. Stationary Source Fuel Combustion consists of electric utilities oil, gas, other, and internal combustion; industrial coal, oil, other, and internal combustion; commercial/institutional coal, oil, and gas combustion, and miscellaneous fuel combustion (except residential).
2. Other Combustion consists of structural fires, agricultural fires, slash/prescribed burning, and other miscellaneous area source combustion.

VII. REFERENCES

Appel, 2003: Kathryn Appel, WATT Meat Book Services, personal communication with P. Hemmer, E.H. Pechan & Associates, Inc., March 2003.

BOC, 2002: United States Bureau of the Census, "Table 195. Per Capita Consumption of Major Food Commodities: 1980 to 2000," Statistical Abstract of the United States, 121st ed., Washington: GPO, 2001, 5 Jun. 2002.

Burger King, 2003: Burger King, "Corporate Facts," accessed from www.burgerking.com in March 2003.

Cabada, et al., 2002: Cabada, Juan, Spyros Pandis, and Allen Robinson, "Sources of Atmospheric Carbonaceous Particulate Matter in Pittsburgh, Pennsylvania," *J. Air & Waste Management Assoc*., 52:732-741, June 2002.

Dun & Bradstreet, 2002: Dun & Bradstreet, Inc., MarketPlace CD-ROM, Jan-Mar, 2002, Waltham, MA, 2002.

EPA, 1992: U.S. Environmental Protection Agency, *Identification and Characterization of Missing or Unaccounted for Area Source Categories*, Air and Energy Engineering Research Laboratory, EPA-600-92-006, January 1992.

EPA, 1999: U.S. Environmental Protection Agency, *Emissions from Street Vendor Cooking Devices (Charcoal Grilling)*, EPA-600/R99-048, Washington, DC, June 1999.

EPA, 2000: U.S. Environmental Protection Agency, *Emission Inventory Improvement Program (EIIP), Volume III, Area Source Category Method Abstracts - Charbroiling*, December 2000.

EPA, 2003a: U.S. Environmental Protection Agency, Average Annual Emissions, All Criteria Pollutants Years Including 1970 - 2001, [Data file]. Available from EPA Web site http://www.epa.gov/ttnchie1/trends/index.html

EPA, 2003b: U.S. Environmental Protection Agency, 1999 Nonpoint Area Source National Emission Inventory for Hazardous Air Pollutants, Version 3, July 2003.

Lucier, 2003: G. Lucier, U.S. Department of Agriculture, personal communication with P. Hemmer, E.H. Pechan & Associates, Inc., May 2003.

McDonald, et al., 2003: McDonald, J.D., B. Zielinska, E.M. Fujita, J.C. Sagebiel, J.C. Chow, and J.G. Watson, "Emissions from Charbroiling and Grilling of Chicken and Beef," *J. Air & Waste Management Assoc.*, vol. 53:185-194, 2003.

Norbeck, 1997: Norbeck, J.M., *Further Development of Emission Test Methods and Development of Emission Factors for Various Commercial Cooking Operations*, Final Report for SCAQMD, July 24, 1997.

NRA, 2002: National Restaurant Association, *Restaurant Industry Operations Report—2002*, August 1, 2002.

PES, 1999: *A Detailed Survey of Restaurant Operations in the South Coast Air Basin*, Final Report, prepared by Pacific Environmental Services, prepared for the South Coast Air Quality Management District, February 5, 1999.

PRI, 2001: Public Research Institute, Potepan, Michael, "Charbroiling Activity Estimation, Draft Report," prepared for California Environmental Protection Agency, California Air Resources Board, June 30, 2001.

Santal, 2003: K. Santal, Massachusetts Department of Environmental Protection, personal communication with S. Roe, E.H. Pechan & Associates, Inc., March 2003.

SCAQMD, 1997: South Coast Air Quality Management District, Perryman, Pamela and Peter Votlucka, "Staff Report for Proposed Rule 1138 - Control of Emissions from Restaurant Operations," October 10, 1997.

SJVUAPCD, 2002: San Joaquin Valley Unified Air Pollution Control District, "Final Draft Staff Report: Rule 4692," February, 2002.

USDA, 2001: U.S. Department of Agriculture, "U.S. Pack of Frozen Potato Products," American Frozen Food Institute, 2001.