Vulcan Science Methods Documentation, Version 2.0

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1.0 Vulcan data source introduction

The Vulcan United States fossil fuel CO_2 emissions inventory is constructed from five primary datasets, constituting eight data types, with additional data used to shape the space/time distribution. Figure 1.1 shows a schematic of the data sources and how they are processed to produce CO_2 emissions.

Data Source	***National Emissions Inventory (NEI)***				***ETS/CEM***	***NMIM NCD***	***Aero2k***	***Portland Cement***
Data Type	**Non-road**	**Non-point**	**Point**	**Airport**	**Electricity Prod.**	**On road**	**Aircraft**	**Cement Prod**
Measurement utilized	Activity/ population	CO	CO	CO	CO_2	VMT/ population	CO_2	Clinker Capacity
Incoming resolution: space/time	County/ Monthly	County/ Annual	Lat:Lon/ Annual	Lat:Lon/ Ann:Summer	Lat:Lon/ Hourly	County/ Monthly	1°x1°/ Monthly	Postal Address/ Annual
Conditioning data		Census, EIA sales (sector/state/ fuel/month), NARR T	EIA sales (sector/state/ fuel/month), NARR T			GIS Road Atlas/ Mobile 6.2		Google Earth geolocation, state capacity factors
Final resolution: space/time	County/ Monthly	Census tract/ Monthly	Lat:Lon/ Monthly	Lat:Lon/ Annual	Lat:Lon/ Hourly	Road Segment/ Hourly	1°x1°/ Monthly	Lat:Lon/ Annual
Sector	Transport	Comm. Res. Ind. Elec. Prod.	Comm. Res. Ind. Elec. Prod.	Transport	Elec. Prod.	Transport	Transport	Cement

CO_2 Emissions

Figure 1.1. Vulcan data sources and processing overview

The eight data types can be succinctly described as follows:

- Point sources: non electricity-producing sources identified as a specific geocoded location
- Non-point sources: county-level aggregation of non-geocoded sources
- Non-road sources: mobile surface sources that do not travel on roadways such as boats, trains, snowmobiles, etc.
- Onroad sources: mobile road-based sources such as automobiles, buses, and motorcycles
- Airport: geolocated sources associated with taxi, takeoff, and landing cycles associated with air travel
- Aircraft: gridded sources associated with the airborne component of air travel.
- Electricity Production: geolocated sources associated with the production of electricity
- Cement: geolocated sources associated with cement production (non fuel-based emissions)

The point, non-point, noroad, and airport emission data files come from the Environmental Protection Agency's (EPA) National Emissions Inventory (NEI) for the year 2002 which is a comprehensive inventory of all criteria air pollutants (CAPs) and hazardous air pollutants (HAPs) across the United States [*USEPA* 2005a].

The NEI is a data structure with which the EPA can meet mandates established by the Clean Air Act (CAA) pertaining to CAPs and HAPs. The CAPs emissions, the component of emissions used by the Vulcan system, are collected under the Consolidated Emissions Reporting Rule (40 CFR Part 51) [*USEPA* 2002]. The NEI can be used to track progress, drive air quality modeling, enable emissions trading, and ensure comprehensive reporting and compliance.

The emissions data within the NEI are collected from state and local agencies and tribes (S/L/T) in addition to other data sources from the Department of Energy's (DOE) Energy Information Administration (EIA) and EPAs Clean Air Markets Division (CAMD) [*DOE/EIA* 2003; *ERG and EHP,* 2004; *USEPA* 2004a; *USEPA* 2005b]. All of this data is inventoried by the EPA and QA/QC operations are performed before releasing the data as the NEI [*USEPA* 2005c]. Currently, the Vulcan system has utilized data from the 2002 NEI and this forms the basis of much of the 2002 CO_2 Vulcan inventory.

The NEI database is composed of a series of individual, but related, data files. These data files share common, required key fields. The Vulcan inventory construction utilized a subset of these database fields in combination with other data streams to produce CO_2 emissions.

The ETS/CEMs data is collected under the Acid Rain Program (ARP), which was instituted in 1990 under Title IV of the Clean Air Act. The ARP regulates electrical generating units (EGUs) that burn fossil fuel and are greater than 25 MW capacity or are less than 25 MW but which burn coal with a sulfur content of greater than 0.05% by weight. Covering 95% of CO_2 emissions from the electricity production sector, this data source supplies CO_2 emissions directly and is either directly measured CO_2 or calculated from fuel consumption measurements and fuel carbon content.

The Aero2k dataset supplies the other component of aircraft emissions, that associated with airborne emissions (above 3000 ft). The Aero2K database quantifies CO_2 emissions (among other pollutants) on a 1° x 1° x 500 ft grid and is incorporated directly into the Vulcan inventory.

The National Mobile Inventory Model (NMIM) County Database (NCD) supplies vehicle miles traveled (VMT) data for each combination of vehicle type, road type, county, and month. The NMIM NCD is part of the NMIM software package produced by the EPA. This is combined with fleet information, vehicle emission factors, and a GIS road atlas in order to locate emissions as roadway line sources according to vehicle, road, county, and month.

Non-fuel combustion cement emissions are derived from individual reported cement facility capacity and state or state-aggregate capacity factors. Geolocation was accomplished by matching postal addresses to facility locations in Google Earth.

The Vulcan effort does not attempt to further QA/QC these large data sources and their related datasets but incorporates this data at "face value" with exceptions noted in this documentation. Details of the EPA QA/QC procedures and potential uncertainties in that process can be found in EPA NEI documentation and websites.

Further details on all of these data sources and their incoporation into the Vulcan inventory is provided in the individual document chapters.

2.0 NEI Point CO_2 Emissions

The NEI point database is comprised of eight related files described in Figure 2.1 [*USEPA* 2006a; *ERG* 2001a]. The three key fields that define a "site" in the point database are the "state and county FIPS" code (which identifies the state and county), the "state facility identifier" (which identifies the individual emitting facility) and the tribal code (used in place of a state and county FIPS in tribal lands).

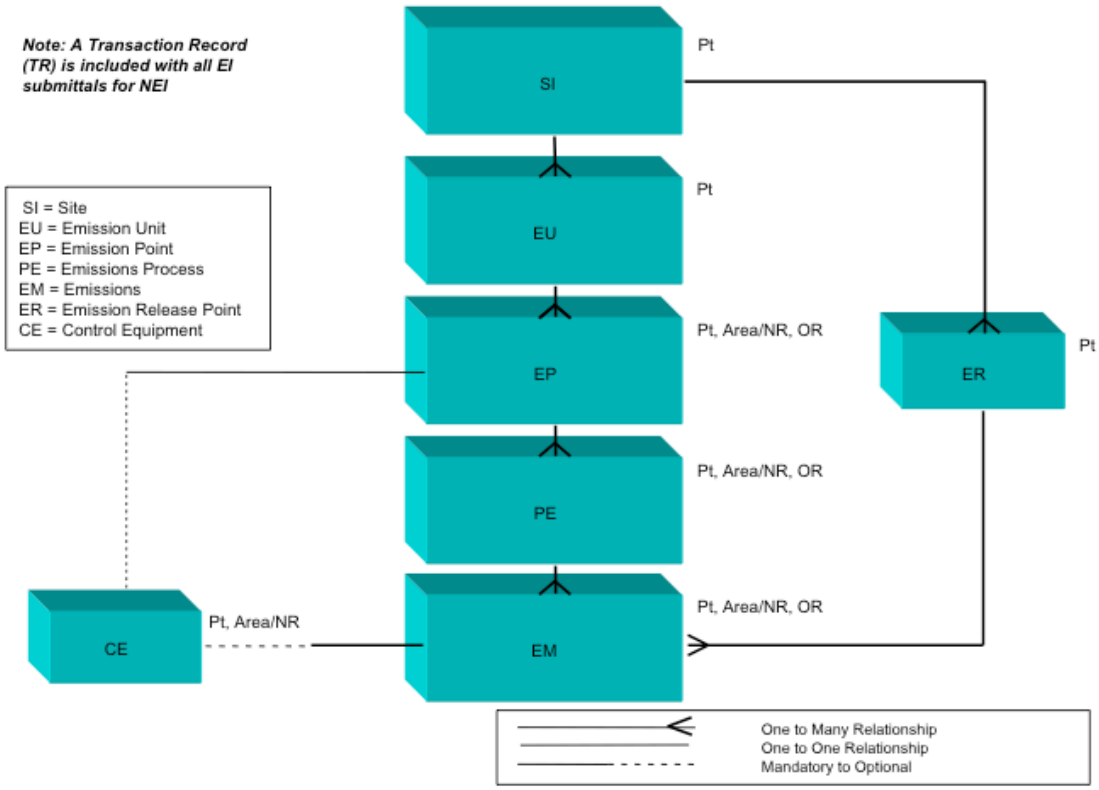

Figure 2.1. The NEI data relationships[1]

The general procedure followed to generate CO_2 emissions from the point NEI data is to utilize the existing reporting of CO emissions at the facility level. As depicted in Figure 2.1 (with the correction noted in the figure footnote), each site or facility can have multiple emission units (different buildings or portions of a complex facility or site), each of which can have multiple emission processes (eg. energy production, heaters, kilns), each process can emit more than one pollutant (toxics, NOx, CO, etc), and these pollutants can be emitted by more than one stack location.

Where CO emissions are reported, and an emission factor can be assigned, CO emissions are relied upon. Where data on CO is nonexistent or significantly limited, NOx emissions are used – though this occurs in a very limited number of cases.

[1] This figure, reproduced from NEI documentation incorrectly identifies the files in the box on the lefthand side. The database labeled "EP" is the "Emissions Process", the database labeled "PE" is the "Emissions Period".

The NEI point source data files are primarily comprised of processes associated with the industrial sector (identifiers are supplied in the NEI) but emissions from residential, commercial and mobile sources are found within the point data[2]. This sectoral designation is important when representing the resulting emissions spatially and categorically, an issue that is discussed in section 7.0.

Fossil fuel is calculated with CO/NOx emission factors and CO_2 emission factors are then applied to these throughput values. Details of this process are as follows:

2.1 Data reduction

Because the NEI contains a significant amount of information on emission processes that do not consume fossil fuels or processes that contain emissions from fossil fuel combustion other than NOx and CO, the first step in utilizing the NEI point data is to reduce the data to the subset relevant to the CO_2 emissions problem. A series of reductions are made to the original NEI point dataset.

2.1.1 Material and pollutant qualifiers

The point source NEI was first reduced by narrowing the database through examination of the emission process material/fuel and how that material/fuel was utilized in the emission process considered. Only records that had the following combination were considered for CO_2 analysis:

1) the pollutant code identified either CO or NOx
   AND
2) the material code ("Mat code") could be matched to a member of the Vulcan fossil fuel list (Table 2.1) or was listed as "null"
   AND
3) the material input/output ("Mat IO") identifier was set to "input" ("I") or "null"

The goal was to limit the processes considered to those producing CO or NOx (the cornerstone to generating CO_2 emissions in the majority of the Vulcan inventory), burning fossil fuel (as opposed to processes consuming biotic materials or producing fossil fuels). Consideration of the "null" entries (which were ambiguous and therefore deemed worthy of further investigation) is made later on in the data reduction.

Though throughput information (eg. tons of coal burned) was sometimes included in these instances, the throughput values were not quality controlled by the EPA and were often found to be inconsistent with emissions.

[2] There are some records for which no sectoral assignment could be determined. However, these occurences were isolated to the nonpoint data pipeline.

Table 2.1. Material/fuel and phase for fossil fuel burning processes in the 2002 NEI

Material	Phase	Material	Phase
Anthracite Culm	Solid	***Jet A Fuel***	Liquid
Anthracite	Solid	***Jet Fuel***	Liquid
Bituminous Coal	Solid	***Jet Kerosene***	Liquid
Bituminous/Subbituminous Coal	Solid	***Jet Naphtha***	Liquid
Butane	Gas	***Kerosene***	Liquid
Coal	Solid	***Lignite***	Solid
Coke	Solid	***Liquified Petroleum Gas (LPG)***	Liquid
Coke Oven Gas	Gas	***Lube Oil***	Liquid
Coke Oven or Blast Furnace Gas	Gas	***Natural Gas***	Gas
Crude Oil	Liquid	***Oil***	Liquid
Diesel	Liquid	***Process Gas***	Gas
Diesel/Kerosene	Liquid	***Propane***	Gas
Distillate	Liquid	***Propane/Butane***	Gas
Distillate Oil	Liquid	***Raw Coke***	Solid
Distillate Oil (Diesel)	Liquid	***Refined Oil***	Liquid
Distillate Oil (No. 1 & 2)	Liquid	***Refinery Gas***	Gas
Distillate Oil (No. 1)	Liquid	***Residual Oil***	Liquid
Distillate Oil (No. 2)	Liquid	***Residual Oil (No. 5)***	Liquid
Distillate Oil (No. 4)	Liquid	***Residual Oil (No. 6)***	Liquid
Ethane	Gas	***Residual/Crude Oil***	Liquid
Gas	Gas	***Sour Gas***	Gas
Gasoline	Liquid	***Subbituminous Coal***	Solid
Heat	TBD[1]	***Waste Oil***	Liquid

[1] records with material identified as heat are further explored for physical fuel consumed via the SCC description.

The next reduction step was to identify only those processes which had either a non-zero NOx or CO emissions value (or both). Fuel throughput and CO_2 emissions cannot be generated without one or the other of these two pollutants as non-zero values. This reduced the database to 132,971 processes[3]. 65 processes had an unidentifiable code for the state and county location (the "FIPS" code), further reducing this set to 132,906 processes. Of the 132,971 processes, XXXX rely on NOx emissions for further processing.

2.1.2 Time period consistency

Emissions reporting in the NEI is made for a small set of different reporting periods or time "types" as follows:

- Type 27: average weekday
- Type 28: average weekend day
- Type 29: average day in period
- Type 30: entire period total

A given process can report emissions for more than one of these time period types. Only processes which identify time type 30 are retained and all others are

[3] If an emission process utilizes emission controls and those controls fully eliminate CO/NOx, the CO_2 from that process is NOT captured in the Vulcan inventory.

removed.[4] In most cases the time type 30 is a complete calendar year total amount. These annual emissions are initially divided equally amongst the total number of days and hours in the year (for the gridded hourly output). Section 8.0 describes further temporal conditioning of the point emissions. Most facilities with emission time type 30 estimate the emissions for a period of 365 days or 8760 hours per year. However, certain facilities report timespans for a specific portion of the year making the effective operational number of days in the year less than 365. In such cases, the annual emissions reported by the facility are equally divided amongst the reported number of days/hours rather than 365 days (8760 hours).[5]

Hence, the effective calculation is as follows:

$$E(t) = \frac{E_p}{\Delta t_p \times 24} \qquad (2.1)$$

Where E is emissions, t is hourly timestep, p is the reported emissions period, and Δt_p is the number of days in the reported time period (most commonly 365).

There are also cases in the input NEI dataset where the operational start/end date of a process is reported as a year other than 2002. These are a mixture of typos by the reporting agency or examples where a previous year emissions have been "carried over" to the 2002 database. Such records are modified to start on 1/1/2002 and end on 12/31/2002.

After removal of the non-30 time types (23,578 processes), we then have 109,328processes remaining in the database.

2.1.3 Missing material identification

In order to explore emission processes for which the fuel or input/output identifier was listed as "null", the NEI input format (NIF) source classification code (SCC) lookup table was used to fill in the missing information and confirm the material classifications provided by the NEI material code.[6] This exercise further identified how the material was used in the emitting process. For materials listed in Table 2.1, only actions identified as "burned" were retained in the Vulcan point inventory. Other actions such as "processed", "shipped", or "produced" were not considered the purview of the Vulcan CO_2 inventory and these emitting processes were removed. There were two categories of emission processes that did not meet these criteria and the most common were as follows:

1) fugitive emissions (surface oxidation) from fossil fuel throughput (leakage from pipelines, spills, etc);

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[4] Version 2.0 of the Vulcan inventory will utilize the multiple time types to further structure emissions during the emitting period.

[5] However, as noted in Section 8.0, the emissions are forced to be constant for the year prior to performing monthly and hourly downscaling.

[6] Material codes are actually supplied in multiple fields in the NEI which are often contradictory. The material codes are associated with each pollutant field in addition to provided as an independent field. The materials identified through the SCC lookup are used to override all other material classifications and form the basis of the fuel combusted.

2) emissions based on the production of a material/fuel other than those identified in Table 2.1. For example, a process that had CO/NOx emissions, is using natural gas, but the reported NOx/CO emissions are relative to the amount of ammonia produced rather than the natural gas burned. Without knowledge regarding how much fuel is burned to produce ammonia (in this example), a reliable estimate of throughput cannot be calculated. It is also unclear whether or not the NOx/CO emissions are indeed related to the fossil fuel combustion or independently related to the production of the non-fossil material. In the latter case, the NOx/CO emissions related to the fossil fuel combustion are reported elsewhere and hence, included; double-counting would be the result of including emissions for the non-fossil material. In the case of the former situation, the total CO_2 emissions would be underreported via these instances since these processes are removed from further consideration;

15,996 processes were eliminated at this step as they had no information by which a material could be identified or were not burning a material listed in Table 2.1.

Elimination of these processes left 85,402 emission processes.

2.1.4 Idiosyncratic adjustments

A series of individual adjustments were made to the NEI point data due to independent data or instances of QA/QC we were able to perform on the NEI database. The following lists these idiosyncratic adjustments:

1. Identification of a typo for FIPS 13153, state facility ID 15300003, SCC 39000201. CO emissions were listed in the NEI point data as 4128 tons. Emissions should be 28 tons CO.
2. Two occurrences of FIPS 51019, state facility ID 3, SCC 39000189 and CO emissions of 3964.41 and 2098.06 tons. The NEI-provided emission factor (221 lbs/ton or 9.2 lbs/10^6BTU) should be used instead of the FIRE-supplied emission factor.
3. Three occurrences of FIPS 13103, state facility ID 10300007, SCC 10200802 and CO emissions of 1018, 913.2, and 8017 tons. The NEI-provided emisions factor (18 lbs/ton or 0.6 lbs/10^6 Btu) should be used instead of the FIRE-supplied emission factor.
4. One occurrence of FIPS 5063, state facility ID 506300036, SCC 10200101 and CO emissions of 1683.7 tons. This should utilize an emission factor of 90 lbs/ton (or 3.744 lbs/10^6 Btu).
5. Two occurrences of FIPS 40123, state facility ID 826 and SCC 39000201. CO emissions were listed in the NEI point data as 381 and 373.8 tons. Emissions should be 81 and 73.8 tons, respectively (this is a typo).

6. All occurrences of SCC 102000704 and 39000701 are assigned a material code of 809 which corresponds to “coke oven gas or blast furnace gas” (see Table 2.1).[7]
7. All occurrences of SCC 102000707, 39000702, and 39000789 are assigned a material code of 425 which corresponds to “coke oven gas” (see Table 2.1).[8]
8. Ten SCCs were present in the NEI point database but not found in the NIF SCC lookup table. Four of these SCCs were considered viable emission processes via the SCC description text supplied in the NEI point database (a fossil fuel was burned in the process).[9] The four SCC are:
    - 20100301: Internal Combustion Engines; Electric Generation; Gasified Coal; Turbine
    - 10100818: External Combustion Boilers; Electric Generation; Petroleum Coke; Circulating Fluidized Bed Combustion
    - 30701415: Industrial Processes; Pulp and Paper and Wood Products; Hardboard (HB) Manufacture; "Tube dryer, direct NG-fired, blowline blend, PF resin, hardwood
    - 10102018: External Combustion Boilers; Electric Generation; Waste Coal; Circulating Fluidized Bed Combustion

9) The emission factors for the Hansen Permanente Plant (facility id: 43130317) in Santa Clara county, CA (FIPS: 6085) had two processes (SCCs: 39000899, 39000201) for which we will not reject the supplied emission factors even though they are outside the stated bounds. They do not supply units but we are confident that they are lbs CO/ton.

10) SCC: 39000899 (coke combustion) will utilize a CO emission factor of 0.220 lbs $CO/10^6$ Btu instead of the default value of 0.021 lbs $CO/10^6$ BTU. This emission factor was found as an NEI provided EF in a few cases and appears more consistent with anticipated results.

11) for plant id: 1191680 and SCC: 10300603 in Middlesex, MA (FIPS: 25017), the CO emissions were incorrectly reported as tons (as 4900 tons) and should have been reported as lbs (which results in 2.45 tons CO/year).

12) All cases of SCC 39000201 will utilize the CO EF identified in point 9): 1.427 lbs $CO/10^6$ Btu.

2.2 Quantifying CO_2 emissions

With the data reduction complete, each process is examined in order to retrieve information by which an amount of emitted CO_2 can be produced. The CO_2 emission quantity is determined from the provided CO and/or NOx emissions amount in combination with an emission factor (EF) for one or both of these pollutants and an

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[7] These processes are common in steel production and were assigned a material type “process gas”. Personal communication with Indiana State Environmental officials provided the more specific fuel type (and a more accurate emission factor). In addition to Indiana, Pennsylvania and Illinois report these SCCs.

[8] See previous footnote.

[9] The material type was identfied through examination of the CO and NOx material codes.

emission factor for CO_2. The CO/NOx EF used is chosen from three different alternatives: 1) the EF provided in the NEI data itself for the particular process in question and for the particular pollutant (CO or NOx), 2) the EF retrieved from the FIRE database, a collection of standard EFs applied to specific SCC/control combinations [*USEPA* 1997; *USEPA* 2006b; *WebFIRE* 2005], and 3) a default EF value (provided in Appendix A, Tables A.1 and A.2).

The basic process by which CO_2 emissions are created is as follows:

$$C_f^p = \frac{12}{44}\frac{PE_f^p}{PF_f^p}CF_f^p \tag{2.2}$$

where *C*, is the emitted amount of carbon, *PE* is the equivalent amount of uncontrolled criteria pollutant emissions (CO or NOx emissions), *p* is the combustion process (e.g. industrial 10 MMBTU boiler, industrial gasoline reciprocating turbine), *f* is the fuel type (e.g. natural gas or bituminous coal), *PF* is the emission factor associated with the criteria pollutant, and *CF* is the emission factor associated with CO_2 (provided in Appendix A, Table A.3).

When CO emissions are available, these are used to generate the fuel consumed (and hence, CO_2 emissions) because the question of emission control is of a lesser concern with CO as it is with NOx emissions.

2.2.1 CO emission factor retrieval

The following series of logical steps trace the procedure for retrieving the most reliable CO and NOx emission factors (*PF*) for each process retained in the Vulcan system. In each case, the retrieval of an emission factor is based on the process under consideration and the material processed. The procedure is determined by the SCC provided in the NEI point database and the material as determined in previous steps (see section 2.1.3).

Where emission factors are supplied in physical units (emitted amount per volume or mass of fuel), they are converted to thermal units (emitted amount per 10^6BTU) for use in the Vulcan emission calculations. Appendix A, Table A.3 provides fuel heat contents used in this process.

Retrieval options:
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1. There is a PF provided within the NEI and there is a FIRE PF (or multiple). Is the provided NEI PF within the tolerance thresholds[10] of the FIRE PF (or any, if multiple)?
    - If so, retrieve the NEI provided PF
    - If not, retrieve the FIRE PF (the largest, if multiple)

[10] The factor must be within a factor of three larger than that supplied or within 75% lower.

2. There is a PF provided within the NEI, but no available PF in the FIRE database. Is the NEI provided PF within the tolerance thresholds of the default PF?
 - If so, retrieve the NEI provided PF
 - If not, retrieve the default PF

3. There is no PF provided within the NEI, but there is a FIRE PF (or multiple)
 - Retrieve the FIRE PF (use largest, if multiple)

4. There is no PF provided within the NEI and there is no FIRE PF
 - Retrieve the default PF

****

The next step in the CO_2 emissions calculation is the estimation of the fuel throughput for the considered process. This is computed as the ratio of the mass of emitted pollutant divided by the PF (with appropriate units ascertained).[11]

2.2.2 CO_2 emissions estimation

Once the material/fuel throughput has been produced, a CO_2 EF is applied (provided in Appendix A, Table A.3). The CO_2 EF is variously referred to as "carbon coefficient" or "carbon factor" in the literature. For this study, it represents the mass of carbon or CO_2 emitted per unit energy of fuel consumed (since all fuel is previously converted to energy units, all CO_2 EFs are thus standardized). Emission factors for CO_2 are based on the fuel carbon content and assume a gross calorific value or high heating value, as this is the convention most commonly used in the US and Canada [*URS*, 2003]. Emission factors are reported as units of carbon dioxide as opposed to units of carbon and assume 100% oxidation of fuel carbon to CO_2 for natual gas, 99% for coal and oil [*IPCC* 1996; *DOE/EIA* 2007b].

2.3 Sources of Uncertainty

The computation of CO_2 emissions in the point data source includes a number of self-reporting uncertainty sources which we designate here as "categorical" and "numerical" uncertainties. Categorical uncertainties include the following:

1. Time period designation
2. Fuel designation
3. SCC designation

Errors in these information sources imply that the facility operator or office tasked with estimating pollutant emissions mis-categorized the time period for which emissions were estimated, the fuel being consumed or the SCC code for which the pollutant emissions were estimated. Estimating the liklihood that categorical errors were made is difficult. Quantifying how that categorical error would impact the final CO_2 emission estimate is also difficult. Given the nature of the reporting (professionals tasked with complying with air quality regulatory law) and the

[11] This fuel throughput calculation assumes that the fuel estimated is the amount of fuel "burned" in the combustion process.

difficulty associated with estimating the potential errors, this study considers these sources of uncertainty to be low. Nonetheless, uncertainty associated with category 3. is attempted below.

The numerical sources of uncertainty in the CO_2 calculation include the following:

1. Pollutant emission quantity reported
2. Provided pollutant emission factor
3. Default pollutant emission factor
4. CO_2 emission factor (carbon content of fuel)
5. Heat content conversions

Among these uncertainty sources, 3 through 5: the CO_2 emission factor, the heat content, and the default pollutant emission factor, can be quantified with available data. The first two uncertainty sources are difficult to quantify. Unlike the categorical uncertainties, however, these are both much more likely to contain errors and those errors would have a direct and potentially large impact on the CO_2 emissions estimation.

In order to provide a first order sense of the impact of the quantifiable components of the last three sources of numerical uncertainty, we take a sensitivity approach. The sensitivity approach asks the question: how wrong could the CO_2 emissions estimate be, given typical variations in the underlying sources of uncertainty? These variations are conservatively interpreted as a one-sigma spread on the central estimate of the CO_2 emissions (though the variations described below are likely higher than a true one-sigma spread of an actual sample of underlying factors).

2.3.1 Pollutant emission factor

For the default pollutant emission factors, a range of values is used as a form of sensitivity. The range reflects values in the WebFire database as well as a range of values that are self-reported in the NEI point database itself. For example, for industrial pulverized bituminous coal combustion, values ranging from 0.5 lbs CO/ton to 22.86 lbs CO/ton are included in the sensitivity test. These represent the highest and lowest possible values for CO emissions/unit fuel available in the WebFire/NEI combined datasets. The lower CO emission factor will lead to a greater amount of fuel consumed and a greater CO_2 emission. Whereas the high CO emission factor will do the opposite (result in lower CO_2 emissions). This range also incorporates the categorical error 3. In the first list above as this spread of CO emission factors generally reaches across SCC values within a specific fuel designation. These extreme ranges are considered 2-sigma errors and hence, the distance between the central EF and the hi and lo extremes are halved to arrive at a one-sigma value.

2.3.2 Heat and carbon content

As described in section 2.2.1, pollutant emissions that are reported in mass or volume units are first converted to emissions per unit thermal content (per 10^6 btu). This requires the use of a heat content conversion which is dependent upon the fuel considered as provided in Appendix A, Table A.3. This alters equation 2.2 as follows,

$$C_f^P = \frac{12}{44}\frac{PE_f^P}{PF_f^P} HC_f CF_f^P \tag{2.3}$$

where HC_f is the heat content which is only dependent upon the fuel consumed in the combustion process.

Fuel heat contents can vary substantially and are generally associated with the parent fuel formation/location (coal mine, oil well, etc). Variation (one standard deviation) in heat content is derived from fuel samples and is described and quantified in DOE/EIA [2007b]. The largest variation in heat content is found for coal and is derived from sampling coal from each producing state destined for power plants in the United States. Depending upon coal rank, variation (standard deviation about the mean value) in heat content ranges from 4 to 12%. Additional analysis was performed here by quantifying the variation in coal delivered to power plants using the DOE/EIA form 423 database and consistent results were found [*DOE/EIA*, 2002a; 2002b].

Variation in heat content for the remaining fuel categories are partly derived from the DOE/EIA form 423 database or quantitatively identical to the variation assigned for the carbon coefficient (CO_2 emission factor). Variation in the CO_2 emission factor is similarly derived from DOE/EIA [2007b]. The largest variation is for refinery gases (33%). Variation in the heat content and carbon content of fuel are generally correlated. We treat them as uncorrelated and additive. This is likely a conservative approach. These stated variations are considered a one-sigma spread.

2.3.3 Utilizing only default pollutant EFs

Finally, the provided pollutant emission factor can be tested somewhat by substituting all provided pollutant emission factors with default factors in all instances. This bypasses both the acceptance of provided emission factors and the SCC-specific WebFire emission factor lookup and defaults to the values in Appendix Table A.1 and Table A.2.

2.3.4 Summary of sensitivities

Hence, we have four sensitivity tests:

1. vary the default pollutant emission factors (hi and lo cases)
2. vary the fuel heat content (hi and lo cases)
3. vary the fuel carbon content (hi and lo cases)
4. utilize only default emission factor

The first three can be quantified in a directional sense to arrive at a "hi" and "lo" CO_2 emissions estimate whereas test 4 will cause results to vary in both numerical directions. Results are produced which isolates the impact of each of these tests and the combination of all four sensitivity tests. The combination sensitivity test is as follows:

Low-end pollutant emission factors + hi-end heat content + hi-end CO_2 EF.

This combination senstivity test is run with and without utilization utilization of default emission factors.

3.0 Cement

CO_2 is emitted from cement manufacturing as a result of fuel combustion and as process-derived emissions [*van Oss* 2005] . The emissions from fuel combustion are captured in the fossil fuel combustion emission processes. The process-derived CO_2 emissions result from the chemical process that converts limestone to calcium oxide and CO_2. This occurs during "clinker" production (clinker is the raw material for cement which is producing by grinding the clinker material).

3.1 Emissions estimation

Estimation of CO_2 emissions from clinker production utilizes two datasets. The first is the data provided by the Portland Cement Association [*PCA* 2006]. The PCA document provides the annual clinker capacity at individual facilities, postal addresses, facility name, zip code and contact phone numbers. The capacity data reflects conditions for the calendar year 2006.

The other dataset utilized is the Minerals Yearbook produced by the United States Geological Survey [*USGS* 2003]. The USGS Yearbook provides the capacity factor (or percent utilization of capacity) for 2002 on a statewide or multi-state basis (some states are quantified individually, others are part of an aggregate).

Clinker production for 2002 is estimated by multiplying the USGS-suppled capacity factor, defined at the state or state-aggregate level, by the individual facility capacity (appropriate to the state or state-aggregate capacity factor) provided by the PCA document. The sum of the individual PCA-reported capacities for all facilities in a state or multi-state aggregate can be compared to the USGS-reported equivalent. This is presented in Figure 3.1a.

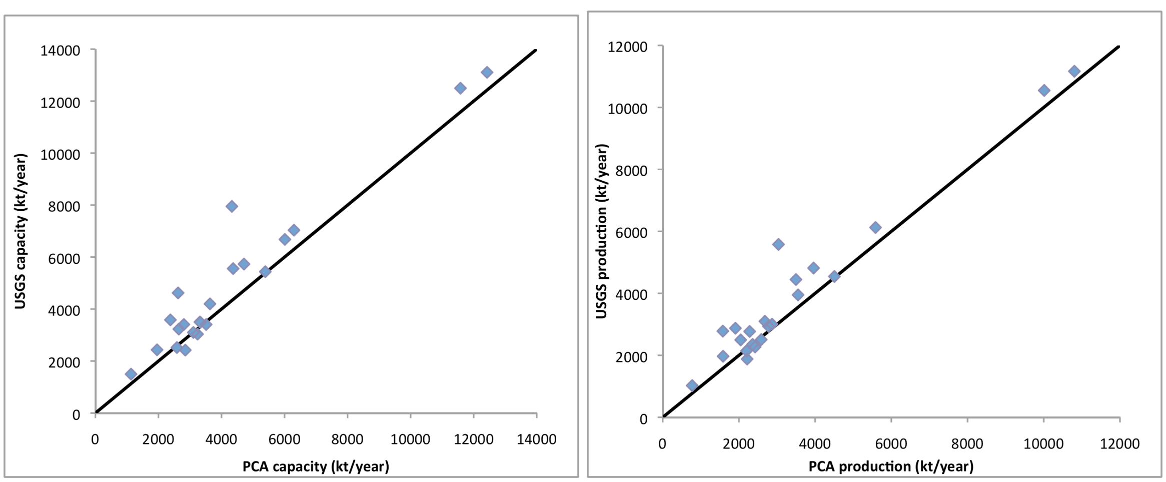

Figure 3.1 *Comparison of PCA-reported [PCA,* 2006*] statewide or multi-state aggregate a) clinker capacity and b) clinker production to that reported by the USGS [USGS 2003]. The 1:1 line is also shown. Units: kilotonnes/year.*

The USGS reported capacity (94,241 kt/year) is consistently higher (25%) than that provided by the PCA reference document (75,239 kt/year). The large outlier value is the datum for the sum of Michigan and Wisconsin.

The same relationship can be constructed for production and this is shown in Figure 3.1b.

The USGS reported production is larger (27%) at the state or state-aggreate level compared to the data reported in the PCA document.

3.2 Geolocation

The geolocation for each of the individual facilities was achieved by entering the PCA document's facility address into Google Earth and visually inspecting the scene for the primary emitting stack of the cement facility. This approach succeeded in locating all 105 facilities present in the PCA document.

These geolocation points are checked against the cement facilities reported through the NEI point database (see section 2.0). 82 of the 105 facilities present in the PCA database are found (with geolocation) in the NEI point data. The average percent difference between the 82 Google Map identiied locations and those entered in the NEI point datebase is -0.01% and 0.01% for the latitude and longitude, respectively.

3.3 CO_2 emissions factor

The CO_2 emission factor used in the Vulcan Project is 0.59 metric tonnes CO_2/short ton of clinker produced[12]. This emission factor is the result of a calculation that reflects IPCC recommendation on the incorporation of cement kiln dust. The calculation is as follows:

$$E_i = 0.525(1.02\,P_i) \tag{3.1}$$

Where E_i is the CO_2 emissions in tonnes of CO_2 from facility *i* and P_i is the clinker produced by facility *i* in units of metric tonnes. The factor, 0.525 metric tonnes CO_2/metric tonne of clinker, is an emission factor recommended by the World Business Council for Sustainable Development and consistent with the Intergovernmental Panel on Climate Change emission factors when corrected for typical MgO contents in clinker [*WBCSD* 2005]. As this emissions factor does not account for the fact that a percentage of the clinker precursor materials remain in the kiln in the form of cement kiln dust (CKD), the IPCC recommends that emissions from CKD be included as equal to 2% of total process-related CO_2 emissions.

The EIA estimates cement manufacturing in 2002 to account for 43 $MtCO_2$/year out of a total 69.4 $MtCO_2$/year for their entire industrial process-derived CO_2 emissions [*DOE/EIA* 2007a]. The latter value includes both limestone and soda ash manufacturing which are currently not included in the Vulcan inventory.[13] These estimates, in turn, are based upon throughput estimates from the U.S. Geological Survey. Vulcan estimates a total of 44.22 $MtCO_2$/year which compares well with the cement manufacturing estimate from the EIA.

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[12] This is equivalent to 0.536 metric tonnes of CO_2/metric tonne of clinker produced.

[13] These categories will be included in Vulcan 2.0.

3.4 Sources of Uncertainty

The primary sources of uncertainty in the calculation of CO_2 emissions from cement manufacturing are as follows:

1. Uncertainty in facility clinker capacity
2. Uncertainty in state or state-aggregate capacity factor
3. Unaccounted for sub-state variation in capacity factors
4. Unaccounted for variation in CO_2 emission factor (temperature, MgO, FeO contents, etc)

Numbers 1 through 3 are external data sources with no uncertainty estimate included. Hence, construction of a probability density function associated with the incoming data is difficult. For the uncertainty sensitivity analysis performed in the Vulcan Project, an attempt is made to reflect a range of possible values for 1, 2, and 4. A high-end estimate is generated by assuming an increase of 10% in these three sources of uncertainty. A low-end estimate is generated by assuming a decrease of 10% in all three of these sources of uncertainty. These are considered one-sigma errors.

4.0 Electricity Production CO_2 Emissions

4.1 ETS/CEM data

The emissions from electricity production is primarily supplied by data obtained from the DOE/EIA and, most importantly, the EPA's CAMD Emission Tracking System/Continuous Emissions Monitoring system (ETS/CEMs) data for Electrical Generating Units (EGUs) [*ERG and EHP*, 2004; *USEPA* 2004a; *USEPA* 2005b; *Ackerman & Sundquist*, 2008; *Petron et al.,* 2008]. The ETS/CEMs data is collected under the Acid Rain Program (ARP), which was instituted in 1990 under Title IV of the Clean Air Act. The ARP regulates EGUs that burn fossil fuel and are greater than 25 MW capacity or are less than 25 MW but which burn coal with a sulfur content of greater than 0.05% by weight. In addition to heat input, these facilities are required to engage in continuous monitoring and reporting of sulfur oxides (SOx), CO_2, and nitrogen oxides (NOx) emissions. These data are reported directly as hourly CO_2 emissions monitored from an emitting stack or through a calculation based on records of fuel use. All emitting locations are geocoded to latitude, longitude and postal address.

Because the ETS/CEMs data within the NEI are reduced to the annual total emissions, the original hourly ETS/CEMs reporting is utilized in the Vulcan inventory. No attempt is made to gap-fill missing data or adjust emissions in any way (time gaps may be due to peaking units or shutdowns, etc). There are 1241 facilities in the hourly data, consistent with the annual files available from the EPA. Furthermore, the total CO_2 emissions for all of the ETS/CEMs data as calculated from the hourly emissions is 0.60 GtC/year, consistent with the annual files.

4.2 Cross-matching to NEI

Removal of the ETS/CEMs facilities from the NEI must be accomplished to avoid double-counting of CO_2 emissions. There were 1241 ETS/CEMs individual facilities in 2002 (which constitute a much larger number of "processes") and the identifying and emissions data associated with these facilities can be downloaded from the CAMD website [*USEPA* 2008a].

Cross-matching the ETS/CEMs and NEI processes was accomplished by attaining the Registry ID associated with the ETS/CEMs facilities from the EPA Envirofacts data warehouse [*USEPA* 2008b]. The Registry ID is a common identifier for the two reporting systems. This procedure led to 911 facility cross-matches. An additional 129 matches were identified from the common ORISPL code, an identifying code utilized by the DOE and often found in the NEI.

The remaining 201 facilities were approached through a combination of proximity and address/facility name matching. All facilities within 0.05 degrees in latitude and longitude were retrieved from the NEI point database and these were individually inspected to determine which, if any, were referencing the same emitting facility. Alternative facility names were determined that these were searched within the NEI. This effort achieved an additional 118 matched facilities. All of the matched facilities were then removed and the separate hourly CO_2 emissions ETS/CEMs data was used in the Vulcan inventory.

The 83 unmatched ETS/CEM facilities accounted for 2.1 Mtonnes of CO_2 or 0.34% of the total ETS/CEMs 2002 CO_2 emissions. No further attempt was made to remove these facilities from the NEI and it remains unclear whether or not these facilities are included in the NEI.

4.3 Fuel assignment

In order to maintain the ability to report CO_2 emissions according to fuel at each emitting process or record, the exact fuel or fuel mix at each of the ETS/CEMs facilities was identified through matching with the EIA form 906 data which provides a detailed summary of key characteristics at all power production facilities [*DOE/EIA* 2008]. The EIA form 906 data provides a listing, for the year 2002, of the fuel share at reporting power production facilities in the US. Using this data, 1167 matches were made through direct ORSPL code matching. Five additional facilities were matched through a combination of state location and facility name. The fuel mix at the remaining 89 facilities were identified through a combination of online searching of utility websites and direct contact with facility operators.

After eliminination of the ETS/CEMs facilities within the point NEI database, we have 101,758 processes in the NEI since a single facility can have multiple processes associated with it.

Some electric generation is further captured in the NEI point file (with no obvious match to ETS/CEMs facilities) and these emissions are assumed to be associated with facilities that are too small to be included in the ETS/CEMs system. They add a small amount of CO_2 emissions to the final value (~0.014 GtC/year) and are added to the utility sector in the final Vulcan sectoral output.

Purdue University utilizes a power plant (the Wade facility) for generating onsite electricity. In 2002, this facility was not required to report emissions under the Acid Rain legislation and reporting of local air pollutants was not located in the NEI (the reason for this is still under investigation). Hence, this facility was individually added to the electricity generation sector of the Vulcan data product from locally provided data (Robin Ridgway, personal communication).

4.4 Sources of Uncertainty

Recent research has attempted to estimate uncertainties associated with power plant CO_2 emissions in the U.S. through the comparison of two power plant CO_2 emissions data sources [*Ackerman and Sundquist,* 2008]. The first is calculated CO_2 emissions accomplished by the DOE/EIA. This calculation includes data collected from each power plant on the physical consumption of fuel and the heat content of that consumed fuel [*DOE/EIA* 2010]. Hence, the amount of thermal energy consumed at each power plant is calculated (see www.eia.doe.gov/cneaf/electricity/page/eia906_920.html for a legacy of the forms used to collect this information). The consumed thermal energy is combined with a fuel-specific CO_2 emission factor (the quantity of CO_2 emissions per unit energy) provided by the DOE/EIA (see Appendix A of *DOE/EIA* 2010). The second source in Ackerman and Sundquist [2008] is the EPA's eGRID database which combines the ETS/CEMs data described previously in this document with a calculation of CO_2

emissions based on fuel consumption data supplied by the DOE/EIA. This latter data is attributed in eGRID documentation to the same sources as used by the DOE/EIA in its CO_2 emissions estimation. Differences between eGRID and the DOE/EIA, for that subset of facilities for which there is only a fuel calculation-based method available, are presumably due to emission factors and related assumptions.

The Ackerman and Sundquist [2008] study generated subsets of the total facility list based on the type of facility (combined heat & power vs non-CHP, for example) and the method employed to report CO_2 emissions. For all fossil fuel facilities, the study found 5.1% and 11% for average signed and average absolute differences between the two datasets. They found that the largest percentage discrepancies were in cases where the eGRID database reported an ETS/CEMs value and the DOE/EIA reported a fuel-based calculation value. In these cases, they found 5.4% and 16.6% differences in the average signed and averaged absolute comparisons, respectively. Where the facility had a mixture of fuel-based calculation and stack monitoring (as with multiple boilers), the values were 21.7% and 24.4% respectively.

Of course, all of these percent differences do not take into account the size of the emissions themselves but treats all facilities, regardless of size, as equal when generating the percent difference statistics (we call these "unweighted" statistics). When the mass of CO_2 emissions are considered the Ackerman and Sundquist [2008] study concludes that all fossil fuel facilities result in a 3.4% difference (signed difference) in CO_2 emissions for the U.S.. Unfortunately, an absolute difference is not calculated with the CO_2 emissions magnitude included in the analysis.

Assigning an uncertainty to the power plant emissions in the Vulcan data product remains a challenge even with the analysis performed by Ackerman and Sundquist [2008]. Some of the differences found are due to differing methodological treatment between the eGRID and DOE/EIA studies and, as such, is not necessarily a reflection of uncertainty of the ETS/CEMs data *per se*. However, that component of the study comparing facilities utilizing ETS/CEMs devices vs fuel calculations may be considered a proxy for the uncertainty associated with these monitoring devices. This is an imperfect metric because the differences in the two datasets reflect not only the potential uncertainty in ETS/CEMs monitoring and/or fuel consumption amounts, but in the methodological application of emission factors and fuel heat contents. Most importantly, the differences noted in Ackerman and Sundquist [2008] are biases as opposed to random uncertainty. They represent the difference between the mean of two distributions.

Ackerman and Sundquist [2008] found a 1.4% signed difference in the total U.S. CO_2 emissions for those facilities that utilized ETS/CEMs devices and this group of facilities accounted for ~70% of the CO_2 emissions. Combination facilities (accounting for ~20% of emissions) had signed differences of 9.9%. Finally, facilities utilizing fuel calculations in both datasets (accounting for the remaining ~10% of CO_2 emissions) had signed differences of 3.9%. A weighted average of these three categories comes to a signed difference of 3.3% very close to the overall signed difference for all fossil fuel facilities of 3.4%. This hi bias is confirmed by industry studies which repeatedly suggest a hi-bias associated with the ETS/CEMs measurements [*Zimmerman et al.*, 2010; *Berry et al.*, 1998; *ICF consulting*] .

The only studies available regarding random uncertainty are non-peer reviewed industry analysis. Zimmerman et al., [2009] analyzed ETS/CEMs data and concluded that random uncertainties were "at least ±4%-5%". This was due to uncertainties in the determination of the mass flow rate of CO_2 (a combination of CO_2 flow rate and concentration).

Hence, we utilize two forms of uncertainty in our sensitivity analysis. We consider that all of the emissions estimates in the ETS/CEMs dataset to be biased high by 3.4%. In addition we include random uncertainty of 5% (assumed a one-sigma error). Hence, we have a "hi" case and a "low" case. The hi case increases all emissions by +1.6% and the lo case decreases emissions by -8.4%.

5.0 NEI Nonpoint CO_2 Emissions

The area or nonpoint source emissions (dominated by residential and commercial economic sectoral categories though industrial and utility sector emissions exist) are stationary sources that are not inventoried at the facility-level and can be thought of as representing "diffuse" sources within a geographic area. The EPA provides recommendations to state/local agencies on how to collect nonpoint source emissions information and the state/local agencies are given a number of options in forming the basis of the reported information [*ERG* 2001b]. The EPA prefers emissions to be estimated by extrapolating from a sample set of data for the activity to the entire population, but a number of other approaches are allowed including material balance, mathematical models, and emission factors. This means that the method employed will vary by location and this generally implies that the nonpoint source emission information has more intrinsic variability in terms of quality and consistency than either the mobile or point sources emissions estimates.

5.1 Data reduction

The NEI nonpoint database is comprised of a file structure similar to the point sources noted in Figure 2.1.and is comprised of five related files [*USEPA* 2006c]. These five nonpoint files are: 1) transmittal (TR), 2) emission process (EP), 3) emission period (PE), 4) control equipment (CE), 5) emission (EM). The majority of analysis is performed with the emission (EM) data file.

The fundamental nonpoint "unit" as defined for the Vulcan calculations is the "process" which identifies a single SCC in a single county using a single fuel and with a unique Mat IO.

As with the point NEI data, the nonpoint database contains information on processes that do not consume fossil fuels or processes that contain emissions from fossil fuel combustion other than NOx and CO. Hence, the database is reduced to only that data relevant to the CO_2 emissions problem. Currently, the Vulcan inventory utilizes CO emissions in order to compute fuel throughput and subsequent CO_2 emissions. A total of 126,680 processes were retrieved from the nonpoint NEI that report CO emissions.

As with the point source data, a series of reductions are made to this NEI nonpoint CO emissions dataset before processing for CO_2 emissions.

5.1.1. Material and pollutant qualifiers

The nonpoint NEI was reduced by narrowing the database by the process material/fuel and the pollutant produced by that process. Only records that had the following combination were considered:

1) the pollutant code indicated CO emissions present
   AND
2) the material can be found in the Vulcan fossil fuel list (Table 2.1)
   AND
3) the Mat IO identifier was set to "input" ("I") or "null"

The material is identified though a combination of examining the provided NEI material code and SCC code. As with the point NEI data, many material codes were absent ("null" values). In order to explore emission processes for which the fuel or input/output identifier was listed as "null", the NEI input format (NIF) source classification code (SCC) lookup table was used to fill in the missing information and confirm the material classifications provided by the NEI material code.[14] This exercise further identified how the material was used in the emitting process. For materials listed in Table 2.1, only actions identified as "burned" in the SCC lookup table were retained in the Vulcan nonpoint inventory. Other actions such as "processed", "shipped", or "produced" were not considered the purview of the Vulcan CO_2 inventory and these processes were removed.

The SCC was also used to identify the economic sector (residential, commercial, etc). If the sector was not readily identifiable, the process was designated to "unknown". These were later assigned based on final state-level mass balance considerations (see section 5.2.3).

5.1.2. Time period consistency (presentation identical to section 2.1.2)

Emissions reporting in the NEI is made for a small set of different reporting periods or time "types" as follows:

- Type 27: average weekday
- Type 28: average weekend day
- Type 29: average day in period
- Type 30: entire period total

A given process can report emissions for more than one of these time period types. Only processes which identify time type 30 are retained and all others are removed.[15] In most cases the time type 30 is a complete calendar year total amount. These annual emissions are initially divided equally amongst total number of days and hours in the year (for the gridded hourly output). Section 8.0 describes further temporal conditioning of the emissions. Though most facilities with emission time type 30 estimate the emissions for a period of 365 days or 8760 hours per year, certain facilities report timespans for a specific portion of the year making the effective operational number of days in the year less than 365. In such cases, the annual emissions reported by the facility are equally divided amongst the reported number of days/hours rather than 365 days (8760 hours).[16]

Hence, the effective calculation is as follows:

[14] Material codes are actually supplied in multiple fields in the NEI which are often contradictory. The material codes are associated with each pollutant field in addition to provided as an independent field. The materials identified through the SCC lookup are used to override all other material classifications and form the basis of the fuel considered.

[15] Version 2.0 of the Vulcan inventory will utilize the multiple time types to further structure emissions during the emitting period.

[16] However, as noted in Section 8.0, the emissions are forced to be constant for the year prior to performing monthly and hourly downscaling.

$$E(t) = \frac{E_p}{\Delta t_p \times 24} \qquad (5.1)$$

Where E is emissions, t is hourly timestep, p is the reported emissions period, and Δt_p is the number of days in the reported time period (most commonly 365).

There are also cases in the input NEI dataset where the operational start/end date of a process is reported as a year other than 2002. These are a mixture of typos by the reporting agency or examples where a previous year emissions have been "carried over" to the 2002 database. Such records are modified to start on 1/1/2002 and end on 12/31/2002.

5.2 Quantifying CO_2 emissions

With the data reduction complete, each process is examined in order to retrieve information by which an amount of emitted CO_2 can be produced. The CO_2 emission quantity is determined from the provided CO emissions amount in combination with a CO emission factor (EF) and an emission factor for CO_2.

The basic process by which CO_2 emissions are created is theoretically identical to the point source process:

$$C_f^p = \frac{12}{44}\frac{PE_f^p}{PF_f^p}CF_f^p \qquad (5.2)$$

where C, is the emitted amount of carbon, PE is the equivalent amount of uncontrolled CO emissions, p is the combustion process, f is the fuel category, PF is the emission factor associated with the criteria pollutant, and CF is the emission factor associated with CO_2 (provided in Appendix A, Table A.3).

5.2.1 CO Emission factor retrieval

The CO EF used is chosen from two different alternatives (in the following order): 1) the EF provided in the NEI data itself for the particular CO-emitting process, 2) a default EF value (provided in Appendix A, Table A.1). CO emission factors provided in units other than mass per unit energy (applies only to those EFs provided within the NEI) are converted using the standard fuel heat contents provided in Appendix A, Table A.3. Standardization of fuel inputs to the combustion processes is essential to maintain numerical integrity.

5.2.2 CO_2 emissions estimation

Once the material/fuel throughput has been produced, a CO_2 emission factor is applied. Emission factors for CO_2 are based on the fuel carbon content and assume a gross calorific value or high heating value, as this is the convention most commonly used in the US and Canada [*URS*, 2003]. Variation in the carbon content of fuels is not accounted for in this method and hence, these US-average values can introduce error (discussed in section 5.4). Emission factors are reported as units of carbon dioxide as opposed to units of carbon and assume 100% oxidation of fuel carbon to CO_2 for natural gas, 99% for coal and oil [*IPCC* 1996; *DOE/EIA* 2007b].

5.2.3 Suspected database errors and corrections

The state of Illinois provided some CO emission factors for LPG use in the commercial sector that were different from all other emission factors for this fuel in this sector. They listed some values as "0.19 lbs CO/e3gals" versus the consistent reporting in all other states of 1.9 lbs CO/e3 gals. This latter value is also consistent with the default value. These instances were changed from 0.19 to 1.9 lbs CO/e3gals.

The state of Alabama provided CO emission factors for bituminous/subbituminous coal use in industrial, residential, and commercial of 0.6 lbs CO/e6ft^3, 6 lbs CO/e6ft^3 and 11 lbs CO/e6ft^3, respectively. This was the only instance of reporting for coal that utilized volumetric units in the denominator. Attempts to convert these units to these to mass units returned emission factors that were clearly in error. In these cases, the Vulcan default CO emission factors were used.

Emissions for SCC 210300500 utilizing residual oil in the commercial sector within the state of Alabama report emission units in "tons". Comparison to other state values for the same fuel and technology suggest that this is an input error and the correct units should be "lbs". The reporting unit for these emissions has been changed systematically to lbs.

Data reported to the nonpoint NEI from across the residential sector in the state of Alabama has been discovered to contain errors [*Cole*, 2008]. It remains unclear what caused the reporting error but CO emissions were discovered to be roughly 5x too large which translated into CO_2 emissions also being roughly 5x too large. Hence, all Alabama residential emissions originating in the nonpoint data files have been reduced by a factor of 5. It is unclear whether or not other reporting anomalies occurred for the state of Alabama (other than those specifically denoted here and in other sections), but the Vulcan team recommends caution when interpreting the Vulcan CO_2 emissions for Alabama.

The state of Connecticut reported incorrect units on their CO emission factors for all natural gas processes. They reported as lbs/e3ft^3 when the only rational denominator would be e6ft^3.

The nonpoint dataset included emission factors that were identified as having "parsing" errors. Emission factors were clearly identified as having a leading "30" in the first two positions in the provided number. These were parsed incorrectly from the time type (the previous field) and this error showed up consistently within a state/sector/fuel combination. In these cases, the leading "30" was stripped from the provided emission factor and the remaining emission factor used in the calculations. There was one case: LPG (mat code 178) in which the leading "30" was real and not an artifact of parsing. This was determined from knowledge of the typical emission factor for LPG. In this instance the leading "30" was not stripped from the provided emission factor.

Emissions for SCC 2104006000 in FIPS 45045 (county Greenville, South Carolina) constitute a variation on the above correction. The original provided emission factor was "30400 lbs/e6ft^3". After removing the leading "30" the resulting emission factor is 400 lbs CO/e6ft^3. Comparison to other state values for the same fuel and technology suggest that this is an input error and the correct emission factor value should be 40 lbs CO/e6ft^3. It is worth noting that the Vulcan default emission factor would be 65 lbs CO/e6ft^3 further strengthening the conclusion that 400 lbs CO/e6ft^3 is an input error.

Emissions for SCC 2104006000 (residential NG; all combustor types) in the state of Utah report an emission factor of 40 CO lbs/e6ft^3. Normalization by population clearly shows a problem with this emission factor and suggests that the emission factor is too low. It is not currently known what method the state of Utah employed to quantify their nonpoint source emissions of CO. In order to generate per capita values that are consistent with surrounding states, the Vulcan default emission factor of 65 lbs CO/e6ft^3 has been used.

A number of records had no sectoral assignment. Sectoral assignments were made through comparison of the state totals constructed here with those coming from the DOE EIA (reference). All unknown sectoral emissions are assigned to the commercial sector for the states of FL, MI, and NM except the unknown emissions in TN are assigned to the industrial sector. The unknown emissions in California are assigned to the nonroad sector (5.9624 MtC/year) and must be performed offline to the main code infrastructure due to the fact that the nonraod sector is not fully incorporated into the Vulcan code.

5.3 Spatial Processing

Nonpoint CO_2 emissions are defined within the NEI at the county-scale and the annual temporal scale. Downscaling of the residential and commercial emissions (in addition to the small amount of industrial sector and electricity production emissions) reported in the nonpoint NEI files are performed through use of census tract-level spatial surrogates prepared by the Environmental Protection Agency [*DynTel*, 2002]. The spatial surrogates used are a combination of different spatial datasets such as Landsat 7 land-use classification and Federal Emergency Management Agency's "HAZUS" data. For the purposes of downscaling the Vulcan emissions, multiple residential, multiple commercial and multiple industrial building classes were combined into a single total floor square footage quantity for the residential, commercial and industrial class at the census tract. Each county's CO_2 emissions are allocated to the US Census tracts within the county according to weighting by the amount of residential/commercial/industrial building square footage within each Census tract.

A small amount of electricity production was present in the nonpoint data source. This occurred in the states of California, New York, New Mexico and Nevada. These county-level emissions were assigned to the centroid of the county as emission points.

This can be further transformed to a 10 km x 10 km grid (see section 7.0) by further allocating the Census tract CO_2 emissions to the 10 km x 10 km grid through area-based weighting (the area-based percent share of sub-portions of each grid cell residing in different tracts). This provides each 10 km x 10 km gridcell with a residential/commercial/industrial CO_2 emission amount that is based on the share of residential/commercial/industrial building square footage.

5.4 Sources of uncertainty

The computation of CO_2 emissions in the non-point data source includes a number of self-reporting uncertainty sources which we designate here as "categorical" and "numerical" uncertainties. Categorical uncertainties include the following:

1. Time period designation
2. Fuel designation
3. SCC designation

Errors in these information sources imply that the state or county office tasked with estimating CO emissions mis-categorized the time period for which emissions were estimated, the fuel being consumed or the SCC code for which the pollutant emissions were estimated. Estimating the liklihood that categorical errors were made is difficult. Quantifying how that categorical error would impact the final CO_2 emission estimate is also difficult. Given the nature of the reporting (county and state environmental professionals tasked with complying with air quality regulatory law) and the difficulty associated with estimating the potential errors, this study considers these sources of uncertainty to be low. Nonetheless, uncertainty associated with category 3. is attempted below.

The numerical sources of uncertainty in the CO_2 calculation include the following:

1. Pollutant emission quantity reported
2. Provided pollutant emission factor
3. Default pollutant emission factor
4. CO_2 emission factor (carbon content of fuel)
5. Heat content conversions

Among these uncertainty sources, 3 through 5: the CO_2 emission factor, the heat content, and the default pollutant emission factor, can be quantified with available data. The first two uncertainty sources are difficult to quantify. Unlike the categorical uncertainties, however, these are both much more likely to contain errors and those errors would have a direct and potentially large impact on the CO_2 emissions estimation.

In order to provide a first order sense of the impact of the quantifiable components of the last three sources of numerical uncertainty, we take a sensitivity approach. The sensitivity approach asks the question: how wrong could the CO_2 emissions estimate be, given typical variations in the underlying sources of uncertainty? These variations are conservatively interpreted as a one sigma spread on the central estimate of the CO_2 emissions (though the variations described below are likely higher than a true one-sigma spread of an actual sample of underlying factors).

5.4.1 Pollutant emission factor

For the default pollutant emission factors, a range of values is used as a form of sensitivity. The range reflects values in the WebFire database as well as a range of values that are self-reported in the NEI point database itself. For example, for commercial non-point natural gas combustion, values ranging from 15 lbs CO/e^6ft^3 to 84 lbs CO/ e^6ft^3 are included in the sensitivity test. These represent the highest and lowest possible values for CO emissions/unit fuel available in the webfire/NEI combined datasets. The lower CO emission factor will lead to a greater amount of fuel consumed and a greater CO_2 emission. Whereas the high CO emission factor will do the opposite (result in lower CO_2 emissions). These extreme ranges are considered 2-sigma errors and hence, the distance between the central EF and the hi and lo extremes are halved to arrive at a one-sigma value.

5.4.2 Heat and carbon content

As described in section 5.2.1, pollutant emissions that are reported in mass or volume units are first converted to emission per unit thermal content (per 10^6 btu). This requires the use of a heat content conversion which is dependent upon the fuel considered as provided in Appendix A, Table A.3. This alters equation 5.2 as follows,

$$C_f^P = \frac{12}{44}\frac{PE_f^P}{PF_f^P} HC_f CF_f^P \qquad (5.3)$$

where HC_f is the heat content which is only dependent upon the fuel consumed in the combustion process.

Fuel heat contents can vary substantially and are generally associated with the parent fuel formation/location (coal mine, oil well, etc). Variation (one standard deviation) in heat content is derived from fuel samples and is described and quantified in DOE/EIA [2007b]. The largest variation in heat content is found for coal and is derived from sampling coal from each producing state destined for power plants in the United States. Depending upon coal rank, variation (standard deviation about the mean value) in heat content ranges from 4 to 12%. Additional analysis was performed here by quantifying the variation in coal delivered to power plants using the DOE/EIA form 423 database and consistent results were found [*DOE/EIA*, 2002a; 2002b].

Variation in heat content for the remaining fuel categories are partly derived from the DOE/EIA form 423 database or quantitatively identical to the variation assigned for the carbon coefficient (CO_2 emission factor). Variation in the CO_2 emission factor is similarly derived from DOE/EIA [2007b]. The largest variation is for refinery gases (33%). Variation in the heat content and carbon content of fuel are generally correlated. We treat them as uncorrelated and additive. This is likely a conservative approach. These stated variations are considered a one-sigma spread.

5.4.3 Utilizing only default pollutant EFs

Finally, the provided pollutant emission factor can be tested somewhat by substituting all provided pollutant emission factors with default factors in all instances. This bypasses both the acceptance of provided emission factors and the SCC-specific WebFire emission factor lookup and defaults to the values in Appendix Table A.1 and Table A.2.

5.4.4 Summary of sensitivities

Hence, we have four sensitivity tests:

1. vary the default pollutant emission factors (hi and lo cases)
2. vary the fuel heat content (hi and lo cases)
3. vary the fuel carbon content (hi and lo cases)
4. utilize only default emission factor

The first three can be quantified in a directional sense to arrive at a "hi" and "lo" CO_2 emissions estimate whereas test 4 will cause results to vary in both numerical directions. Results are produced which isolates the impact of each of these tests and the combination of all four sensitivity tests. The combination sensitivity test is as follows:

Low-end pollutant emission factors + hi-end heat content + hi-end CO_2 EF.

This combination senstivity test is run with and without utilization of default emission factors.

6.0 Transportation CO_2 Emissions

The transport sector contains three separate components: onroad emissions (mobile transport using designated roadways), nonroad emissions (e.g. boats, trains, ATVs) and emissions associated with air travel (airports and airplanes).

6.1 Onroad Sources

The onroad mobile portion of the Vulcan CO_2 emission inventory is constructed from a series of existing databases and modeling efforts to generate monthly carbon dioxide (CO_2) emissions for the year 2002 at the spatial scale of a U.S. county for the entire U.S. The emissions are based on a combination of county-level data from the National Mobile Inventory Model (NMIM) County Database (NCD) and standard internal combustion engine stoichiometry from the Mobile6.2 combustion emissions model [*USEPA* 2005b; *USEPA* 2001; *Harrington* 1998; *Gurney et al.*, 2009]. The NMIM NCD is part of the NMIM software package produced by the EPA [*USEPA* 2005d]. In addition to estimating CO_2 emissions from transportation, the NMIM provides the information necessary to estimate criteria air pollutant emissions and much of the data volume is devoted to this objective.

Further spatial allocation is performed in order to place these emissions onto U.S. roads and onto the common 10 km x 10 km spatial grid (see Section 7.0). Temporal allocation, based on traffic count data, is performed to place these emissions into hourly patterns [*Mendoza et al.*, in preparation].

6.1.1. Vehicle Miles Traveled

The Vulcan onroad transportation emissions calculation utilizes the total vehicle miles traveled (VMT) from the National Mobile Inventory Model (NMIM) County Database (NCD) in which the data is provided for each combination of vehicle type, road type, county, and month for the year 2002 (see Appendix B for tabular information describing these elements).

The VMT data has been compiled from historical data obtained from the Federal Highway Administration's (FHWA) Highway Performance Monitoring System (HPMS) [*FHWA* 2005]. The data contained in HPMS is obtained from a collaboration between State Highway Agencies (SHAs), local governments, and metropolitan planning organizations (MPOs). The VMT data is a mixture of "universe", "expanded sample", and "summary" data. Universe data refers to a limited set of data items reported for the entire public road system, either as individual or grouped road length sections. For example, the data for the entire interstate system would be considered universe data. Sample data is defined as data reported for a randomly selected sample of roadway links in a road system. This is the case for minor arterial, and collector roads in both urban and rural systems. These sections are generally a fixed set of road segments that are monitored year to year to create a sample. Summary data is data reported in aggregate form by road type. In the case of minor collector and local roads, states are not required to report Annual Average Daily Traffic (AADT) except for National Highway System (NHS) sections. Table B.5 (Appendix B) shows the data categories for selected HPMS data.

Reported HPMS data represent conditions as of December 31st of the data year and State highway agencies are required to submit Linear Referencing System (LRS) data and any updates on a yearly basis. An LRS is used to obtain the length of road sections. While there may be other participants in the collection and reporting process, the ultimate responsibility for the accuracy and timely reporting of HPMS data lies with each individual State highway agency. Sample Daily Vehicle Miles Traveled (DVMT) are obtained by multiplying standard sample section AADT by the section length and by the standard sample expansion factor. The expansion factor is an annual growth factor used if the AADT is not current for the particular data year and older AADTs are used. As outlined in FHWA [2005], the AADT submitted for each road section as part of HPMS reporting must meet the following criteria (quoted from document):

a. Classification data are representative of specific functional systems.
b. Each season of the year is represented in the development of axle correction factors.
c. Classification sessions are long enough to account for the changes in vehicle mix from day to day. The Traffic Monitoring Guide (TMG) recommends that vehicle classification sessions be at least 48-hours. Data for less than 24 continuous hours is not appropriate.
d. The total volume of vehicles observed is at least equal to that for an average day.
e. Classification counts are well distributed among rural and urban locations.
f. Classification counts are collected, at a minimum, over a 3-year cycle, one-third of the counts per year.
g. There are sufficient classification categories to represent vehicles with two to seven axles.

Though the NCD reports VMT at the county level, the county values are often an estimate derived from state-level data which is allocated to the counties by road type and vehicle type.

Roads can first be broadly classified into "rural" and "urban" road types. Rural VMT is quantified at the state level for the following six road types:

1) interstate
2) other principal arterial
3) minor arterial
4) major collector
5) minor collector
6) local

The county-level rural interstate VMT is derived from the state level total via a simple fractional apportionment based on the relative mileage,

$$VMT_C^{RI} = VMT_S^{RI}\left(\frac{L_C^{RI}}{L_C^{RI}}\right) \tag{6.1}$$

where VMT_C^{RI} is the rural interstate (*RI*) VMT in county *C*, VMT_S^{RI} is the total rural interstate VMT in state *S*, L_C^{RI} is the total rural interstate mileage length in county *C*, and L_S^{RI} is the total rural interstate mileage in state *S* [*FWHA* 2003].

All other rural road type VMT is derived from the state level total via a fractional apportionment based on relative population,

$$VMT_C^{RX} = VMT_S^{RX}\left(\frac{P_C}{P_S}\right) \tag{6.2}$$

where VMT_C^{RX} is the VMT on rural road type *X* in county *C*, VMT_S^{RX} is the total VMT on rural road type *X* in state *S*, P_C is the rural population in county *C* (county must have some length of road type *X*, otherwise P_C is zero), P_S is the total rural population in state *S* (the sum of only those counties with non-zero mileage from rural roadway type *X*) [*USCB* 2004].

The 2002 rural population was estimated at the county level by multiplying the Census Bureau's 2002 county-level intercensal population estimates by the ratio of each county's rural population in the 2000 Census to its total rural plus urban population.

Urban VMT is quantified for the following six roadway types:

1) interstate
2) other freeways
3) other expressways
4) other principal arterial
5) collector
6) local

The approach to quantifying county-level urban VMT by road type considers urban areas in two different classifications: 1) "large" – greater than 50,000 residents, and 2) "small" – less than 50,000 residents. Table HM-71 in FHWA [2003] provides the VMT from all large urban areas, by road type, in the U.S.. Many of these large urban areas stretch across multiple states and multiple counties. Hence, in order to quantify the county-level VMT from this large urban area data, the EPA distributes the large urban area's VMT according to the fraction of the urban area's population in each county,

$$VMT_C^{U_AX} = VMT^{U_AX}\left(\frac{P_C^{U_AX}}{P^{U_AX}}\right) \tag{6.3}$$

where $VMT_C^{U_AX}$ is the VMT of large urban area U_A on road type *X* in county *C*, VMT^{U_AX} is the total VMT of large urban area U_A on road type *X*, $P_C^{U_AX}$ is the population of large urban area U_A in county *C* for road type *X* (the county must have some length of road type *X* in large urban area U_A, otherwise $P_C^{U_AX}$ is zero), P^{U_AX} is the population of large urban area U_A for road type *X* (the sum of only those counties with non-zero mileage in large urban area U_A from road type *X*) [*FHWA* 2003; *USCB* 2004b].

In order to quantify VMT at the county-level for the small urban areas, the EPA first quantifies the total small urban area VMT within each U.S. state by subtracting the state-total large urban area VMT (the sum of all VMT in large urban areas from table

HM-71 in *FHWA* [2003]) from the total urban area VMT within each state (found in table VM-2 in *FHWA* [2003]). This provides a state total VMT for small urban areas disaggregated by the different urban road types.

The county's share of the small urban VMT on road type X is,

$$VMT_C^{uX} = VMT_S^{uX}\left(\frac{P_C^{uX}}{P_S^{uX}}\right) \tag{6.4}$$

where VMT_C^{uX} is the VMT of small urban areas in county *C* on road type *X*, VMT_S^{uX} is the VMT of small urban areas in state *S* on road type *X* (calculation described in previous paragraph), P_C^{uX} is the small urban population in county *C* for road type *X* (the county must have some length of road type *X* in small urban areas, otherwise, P_C^{uX} is zero) and P_S^{uX} is the state-level small urban population in state *S* for road type *X*.

In both the large urban and small urban VMT allocation schemes, urban population values are needed at different scales and for the year 2002. Hence, the EPA utilizes the following approach in order to estimate 2002 small and large urban population values.

The census 2000 state-level large urban population was obtained by summing the large urban area population for all counties within a state [*USCB* 2004b]. This population was then subtracted from the census state-level total urban population in 2000 to obtain the state-level small urban population [*UCSB* 2004a].

$$P_S^u = P_S^T - P_S^U \tag{6.5}$$

Where P_S^u is the state-level small urban center population, P_S^T is the state-level total urban population, and P_S^U is the state-level large urban center population.

The county-level small urban population in 2002 was calculated as the total county-level urban population in 2002 multipled by the ratio of small to total urban county-level population in 2000:

$$P_{C2002}^u = P_{C2002}^T\left(\frac{P_{C2000}^u}{P_{C2000}^T}\right) \tag{6.6}$$

Where P_{C2002}^u is the 2002 small urban population for county *C*, P_{C2002}^T is the 2002 intercensal total population for county *C*, P_{C2000}^u is the 2000 small urban population for county *C*, and P_{C2000}^T is the 2000 total county population for county *C* for 2000.

In addition to VMT designation by county and road type, the NCD contains the 2002 VMT allocated to the 28 MOBILE6 vehicle types. The allocation uses the distribution of the 2002 VMT among the six HPMS vehicle types (found in Table VM-1 of *FHWA* [2003]) and a mapping of these HPMS vehicle categories to the 28 MOBILE6 vehicle types, provided by the EPA's Office of Transportation and Air Quality (OTAQ) [*OTAQ* 2007]. The VMT totals for each of the six HPMS vehicle categories (passenger cars, motorcycles, other 2-axle 4-tire vehicles, single unit 2-axle 6-tire or more trucks, combination trucks, and buses) were calculated as a fraction of the total VMT. This calculation was performed separately for five groups of roadway classes. EPA assigned each of the 28 MOBILE6 vehicle types to one of the 6 HPMS vehicle categories (see Appendix B, Table B.7). Using the default MOBILE6 VMT fractions for 2002, the MOBILE6 VMT fractions were renormalized among all MOBILE6 vehicle types mapped to a given HPMS vehicle category. Then the HPMS VMT fractions for each roadway group were separately multiplied by the renormalized MOBILE6 VMT fractions for all MOBILE6 vehicle types included within a given HPMS vehicle category. Each of the VMT records in the 2002 VMT database, at the county/roadway type level of detail was multiplied by the fraction of VMT in each of the corresponding MOBILE6 vehicle type categories to obtain total annual VMT at the county/roadway type/MOBILE6 vehicle type level.

The VMT for twenty-eight MOBILE6 vehicle classes are aggregated to the more commonly used twelve Source Classification Code vehicle classes. The aggregation map is shown in Appendix B, Table B.8.

Monthly values of the VMT for each county/vehicle/road type combination are achieved by multiplying the annual VMT (in million of miles traveled) by the county/vehicle/road-specific monthly allocation factors (twelve fractions) supplied within the NCD. 157 counties out of 3,142 (4.99%) have a specific VMT monthly allocation structure. These proportions are obtained by local transit authorities and estimate the traffic volume and disaggregate by road and vehicle type. If no county-specific values are found, a standard NCD monthly allocation table is used. This standard allocation table is produced from accepted national average AADT values (monthly allocation specific to road class and vehicle type) for a particular road section multiplied by the road section length if a state did not report specific values. Appendix B, Table B.9 shows the seasonal VMT factors describing the VMT allocation by season and Appendix B, Table B.10 shows the distribution of these seasonal factors into monthly percentages of total annual VMT weighted by length of month.

Little county-specific monthly structure is available and the average AADT values are used in nearly all counties, contributing uncertainty to the monthly VMT time structure.. Uncertainty in VMT allocation arises due to the use of national average monthly allocation for over 95% of the counties. Uncertainty in the VMT itself is due to estimation methods used by local and federal agencies. Factors such as malfunctioning measuring devices, heterogeneity of the spatial allocation of measuring devices, and data gaps play a role in the errors associated with the VMT and its allocation.

6.1.2 CO_2 Emission Factors

To obtain mobile CO_2 emission factors (grams/mile driven), EPAs MOBILE6.2 mobile combustion model was utilized [*USEPA* 2001; *Harrington* 1998]. MOBILE6.2 uses inputs comprising different transport scenarios in order to obtain the appropriate mobile CO_2 emission factors. A scenario consists of a particular vehicle type combined with a particular road type (which determines mean travel speed; see Appendix B, Table B.3). MOBILE6.2 emission factors are derived from emissions tests conducted under standard conditions such as temperature, fuel, and driving cycle. Emission factors further assume a pattern of deterioration in emission performance over time based on results of standardized emission tests [*USEPA* 2003]. There are twenty-eight vehicle types and twelve road types and in order to encompass all of them, 168 MOBILE6.2 scenario runs would be required for every US county. Instead, eighteen scenarios were run which have been historically used in NEI datasets and encompass the entirety of the possible scenarios while retaining flexibility (Appendix B, Table B.3).

Out of 3,141 counties in the US, 468 counties have fleet information based on state vehicle registration data. In addition to these individual county-level reports, 234 counties reported fleet data that utilize statewide average fleet estimates rather than county-by-county estimates. States for which either the entire or individual counties reported fleet information are Arizona (4), Delaware (10), DC (11), Illinois (17), Iowa (19), Kentucky (21), Maryland (24), Massachusetts (25)*, Minnesota (27), New Jersey (34), New York (36), Ohio (39), Oregon (41), Rhode Island (44), Tennessee (47), Texas (48), Utah (49), Vermont (50)*, Virginia (51)*, Washington (53)*, Wisconsin (55)*. The asterisk denotes those states for which only statewide average fleet information was available. Consequently about 78% of the counties use a default fleet based on a national average which has a fixed proportion of age cohorts for each vehicle class [*USEPA,* 2001].

The CO_2 emission factors calculated above represent the estimated average grams per mile of CO_2 emitted by a vehicle in a particular road type for a county. Each county has a VMT value for each available road type and vehicle type combination. The product of VMT and the corresponding CO_2 emission factor yields the county CO_2 emissions for each road type and vehicle type combination. The twenty-eight vehicle classes are then collapsed to a simpler and more commonly-used twelve classes using Appendix B, Table B.4. Six of the vehicle types are light duty and six are heavy duty. Five vehicle types use gasoline and seven use diesel as their fuel. Each county-specific fleet is therefore defined as the combination of the vehicle type mix and their respective VMT. The combination of the fleet, VMT and emission factors results in a unique set of CO_2 emissions for each vehicle type, road type, and month within each county.

6.1.3 Time structure

The monthly/county/road/vehicle-specific CO_2 emissions are further subdivided in time using traffic count data from the Federal Highway Administration.

6.1.3a Traffic data records

Hourly traffic data at monitoring stations were obtained from the Federal Highway Administration's (FHWA) permanent automatic traffic recorder (ATR) network. Permanent traffic recorder data is submitted by the state managing the ATR to the FHWA within 20 days after the closing of each calendar month [www.fhwa.dot.gov/ohim/tvtw/tvtfaq.cfm]. The data from the ATRs are compiled into a monthly publication, *Traffic Volume Trends* (TVT) by the FHWA Office of Highway Policy Information [*FHWA* 2001b]. The data records from the TVT are divided into four types: station description data, traffic volume data, vehicle classification data, and truck weight data. Each type of data has its own individualized record format and certain data items are common to all four types of records. For example, all records contain a six-character station identification. This allows States to use a common identification system for all traffic monitoring stations. This identification system combined with the latitude and longitude values enable geolocation of the stations. This allows traffic data to be overlaid on the National Highway Planning Network (NHPN) and similar systems [*FHWA* 2001a].

In the Vulcan Project, we utilize the ATR data from the years 2007 and 2008 – two recent and relatively complete years of data. These data are combined as described below to create a "climatology" of traffic space and time distribution allocation. Two of the four data types present in the ATR data are used in the Vulcan Project to distribute onroad emissions over time: the station description data and the traffic volume data. The station description data contains all the information required to identify a station's location such as FIPS State Code, Station ID, Direction of Travel, Lane of Travel, Latitude, and Longitude coordinates. Other information such as the sensor types is also present. The full list of fields can be found in Table 6.1.

Table 6.1: Station Description Record

Field	Columns	Width	Description
1	1	1	Record Type
2	2-3	2	FIPS State Code
3	4-9	6	Station ID
4	10	1	Direction of Travel Code
5	11	1	Lane of Travel
6	12-13	2	Year of Data
7	14-15	2	Functional Classification Code
8	16	1	Number of Lanes in Direction Indicated
9	17	1	Sample Type for Traffic Volume
10	18	1	Number of Lanes Monitored for Traffic Volume
11	19	1	Method of Traffic Volume Counting
12	20	1	Sample Type for Vehicle Classification
13	21	1	Number of Lanes Monitored for Vehicle Class
14	22	1	Method of Vehicle Classification
15	23	1	Algorithm for Vehicle Classification
16	24-25	2	Classification System for Vehicle Classification
17	26	1	Sample Type for Truck Weight
18	27	1	Number of Lanes Monitored for Truck Weight
19	28	1	Method of Truck Weighing
20	29	1	Calibration of Weighing System
21	30	1	Method of Data Retrieval
22	31	1	Type of Sensor
23	32	1	Second Type of Sensor
24	33	1	Primary Purpose - NEW
25	34-45	12	LRS Identification - NEW
26	46-51	6	LRS Location Point - NEW
27	52-59	8	Latitude - NEW
28	60-68	9	Longitude - NEW
29	69-72	4	SHRP Site Identification - NEW
30	73-78	6	Previous Station ID
31	79-80	2	Year Station Established

32	81-82	2	Year Station Discontinued
33	83-85	3	FIPS County Code
34	86	1	HPMS Sample Type
35	87-98	12	HPMS Sample Identifier
36	99	1	National Highway System - NEW
37	100	1	Posted Route Signing
38	101-108	8	Posted Signed Route Number
39	109	1	Concurrent Route Signing
40	110-117	8	Concurrent Signed Route Number
41	118-167	50	Station Location

The traffic volume data contains the actual vehicle count from each station. The FIPS State Code and Station Identification fields are used to identify the location of the station. The other fields identify the direction of travel, lane of travel, year, day, month, and the hourly traffic counts. Tables 6.2 and 6.3 show the possible values for direction, and lane of travel respectively. Table 6.4 shows the full list of fields.

Table 6.2: Direction of Travel

Code	***Direction***
1	North
2	Northeast
3	East
4	Southeast
5	South
6	Southwest
7	West
8	Northwest
9	North-South or Northeast-Southwest combined (ATR stations only)
0	East-West or Southeast-Northwest combined (ATR stations only)

Table 6.3: Lane of Travel

Code	***Lane***
0	Data with lanes combined
1	Outside (rightmost) lane
2-9	Other lanes

Table 6.4: Hourly Traffic Volume Record

Field	Columns	Length	Description
1	1	1	Record Type
2	2-3	2	FIPS State Code
3	4-5	2	Functional Classification
4	6-11	6	Station Identification
5	12	1	Direction of Travel
6	13	1	Lane of Travel
7	14-15	2	Year of Data
8	16-17	2	Month of Data
9	18-19	2	Day of Data
0	20	1	Day of Week
11	21-25	5	Traffic Volume Counted, 00:01 - 01:00
12	26-30	5	Traffic Volume Counted, 01:01 - 02:00
13	31-35	5	Traffic Volume Counted, 01:01 - 02:00
14	36-40	5	Traffic Volume Counted, 03:01 - 04:00
15	41-45	5	Traffic Volume Counted, 04:01 - 05:00
16	46-50	5	Traffic Volume Counted, 05:01 - 06:00
17	51-55	5	Traffic Volume Counted, 06:01 - 07:00
18	56-60	5	Traffic Volume Counted, 07:01 - 08:00
19	61-65	5	Traffic Volume Counted, 08:01 - 09:00
20	66-70	5	Traffic Volume Counted, 09:01 - 10:00
21	71-75	5	Traffic Volume Counted, 10:01 - 11:00
22	76-80	5	Traffic Volume Counted, 11:01 - 12:00
23	81-85	5	Traffic Volume Counted, 12:01 - 13:00
24	86-90	5	Traffic Volume Counted, 13:01 - 14:00
25	91-95	5	Traffic Volume Counted, 14:01 - 15:00
26	96-100	5	Traffic Volume Counted, 15:01 - 16:00
27	101-105	5	Traffic Volume Counted, 16:01 - 17:00
28	106-110	5	Traffic Volume Counted, 17:01 - 18:00
29	111-115	5	Traffic Volume Counted, 18:01 - 19:00
30	116-120	5	Traffic Volume Counted, 19:01 - 20:00
31	121-125	5	Traffic Volume Counted, 20:01 - 21:00
32	126-130	5	Traffic Volume Counted, 21:01 - 22:00
33	131-135	5	Traffic Volume Counted, 22:01 - 23:00
34	136-140	5	Traffic Volume Counted, 23:01 - 24:00
35	141	1	Restrictions

The last field in Table 6.4, "Restrictions", was used to evaluate the quality of the data. A value of "0" means that the data from the station has no restrictions, while a value of "1" or "2" show that there was either construction or a malfunction of the device. For the years 2008 and 2007, all the data had a value of "0" for this field and none was discarded.

6.1.3.b Data conditioning and gap filling

The ATR data for 2007 and 2008 had 5809 and 5774 unique stations, respectively. There were a small number of unique stations in each year with most being identical. Furthermore, after combining the two years, there were only 4772 stations that could be geolocated using latitude and longitude coordinates. Some stations are located at intersections and have data for more than one road type, raising the number of unique station/road type combinations to 4883.

The raw data was present in the format outlined in Table 6.4. There were 3,407,991 individual records for 2007 and 3,662,160 individual records for 2008. A record details a full 24-hour cycle of vehicle counts for a specific lane of traffic traveling in a specific direction for a particular station in a particular day. The traffic counts for all the lanes for each direction and all the directions for a single station were summed in order to obtain a 24-hour cycle for all lanes and directions combined. For each station the maximum number of lanes and directions was found and any daily sum record not containing data from all lanes and directions was removed. This was done in order to only take days that had a complete 24 hour traffic cycle. This process resulted in an annual file containing the traffic counts only for days that were fully populated with respect to the maximum number of lanes and directions. An external file was created that listed the days that were present for each station as a look-up table that will be used in the following step. Some stations are located at the intersection of two road types and, as such, have data for two different road types. Consequently, each station is uniquely identified by the state FIPS code, station ID, and road type. The data for the different road types within a station are kept separate.

Once the station totals file was created, an annual file of hourly totals for each station using data from both 2007 and 2008 was created. This file is used to create the 2002 hourly traffic pattern. There are two temporal allocation challenges when combining 2007 and 2008 data to make a 2002 hourly file; the starting day for each year, and the leap-year extra day for 2008. Both of these problems were solved using a day offset method.

Both 2007 and 2002 have 365 days except 2007 starts on Monday (January 1st) while 2002 starts on Tuesday. To account for this, 2007 data is offset by one day which means that the data for January 1st is not used and instead the first day is a Tuesday just like 2002. This offset is kept constant throughout the year which means that the last day of data from the 2007 dataset, December 31st, thus matches 2002's December 30th. The year 2008 also starts on a Tuesday, like 2002, and there is no offset for January and February. However, there is a 1-day offset due to the leap year which means that February 29th of 2008 maps to March 1st 2002. This means that the data for December 31st 2008 is not used at all like January 1st 2007.

The hourly totals for each individual month are calculated at each station by looking at each day of each month and obtaining hourly data for each day, when available, from either 2007 or 2008. If a certain day of a month has data for only one of the two years, that data is directly imported into that month's hourly data. If there is data present from both years, the average hourly value is calculated for each hour of that day and imported into the month's hourly data. Once the month is filled with available data from 2007 and 2008, a sample week is created from the data collected. This sample week is generated from the average hourly values from the hourly data collected in the previous step. The sample week is then used to fill in any missing days in the month in order to obtain a full month worth of data.

In the case where there is not a full week's worth of data that can be used to create the sample week, a linear interpolation gap-filling method is employed. A station can not have more than six months of data missing in order for gaps to be filled. The six months can be continuous or there can be several groups of missing months. If there are more than six months missing, the station is not used in the analysis.

Only 4561 stations fulfill the criteria of having six or less months of missing data. Once a station is accepted, each gap is marked by finding the month prior to the beginning of the gap and the subsequent month to the last month in the gap. At times this may involve “wrapping-around” the year. For example, if a gap extends from January to March, the prior month would be December and the posterior map would be April. A sample week is created for the months bracketing the gap in order to have a basis for the linear interpolation. This sample week is obtained by averaging the values for each hour of the week for each week. This means that for each month the 1^{st} hour of Monday will consist of the average of the 1^{st} hour of all the Mondays in the month.

Once the sample weeks for the prior and posterior months are created, the number of each day of the week missing within the gap is obtained. For example, a month such as March with 31 days would have 3 days that are missed 5 times and the remaining 4 days will be missed only 4 times. The linear interpolation is formed by taking the difference in traffic counts for each hour of the day of the sample week for the month prior and posterior to the gap, and dividing that value by the number of missing days and creating the linear “step”. The missing days are then filled for each subsequent same day and hour (such as the 1^{st} hour of each Monday) by increasing or decreasing the value of the prior month’s weekly traffic count by the linear interpolation step. Once all the gaps are filled for a station, fractions are created for each hour by taking the value of each hour and dividing by the sum of values for all the hours.

6.1.3c Application of ATR data

The onroad mobile fossil fuel CO_2 emissions obtained from NMIM NCD/Mobile6.2 process are provided at the monthly and county scale disaggregated by road and vehicle type. The ATR data is used to further downscale these estimates in space and time.

For each road type category (“functional classification” in Table 6.5), the spatial distribution of traffic monitoring stations is unevenly distributed across the country. In order to objectively allocate monthly CO_2 emissions to individual hours, a “nearest-neighbor” algorithm utilizing Thiessen polygons, shown in Figure 6.1, was utilized. Due to the GIS road layer having only six road type classifications while the ATR stations have twelve road types, ATR road type classifications were combined to make six road classifications as shown in Table 6.5. The available number of usable stations is also listed. As can be seen, the number of stations located in urban collector roads is very small compared to the other road types. Consequently, it was decided to combine the stations for urban arterial and urban collector roads and create Thiessen polygons based on the combination of the two road types. As a result both road types have the same time structure. Several of the stations in these two road classifications are present in both the arterial and urban collector class because they are located at intersections. Hence, combining these two road classifications the purposes of allocating the time distribution has limited impact on the results.

Table 6.5: Functional Classification Code

	Code	Functional Classification	GIS Road Type	GIS Road Layer	Available
RURAL	01	Principal Arterial - Interstate	1	Rural Interstate	610
	02	Principal Arterial - Other	2	Rural Arterial	1642
	06	Minor Arterial			
	07	Major Collector	3	Rural Collector	400
	08	Minor Collector			
	09	Local System			
URBAN	11	Principal Arterial - Interstate	4	Urban Interstate	992
	12	Principal Arterial - Other Freeways or Expressways			
	14	Principal Arterial - Other	5	Urban Arterial	821
	16	Minor Arterial			
	17	Collector	6	Urban Collector	96
	19	Local System			

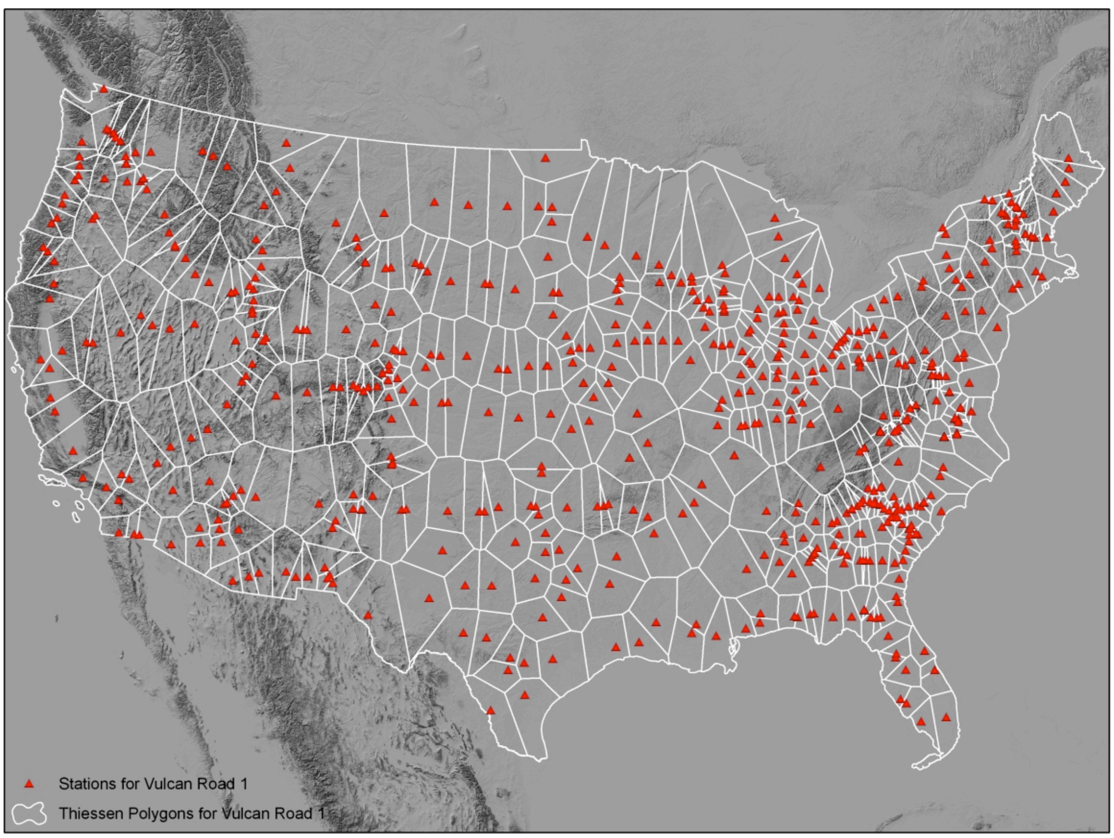


Figure 6.1 – Thiessen Polygons for Road Type 1 (principal arterial – interstate)

The Thiessen polygons determine the spatial extent of each ATR station's influence on the surrounding roads. A superposition of these polygons with a county map, the 2008 Census GIS road atlas, and the Vulcan 10km x 10km grid, determines what fraction of the emissions from a particular county is affected by a particular polygon's time structure. This superposition also determines allocation of emissions into the Vulcan 10km x 10km grid. Table 6.6 shows a sample of the fraction table used to allocate county emissions to the 10km x 10km gridded data product.

Table 6.6: Sample of the fractional distribution of county emissions using the Thiessen polygons to distribute the ATR station influence.

ATR Station	Grid i	Grid j	State FIPS	County FIPS	Length in Grid	Length in County	Weight
56000106	199	176	56	1	5.204939	93.9007	0.055430
56000106	199	175	56	1	7.13245	93.9007	0.075957
56000106	200	176	56	1	12.0616	93.9007	0.128449
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
1000050	364	266	1	125	20.9728	134.101	0.156395
1000050	365	266	1	125	23.614	134.101	0.176091
1000050	366	266	1	125	2.84498	134.101	0.021215

In order to use the ATR data to distribute emissions over time, the county-level monthly CO_2 emissions are first summed to obtain annual county totals (still disaggregated by road and vehicle type). The hourly fraction of the annual traffic (defined as the sum of all lanes and all directions) at each ATR station is then used to allocate the annual CO_2 emissions, which are spatially allocated via the Thiessen polygons as perviously explained.

The first row of Table 6.6 demonstrates the allocation influence or weight of the time structure for a particular station (56000106) on a gridcell (199, 176) for county 1. This is obtained by taking the length of road contained in the gridcell (5.204939) and dividing that value by the total length of road contained in the county (93.9007) yielding a value of 0.055430. This means that about 5.5% of the emission values from county 1 will be placed on cell 199,176 and follow the time structure dictated by station 56000106.

The hourly-resolved CO_2 emissions in each 10km x 10km grid cell are therefore defined as:

$$EM(h,x,y)_{CO_2} = EM(f,c)_{CO_2} \times ATR(h) \times Frac(f,c,x,y) \quad (6.7)$$

where $EM(f,c)_{CO_2}$ is the annual CO_2 emissions for road type (f) in particular county (c), $ATR(h)$, is the hourly ATR traffic volume fraction at hour (h), and $Frac(f,c,x,y)$, is the weight function (last column of Table 6.6) which denotes the fractional amount of road type (f) from county (c) present on cell (x,y) due to the superposition of the polygon's shape on the county and grid cell in question. This fraction determines the effect of the polygon's time structure on the CO_2 emissions present in the 10km x 10km cell.

6.1.4 Spatial Rendering

6.1.4a Roadway rendering

The first rendering allocates the hourly/county/road/vehicle-specific CO_2 emissions that are available from the Vulcan fossil fuel CO_2 inventory onto roadways using a GIS road atlas [*NTAD* 2003] which has all twelve road types (six rural and six urban subdivisions). The crosswalk table that places the twelve road types onto six road types is found in Appendix B, Table B.13. The hourly sum of all vehicle classes on a single road class within a county are distributed evenly over the total road class distance in the county. This results in a per kilometer amount of CO_2 emissions that remains constant over space within a county and road class. Time variations are as described in section 6.1.3 using ATR data.

Certain road classes in the currently-used GIS road atlas are not present in all counties. In some locations the following road classes are often missing: rural major collector, rural minor collector, rural local, urban minor arterial, urban collector, and urban local. Hence, there is a mismatch between the road classes identified by the Vulcan onroad CO_2 emissions and the available road types. In order to solve this problem, we moved the road-specific rural CO_2 emissions from rural major collector (32.06 MtC/year), rural minor collector (9.46 MtC/year), and rural local (21.98 MtC/year) to the next coarsest road class - rural minor arterial in rural areas. Similarly, we moved the road-specific urban CO_2 emissions from urban minor arterial (49.37 MtC/year), urban collector (20.01 MtC/year), and urban local (33.72 MtC/year) to next coarsest road class - urban principal arterial-other. Through this method, we are able to render all of the road-specific CO_2 emissions to the roads present in the GIS road atlas. Roughly 168 MtC/year out of our total 440 MtC/year were moved upscale via this method.

This approach can lead to some unrealistic spatial anomalies in the vehicle emissions. A given road type traversing a county boundary can exhibit "jumps" or large changes in CO_2 emissions by virtue of the fact that the county emissions are distributed evenly on a given road type within each county separately even though the road segment traverses county boundaries with no emission shift at the boundary. Similarly, a single roadway that changes from urban to rural, for example, at the edge of a city or densely populated area will also exhibit a sudden change in CO_2 emissions within the Vulcan inventory, which likely does not occur as dramatically in the real world.

6.1.4b Rendering to regular grid

The second rendering of the county-level mobile emissions features both a geoprocessing and visualization component. In order to aggregate mobile emissions into a common 10 km x 10 km grid (see section 7.0), road segments with their emissions values must be fractured by the edges of the grid cells, then collected into the cells to which they belong. Using the border of a grid cell to split a road segment with emission value V results in two road segments with value V. If those two segments were then aggregated into their parent grid cells, drastic overmeasurement would occur, with value V being added to the gridded sum twice.

In order to account for this, emissions values must be smeared to road segments per kilometer so that when the segment is split by a cell border each resulting segment's total emission can be recalculated by its new, shorter length.

Within a GIS, all road segments have their lengths calculated per kilometer. The emissions value assigned to each segment (based on its road class and parent county) is then divided by kilometers to reach a per-kilometer emissions value for each segment. The road segments are then physically split by the 10 km x 10 km grid cells. New length values are calculated for each road segment and new total emissions are calculated by factoring the original segment's total emissions value by the percentage of its original length now represented by its fractured pieces. A road segment with original emissions *V*, and length of 100km would have a per-kilometer value of V/100. Split at kilometer 40 by a grid cell, each of the two resulting segments would have length=40 km, length=60 km, respectively. Knowing the original value, *V* of the segment's emissions while intact, the new segments' per kilometer values can be calculated using the percentage of length of the intact segment now represented by the fragment. This per-kilometer value is then used to aggregate into the 10 km x 10 km grid cells all road segments now found within each cell, each of which represents x kilometers of road/road type (fragments from one or more counties that happen to fall within the cell) that carry with them a certain per-kilometer value of emission output.

6.2 Nonroad mobile emissions

The nonroad mobile emissions are derived from NMIM NCD and represent mobile sources that do not travel on roads such as trains, boats, snowmobiles, and lawnmowers [*USEPA* 2005d; *USEPA* 2005e]. The original 446 vehicle classes (few counties contain all possible classes, however) were reduced to 12 through grouping of like processes. Each can utilize 4 different fuel types and some variation by engine configuration is retained. As with onroad mobile emissions, the space/time resolution of the incoming data is at the county level and at monthly timesteps within the year 2002.

The SCC for nonroad equipment always falls under only one of the segments in Appendix B, Table B.11 corresponding to its most typical application, although it may be used in other segments as well. As an example, skid steer loaders are in the construction segment, but they may also be used in agriculture. The fuel types present in the NONROAD sector are gasoline, diesel, LPG, and CNG.

The nonroad emissions are calculated as the product of four provided data elements,

$$E(t)_v^c = EF_v \times P_v^c \times A(t)_v^c \times S(t)_v^c \qquad (6.8)$$

$E(t)_v^c$ is the monthly CO_2 emission in county *c* for vehicle type *v*, EF_v is the CO_2 emission factor in grams of CO_2 per operating hour for vehicle type *v*, *P* is the population (number of individual vehicles) of vehicle type *v* in county *c*, $A(t)_v^c$ is the activity level (in hours per year) for vehicle type *v* in county *c,* and $S(t)_v^c$ is the seasonality for each month for vehicle type *v* in county *c.* The seasonality is defined as the fraction of the total number of hours in a year that is allocated for each month.

The emission factor data is obtained from the USEPA's NONROAD model (*USEPA* 2005f). The activity, seasonality, and population tables are obtained from the NMIM NCD which represents extensive data collection from S/L/T's and estimation performed by the USEPA [*USEPA* 2005e].

The NCD contains fields that may be populated with the file names of external data files containing state or county data specific to nonroad. If alternate data files are not provided, NMIM uses the default NONROAD model data files. NONROAD external data files include:

1. Activity rates (including annual hours of use and load factor)
2. Temporal (monthly and daily) allocations
3. Source populations.
4. Growth indexes
5. Geographic allocations by equipment category

Many of the nonroad specific parameters are contained in the NONROAD model itself as defaults. Appendix B, Table B.12 details the state-specific data provided by S/L/T agencies used to replace the NONROAD model default national average values.

Currently, the nonroad sources do not include railroad or commercial marine vessel (CMV) emissions as these were not included in the NMIM NCD. The will be included in future versions of the Vulcan inventory.

6.3 Aircraft emissions

Aircraft emissions in the Vulcan inventory are derived from two different datasets. The first is the NEI airport datafile that reports emissions of CAPs at geocoded airport locations in the U.S. [*USEPA* 2005e]. As with the other NEI datasets, emissions are classified according to key fields such as SCC and fuel. The NEI airport datafile includes information on 3865 airport facilities. The NEI airport emission data is reported in units of short tons of CO for either the entire year or a daily average of CO emitted, also in units of short tons. The majority of airports operate year-round and have emissions reported as an annual total but some airports operate only during the months of June through August and the emissions are reported as a daily average value. The CO emissions are converted to CO_2 emissions using the following expression,

$$C_f^p = \frac{12}{44}\frac{PE_f^p}{PF_f^p}CF_f^p \qquad (6.9)$$

where *C*, is the emitted amount of carbon, *PE* is the equivalent amount of uncontrolled aircraft CO pollutant emissions, *p* is the aircraft type, *f* is the fuel, *PF* is the CO emission factor (provided in Appendix A, Table A.1), and *CF* is the emission factor associated with CO_2 (provided in Appendix A, Table A.3).

There are five main aircraft types: General Aviation, Military Aircraft, Business Turboprop, and Air Taxis, and Air Carriers. Each of these have specific emissions for each airport and the total emissions for an airport location is the sum of the emissions from each aircraft type that uses the facility. All aircraft are assumed to use jet fuel and the CO_2 emission factor used is 0.0702 tonnes $CO_2/1x10^6$ btu.

Three CO emission factors are used: 1.082, 0.944, and 0.056 lbs $CO/1x10^6$ btu used respectively for SCC codes containing "reciprocating" or "turbine aircraft" in their name, SCC codes containing "engine" in their name, and all other SCC codes for aircraft using jet fuel, respectively.

The second dataset utilized is the Aero2K database that quantifies global airborne emissions (including take-off/landing) on a 1° x 1° x 500 ft grid and includes information on fuel, CO_2, CO, NOx, H_2O, soot, hydrocarbons, and particulates for commercial aircraft and all but CO_2 for military aircraft [*Eyers* 2004]. The emissions are based on flight path information collected from commercial and military aircraft. The aircraft population was obtained from commercial airline data which provides fleet information in terms of aircraft and engine type. In order to keep the database to a manageable size, forty representative aircraft types were chosen which fit into four broad categories: Large Jets, Regional Jets, Turboprops, and Bizjets. The CO_2 emissions were obtained by multiplying the fuel consumption of each aircraft/engine type by the amount of distance travelled and the take-off/climb/cruise/descent/landing cycle. The fuel usage predictions were calculated using PIANO for the year 2002 [*Piano* 2002].

Fuel profiling and prediction takes place within the AERO2k Data Integration Tool [*Eyers* 2004]. The method for assigning fuel data to the flight profiles in the flights relies on a series of data-tables as follows:

1. Take-off. Using 60.9% of maximum payload, estimate the take-off weight for the mission range to be flown. Taxi, take-off and climb out (to 3000 ft) data from emissions databank and airport-specific departure times-in-mode look-up table.
2. Climb (>3000ft). Determine initial cruise altitude from the profile data, calculate fuel used in climb from climb data tables, re-calculate aircraft mass at top of climb, and calculate distance flown.
3. Cruise. Select appropriate cruise fuel flow data from the cruise data tables, for the altitude, Mach number and aircraft mass. Continue to re-calculate distance flown and aircraft mass through-out the cruise segment.
4. Step-climb or mid-cruise descent if appropriate, then repeat Cruise step.
5. Descent (to 3000 ft). Descent fuel from final cruise altitude to 3000 ft calculated from descent data tables.

6. Landing. Data from emissions databank and airport-specific arrival times-in-mode lookup table.

Aero2k CO_2 emissions above 3000 feet are allocated to US airports through a proportional allocation scheme. This procedure involves selecting a rectangular region encompassing the area in question and integrating the emissions contained in that area to obtain emissions aloft. For the Continental United States this rectangle was drawn from 50N, 124W to 23N, 65W. The region for Alaska was drawn from 72N, 172E to 51N, 130W. Both of these closely match the boundaries of each region. Hawaii had a 10 degree buffer on all four sides to account for travel outward and into the state; the region was drawn from 39N, 171E to 39N, 144W. Only the AERO2k emissions above 3000 ft from both the Commercial and Military aircraft sector were summed over these regions to obtain the total for each part of the country. These individual aloft regional CO_2 emission totals were allocated to surface airports via each surface airport's share of the regional total. AERO2k provides CO_2 emissions estimates for commercial aircraft but CO emission estimates for military aircraft. The latter are converted to CO_2 emissions using default emission factor values for jet fuel of 0.963 lbs $CO/1x10^6$ btu and 0.071 tonnes $CO_2/1x10^6$ btu, respectively. This allows for a direct comparison to independent state-level estimates that track fuel sales, such as that performed by the State Energy Data System (SEDS) of the DOE/EIA [*DOE/EIA* 2007]. However, for the purposes of atmospheric modeling, the emissions above 3000 ft are maintained as a separate inventory in three dimensions. Hence, the gridded hourly Vulcan emissions surface files have only those emissions associated with the LTO cycle as represented in the NEI data.

6.4 Sources of Uncertainty

TBD

7.0 Sectoral assignment and geospatial representation

The Vulcan CO_2 emissions are reported following a number of categorical divisions. The most common are emissions reporting by broad economic sectoral division (industrial, residential, commercial, mobile, utility, and cement). Initially, a small proportion of the incoming data (~7 MtC/year) could not be classified as one of the six sectors but these have since been assigned and are notated elsewhere in this document (see Section 5.2.3). All of these sectors are reported in both the NEI point and nonpoint source data. Nearly all of the onroad mobile emission reporting is found in the NMIM NCD data and similarly, nearly all of the electricity production emissions are derived from the geocoded ETS/CEM data.

Geospatial representation of the Vulcan inventory is performed in two different ways. The first is representation in a "native" format or at the spatial resolution most resembling the incoming data (points, county, etc). The second is representation on a common 10 km x 10 km grid to facilitate atmospheric modeling.

When representing the sectoral emission in a "native" format, a mixture of resolutions occur. For example, industrial sources are represented as both geocoded points (as derived from the NEI point source data files) and as emission spread over census tracts (in the case of industrial emissions reported in the NEI nonpoint source data files - see section 5.3). A similar result occurs for the electricity production sector in which the ETS/CEMs data is geocoded but some electricity production emissions are present in the nonpoint source data files and these are downscaled similarly to the industrial sources.

The residential sector is derived from nonpoint source data only and is therefore represented within census tracts per section 5.3. Commercial emissions are derived from both the point and nonpoint source data and are hence, a mixture of geocoded point locations and within census tracts per section 5.3.

Nonroad transportation emissions are distributed evenly over the county where emissions are reported and are hence, represented as county totals. Further spatial allocation will be performed in future Vulcan releases.

The NEI airport emissions are represented as geocoded locations. However, emissions associated with the airborne portion of this category, as derived from the Aero2K inventory above 3000 feet are allocated to the airport locations based on each airport's share of total airport emissions in the airport NEI. Aero2K emissions below 3000 feet are not included as these are considered the take-off/landing component of the aircraft emissions and, hence, are already included in the NEI airport database. The allocation of airborne emissions to airport locations is performed in order to compare the Vulcan inventory to independent sources that quantify emissions according to fuel sales. From a visualization perspective, the reduction of the airborne emissions to airports simplifies the two-dimensional representation of the Vulcan inventory. However, for the purposes of atmospheric modeling, the Aero2K inventory is also maintained as a separate 3D emission dataset as a partner to the NEI airport emissions.

All of the sectoral emissions are also represented on the common 10 km x 10 km grid, Point values are placed in the grid cell occupied by the geocoded point source while sources distributed across roads or census tracts are placed within 10 km x 10 km gridcells via area-weighted proportions. The center of the first gridcell is located at: -137.16° W, 51.95° N and the map projection is Lambert Conformal Conic with standard parallels of 33.0°, 45.0°, a central meridian of -97.0°, and a latitude of projection origin of 40.0°. The Vulcan results have also been transformed to a 0.1° x 0.1° grid and regridding information can be found on the Vulcan website.

8.0 Temporal Processing

The Residential and Commercial annual emissions as derived from the NEI reflect a mix of annual level data and portion-year emissions as was noted in section 2.1.2 and 5.1.2 which describe the time period consistency in the point and area source data, respectively. Though only time type 30 data is retained, some of the incoming data contains start and end dates that cover sub-portions of the year. The result is that the initial Vulcan emissions output for these two sectors is not completely "flat" in time but contains some temporal structure. Given that we utilize independent data (fuel sales/consumption, heating degree day, etc) to perform temporal structuring, we "override" the implied time structure provided by the NEI data and spread it evenly over each hour of the year.

8.1 Monthly downscaling

The next step in conditioning the temporal structure is the monthly downscaling. This is achieved through the use of monthly, state-level residential and commercial natural gas sales/consumption fractions based on the Department of Energy/Energy Information Administration's (DOE/EIA) form EIA-857 surveys [*DOE/EIA* 2009].

We focus on natural gas use as a temporal proxy for all space heating because it is the dominant fuel used in space heating at the end-user point. At the national level, the Vulcan results indicate that natural gas constitutes 72% of the CO_2 emissions in the residential sector and roughly 65% in the commercial sector. Some fuel oil (distillate – 18% of residential CO_2 emissions) and LPG (9% of residential emissions) is used in isolated portions of the United States and it is assumed that the time structure of that fuel use for space heating is no different than that constructed for natural gas space heating.

Hence, these temporal proxies are imperfect to the extent that the remaining fuel consumption in these sectors has a different monthly time structure (currently under investigation). Natural gas is used in this way because the DOE does not report at the state/month/sectoral level for liquid or solid fuels. This monthly temporal allocation will have no sub-state spatial footprint as the EIA data is resolved only at the state level.

The DOE/EIA form-857 surveys are designed to collect data on the quantity and cost of natural gas delivered to distribution systems and the quantity and revenue of natural gas delivered to residential and commercial end-user consumers, separately. A sample of approximately 400 natural gas companies, including interstate pipelines, intrastate pipelines, and local distribution companies, report to the survey. The form DOE/EIA form-857 comprises reporting by companies statistically selected by the DOE from a list of all companies in the US that deliver natural gas to consumers, including pipeline companies that serve consumers directly. The selection provides a representative sample of natural gas deliveries to states.

The classification of consumers are as follows:

1) Residential:
    - master-metered apartments
    - mobile homes

- multi-family dwellings that are individually metered
- and single-family dwellings

uses: natural gas for space heating, water heating and cooking

2) Commercial:

- businesses (eg. Restaurants, hotels, retail)
- federal, state and local governments
- other private and public organizations such as religious, social, and fraternal groups

uses: natural gas for space heating, water heating cooking and a wide variety of other equipment.

Commercial use of natural gas is complicated by the fact that a higher percentage is used for needs other than space heating. However, there is insufficient data to apportion natural gas in the commercial sector among various uses and it is assumed that the time structure of total commercial natural gas consumption is an accurate portrayal of the space heating component. Figure 8.1 presents residential and commercial natural gas consumption for 2002 in a series of states.

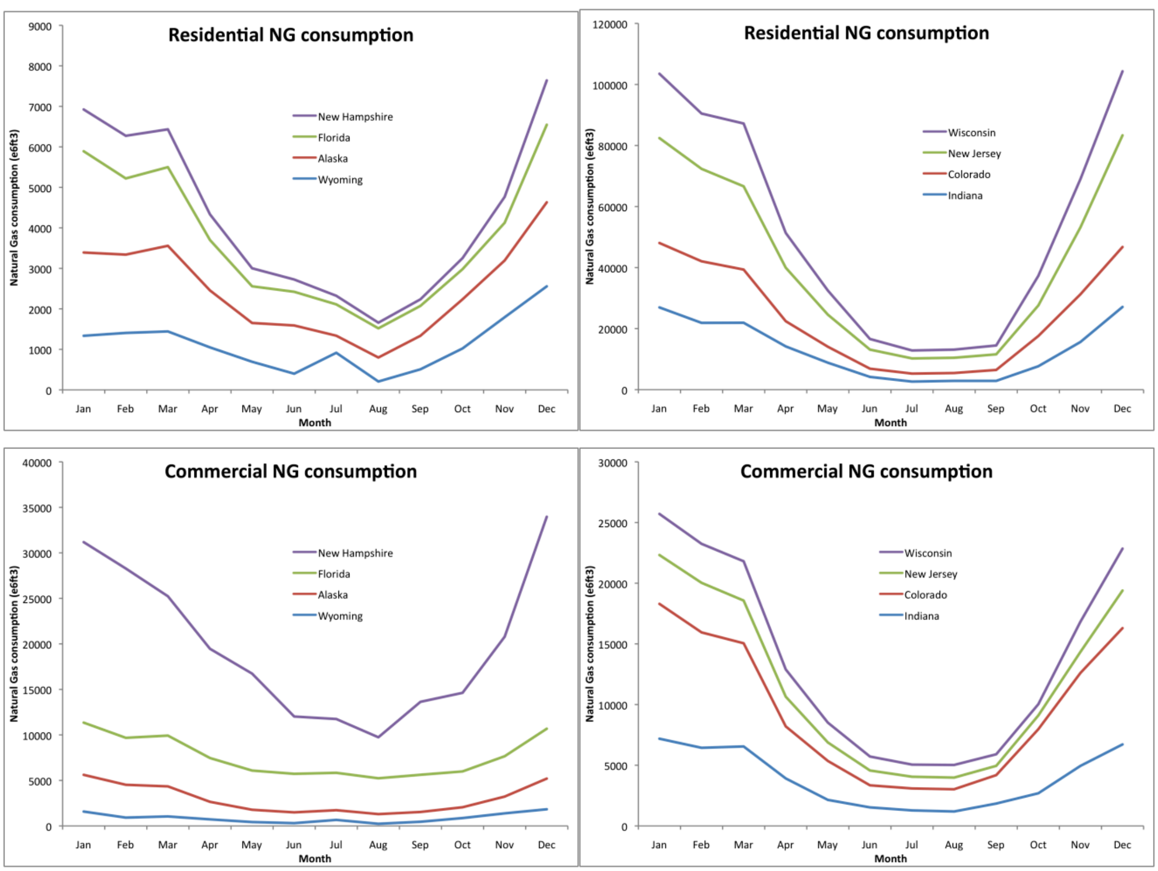


Figure 8.1. *Monthly residential and commercial natural gas consumption in a series of states for the year 2002. Units: $1x10^6$ ft^3/month. These are not "adjusted" values (no month length adjustment performed).*

The state/month DOE/EIA natural gas residential and commercial sales/consumption data is converted into a monthly fraction. Details can be found in either (on KRG macintosh):

/KRG_Work/Carbon_Cycle/fossil/datasets/EIA/monthly_fuel/NG.state.month.commercial.fracs.xlsx

or

/KRG_Work/Carbon_Cycle/fossil/datasets/EIA/monthly_fuel/NG.state.month.residential.fracs.xlsx

which are both currently also found on baja3 in a '/build_xxx/10k/EIA_time/' folder as text files.

These state-level monthly fractions are applied to the hourly, gridded Vulcan fossil fuel CO_2 residential and commercial emissions that emerge from the NEI data ("flattened" to remove any vestigial temporal structure as noted in sections 2.1.2 and 5.1.2). In order to apply state-level values to 10k gridcell values, a weightfile outlining what portion of each 10k gridcell resides within a given state domain, is utilized. This file can be found on Baja3 in '/build_xxx/10k/EIA_time/10k_2_state_0813.sorted.prn'. The processing of this is performed within the 'make.all.f' programs in each build.

8.2 Sub-monthly downscaling

In order to reflect sub-monthly temporal variations in space heating fossil fuel CO_2 emissions, we relied upon the well-established relationship between space heating needs and external surface temperature via the heating degree day relationship (*Ruth and Lin* 2006) defined as:

$$HDD(\vec{x},t) = HDD_{sp} - T(\vec{x},t) \tag{8.1}$$

Where $\vec{x}$ denotes the gridcell, HDD_{sp} is the set point temperature and T represents the surface air temperature. The set point temperature was chosen as 68 °F, the commonly established set point from the literature on the topic for a US-average [*Ruth and Lin* 2006; *Amato et al.,* 2005] and the surface air temperature was taken from the NCEP North American Regional Reanalysis (NARR) [*Mesinger et al.*, 2006].

The NARR contains surface air temperature every 3 hours on a roughly 0.3°x0.3° (32.46 km in Lambert Conformal) grid for the contiguous US and this was regridded to the 10km x 10km Vulcan grid. This allowed for the computation of an *HDD* value every 3 hours for every gridcell on the Vulcan grid.

In generating the 3-hourly fractional allocation, two different fuel uses were assigned based on the categories outlined in the previous section: 1) space heating and 2) other uses (sum of water heating, cooking and all other miscellaneous uses). For the commercial sector, the other fuel uses are assumed to be small. Space heating was defined as varying according to the HDD computation while the other uses were deemed constant over time based on the observation that water heating is not directly related to external temperature but to occupancy, shower frequency, etc [*Mansur et al.,* 2008]. The portion of monthly fossil fuel CO_2 emissions resulting from other uses, as a percentage of the monthly total residential and commercial emissions, was derived from the HDD calculation:

$$P_o(\vec{x},m) = \frac{\sum_{t=1} t;\ when\ T(\vec{x},t) \geq HDD_{sp}}{\sum_{t=1} t} \tag{8.2}$$

where P_o represents that proportion of the monthly fossil fuel residential or commercial CO_2 emissions allocated to the other uses, *m* denotes the month, and *t* denotes the hour. This assumes that the proportion of fuel devoted to space heating in a month is equal to the number of hours the surface air temperature falls below HDD_{sp} out of the total number of hours in a month. Hence, locations where there were many hours below the HDD_{sp} (e.g. Wisconsin) would have a large proportion of the monthly fuel use devoted to space heating while locations in which few hours were below the HDD_{sp} (e.g. Florida) would have relatively small proportions of the month fuel use devoted to space heating.

The proportion of monthly fossil fuel residential or commercial CO_2 emission devoted to space heating is then:

$$P_{sh}(\vec{x},m) = 1 - P_o(\vec{x},m) \tag{8.3}$$

where P_{sh} denotes the space heating proportion.

With these proportions defined, one can calculate the hourly emissions based on the sum of the hourly CO_2 emissions devoted to uses other than space heating and the hourly CO_2 emissions devoted to space heating. The latter quantity has a time varying quality which we reflect by quantifying the variation of the HDD at a given hour about the mean HDD value for the month. This hourly adjustment factor can be expressed as,

$$f(\vec{x},t) = \left[\frac{HDD_{sp} - T(\vec{x},t)}{\sum_{t=1} \left(HDD_{sp} - T(\vec{x},t)\right) \Big/ \sum_{t=1} t;\ when\ T(\vec{x},t) \leq HDD_{sp}} \right];\ \text{for t when } T(x,t) < HDD_{sp} \tag{8.4}$$

where this is only defined at hours where $T(\vec{x},t)$ is below the set point value. Hours where $T(\vec{x},t)$ is above the set point value are assigned an adjustment factor value of 0.

This adjustment factor can then be incorporated into the complete hourly calculation to produce a final hourly CO_2 emissions amount:

$$E(\vec{x},t) = f(\vec{x},t)\frac{E(\vec{x},m)}{\sum_{t=1}^{mlen} t} P_{sh}(\vec{x},m) + \frac{E(\vec{x},m)}{\sum_{t=1}^{mlen} t} P_o(\vec{x},m) \tag{8.5}$$

An entire month in which the surface air temperature never falls below the HDD_{sp} will exhibit a constant emission throughout the month. Months in which at least a single hour fell below the HDD_{sp} will have hours in which the fractional allocation value reflects the constant fraction devoted to the other uses and hours in which the fractional allocation values represent the sum of a time varying portion (devoted to space heating) and the constant amount from other uses.

Figure 8.2 shows examples of gridcell level emissions in four locations around the US.

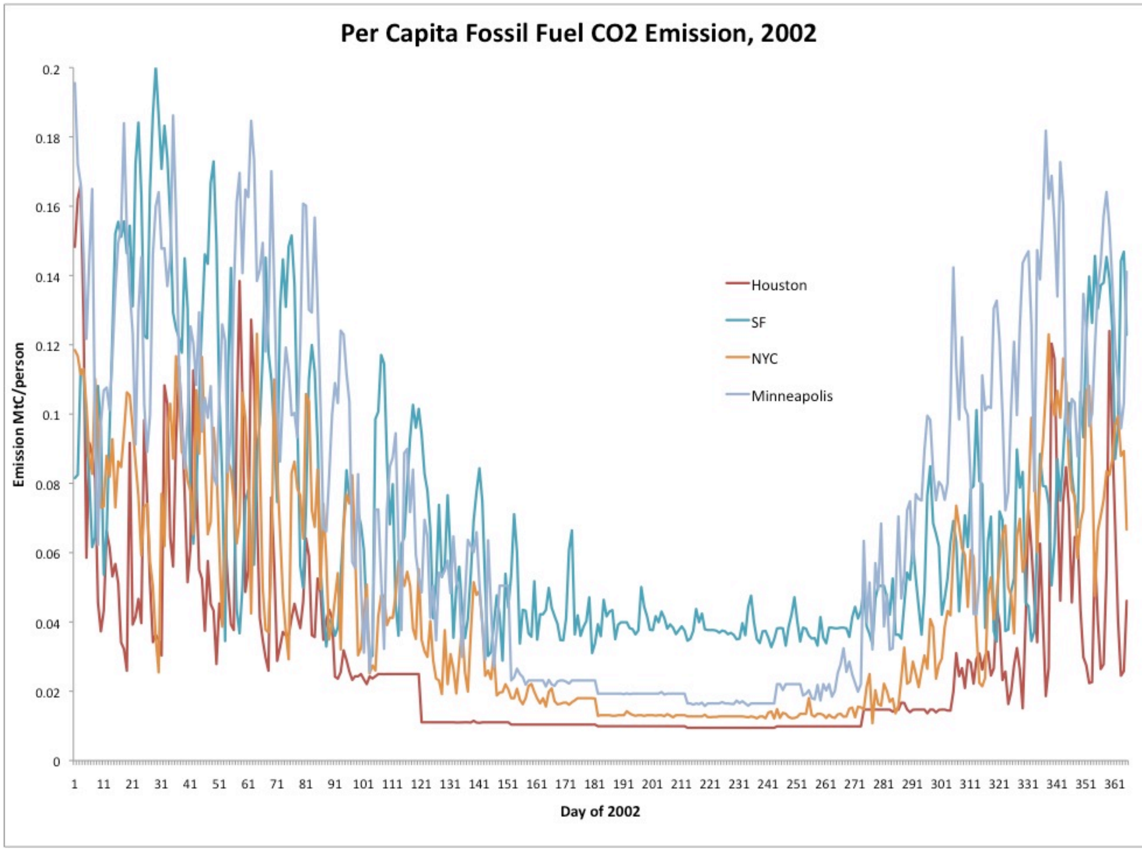


Figure 8.2. *Daily fossil fuel CO_2 emissions in the residential sector at four locations in the United States. Units: million tonnes C/day.*

8.3 Multiyear time structure

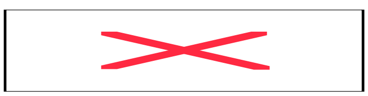
In order to produce emissions for years other than the base year of 2002, annual sales/consumption data from the DOE/EIA is utilized [*DOE/EIA* 2007c]. The SEDS sales/consumption data is organized by state, sector and fuel and spans the 1960 to 2007 time period. As with the monthly state-level residential natural gas data referred to previously, the basis of the SEDS sales/consumption data are derived from survey data collection efforts. Principal among these are the data outlined in the *Annual Coal Report*, the *Natural Gas Annual* and the *Petroleum Supply Annual* document series. The strategy is to construct ratios of a given year's state/sector/fuel sales/consumption relative to 2002. These ratios are then applied to the 2002 Vulcan hourly gridded output to construct a multiyear data product. This implies a number of approximations:

1) this assumes that the time structure of SEDS sales/consumption at the state/sector/fuel level can be directly mapped to the time structure of the resulting CO_2 emissions. This would be violated if, for example, the carbon content of fuel at the state/sector/fuel level varies over time.

2) this assumes no variation of sub-state spatial distibution of CO_2 emissions over time due to, for example, housing development, new point sources, etc.

The SEDS sales/consumption data includes production within a state that is exported to locations outside the state. When exports exceed in-state consumption, a negative sales/consumption value results. However, without details on import/export, it is not possible to ascertain how much domestic consumption occurred in the instances of negative entries. The exported sales/consumption quantity will be captured correctly in the entries for the importing states. Because negative entries are not useable for temporal structuring, these values are replaced by zero entries wherever they occur. This is acknowledged as creating a potential negative bias for the temporal structure in those state/sector/fuel cases in which negative entries occur.

Because stockpiling of fuel can occur over time, the sales/consumption values can exhibit significant interannual variiablity that is not an refelctive of actual combustion in a given year. This is particularly noticeable in the coal data. In order to attempt to account for potential stockpiling, a "backward looking" exponential smoothing filter is applied. This filter transforms each year's sales/consumption of coal to represent a diminishing proportion of previous year's original sales/consumption values. A five year backward-looking window is used. The expression is as follows:

 (8.6)

where *E(t)'* is the new emissions at timestep *t*, and *E(t)* is the original emissions at timestep *t*. The window, w, designates the number of years in arrears that contribute to the current year sales/consumption. Currenlty, this value is 5. The logic is that a given year's sales/consumption is a diminishing contribution from previous year values.

With a smoother in placed the annual state/sector/fuel-specific fractions are constructed. In instances in which the baseyear of 2002 contains a zero value, we simply transfer the 2002 vulcan value to all other years. This is being reviewed for a superior approach and will be available in future releases.

Because the Vulcan fuel list is far more detailed than the categories available in the SEDS sales/consumption data, a crosswalk file is constructed that maps every Vulcan fuel/sector combination to a fuel/sector combination in the SEDS sales/consumption datafile. This is shown in Table 8.1.

Table 8.1 Fuel mapping from Vulcan fuel categories to the SEDS sales/consumption fuel categories

Vulcan Fuel	Vulcan Fuel Description	Sector	SEDS Fuel code	SEDS Fuel Description
2	Waste Oil	COM	279	Residual Oil
2	Waste Oil	IND	216	Oil
2	Waste Oil	UTL	279	Residual Oil
44	Diesel	MOB	56	Distillate Oil

44	Diesel	UTL	56	Distillate Oil
44	Diesel	IND	56	Distillate Oil
57	Distillate Oil (Diesel)	COM	56	Distillate Oil
57	Distillate Oil (Diesel)	IND	56	Distillate Oil
57	Distillate Oil (Diesel)	UTL	56	Distillate Oil
58	Distillate Oil (No. 1 & 2)	IND	56	Distillate Oil
126	Gas	IND	209	Natural Gas
159	JetFuel	RES	162	Kerosene
159	JetFuel	IND	162	Kerosene
159	JetFuel	UTL	56	Distillate Oil
160	Jet Naphta	COM	162	Kerosene
160	Jet Naphta	IND	162	Kerosene
173	Lignite	IND	717	Coal
216	Oil	COM	56	Distillate Oil
216	Oil	RES	56	Distillate Oil
251	Process Gas	IND	717	Coal
251	Process Gas	COM	717	Coal
251	Process Gas	UTL	717	Coal
255	Propane	IND	178	LPG
255	Propane	COM	178	LPG
255	Propane	RES	178	LPG
255	Propane	UTL	209	Natural Gas
256	Propane/Butane	IND	178	LPG
256	Propane/Butane	COM	178	LPG
279	Residual oil	RES	56	Distillate Oil
323	Subbituminous Coal	IND	717	Coal
323	Subbituminous Coal	COM	717	Coal
323	Subbituminous Coal	UTL	717	Coal
374	Crude Oil	IND	279	Residual Oil
425	Coke Oven Gas	IND	279	Petroleum Products
640	Antracite	RES	717	Coal
640	Antracite	COM	717	Coal
640	Antracite	IND	717	Coal
640	Antracite	UTL	717	Coal
663	Bituminous Coal	IND	717	Coal
663	Bituminous Coal	COM	717	Coal
663	Bituminous Coal	UTL	717	Coal
664	Bituminous/Subbituminous Coal	RES	717	Coal
664	Bituminous/Subbituminous Coal	COM	717	Coal
664	Bituminous/Subbituminous Coal	IND	717	Coal
664	Bituminous/Subbituminous Coal	UTL	717	Coal
675	Butane	IND	178	LPG
675	Butane	COM	178	LPG
724	Coke	IND	717	Coal
809	Coke Oven or Blast Furnace Gas	IND	717	Coal
818	Diesel/Kerosene	IND	162	Kerosene
823	Distillate Oil (No. 1 & 2)	IND	56	Distillate Oil
823	Distillate Oil (No. 1 & 2)	UTL	56	Distillate Oil
823	Distillate Oil (No. 1 & 2)	COM	56	Distillate Oil
825	Distillate Oil (No. 4)	IND	56	Distillate Oil
825	Distillate Oil (No. 4)	UTL	56	Distillate Oil
825	Distillate Oil (No. 4)	COM	56	Distillate Oil
864	Jet A Fuel	IND	162	Kerosene
865	Jet A Kerosene	IND	162	Kerosene
922	Residual Oil (No. 5)	COM	279	Residual Oil
922	Residual Oil (No. 5)	IND	279	Residual Oil
922	Residual Oil (No. 5)	UTL	279	Residual Oil
923	Residual Oil (No. 6)	IND	279	Residual Oil
923	Residual Oil (No. 6)	COM	279	Residual Oil
923	Residual Oil (No. 6)	UTL	279	Residual Oil
924	Residual/Crude Oil	IND	279	Residual Oil

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Appendix A

Table A.1. Default fuel/combustion category emission factors for carbon monoxide (CO)

Mat id	*unit*	*lbs CO/ unit*	*lbs CO/ 10^6btu*	*material name*	*modifier*
663	TON	0.5	0.021	bituminous coal	scc contains: "pulverized"
663	TON	0.5	0.021	bituminous coal	scc contains: "cyclone"
663	TON	0.6	0.025	bituminous coal	scc contains: "cogeneration"
663	TON	275	11.441	bituminous coal	scc contains: "hand-fired"
663	TON	6	0.250	bituminous coal	scc contains: "spreader stoker"
663	TON	6	0.250	bituminous coal	scc contains: "overfeed stoker"
663	TON	18	0.749	bituminous coal	scc contains: "atmospheric fluidized bed"
663	TON	11	0.458	bituminous coal	scc contains: "underfeed stoker"
663	TON	5.94	0.247	bituminous coal	all else
663	TON	6	0.250	bituminous coal	all commercial nonpoint coal use
663	TON	275	11.441	bituminous coal	all residential nonpoint coal use
663	TON	6	0.250	bituminous coal	all industrial nonpoint coal use
323	TON	0.5	0.029	subbituminous coal	scc contains: "pulverized"
323	TON	0.5	0.029	subbituminous coal	scc contains: "cyclone"
323	TON	0.6	0.034	subbituminous coal	scc contains: "cogeneration"
323	TON	275	15.705	subbituminous coal	scc contains: "hand-fired"
323	TON	5.5	0.314	subbituminous coal	scc contains: "stoker"
323	TON	18	1.028	subbituminous coal	scc contains: "atmospheric fluidized bed"
323	TON	11	0.628	subbituminous coal	scc contains: "underfeed stoker"
323	TON	6.02	0.344	subbituminous coal	all else
323	TON	6	0.343	subbituminous coal	all commercial nonpoint use
323	TON	275	15.705	subbituminous coal	all residential nonpoint use
323	TON	6	0.343	subbituminous coal	all industrial nonpoint use
664	TON	0.5	0.025	bituminous/subbituminous	scc contains: "pulverized"
664	TON	0.5	0.025	bituminous/subbituminous	scc contains: "cyclone"
664	TON	0.5	0.025	bituminous/subbituminous	scc contains: "cogeneration"
664	TON	275	13.573	bituminous/subbituminous	scc contains: "hand-fired"
664	TON	5	0.261	bituminous/subbituminous	scc contains: "spreader stoker"
664	TON	6	0.296	bituminous/subbituminous	scc contains: "overfeed stoker"
664	TON	18	0.888	bituminous/subbituminous	scc contains: "atmospheric fluidized bed"
664	TON	11	0.543	bituminous/subbituminous	scc contains: "underfeed stoker"
664	TON	5.94	0.295	bituminous/subbituminous	all else
664	TON	6	0.296	bituminous/subbituminous	all commercial nonpoint use
664	TON	275	13.573	bituminous/subbituminous	all residential nonpoint use
664	TON	6	0.296	bituminous/subbituminous	all industrial nonpoint use
717	TON	0.07	0.003	coal	scc contains: "Oven Pushing"
717	TON	0.6	0.029	coal	all else
717	TON	11	0.530	coal	all commercial nonpoint use
717	TON	275	13.238	coal	all residential nonpoint use
717	TON	6	0.289	coal	all industrial nonpoint use
640	TON	90	3.609	anthracite	scc contains: "hand-fired"
640	TON	0.6	0.024	anthracite	all else
640	TON	275	11.028	anthracite	all residential nonpoint use
639	TON	0.3	0.012	anthracite culm	
173	TON	5.5	0.424	lignite	scc contains "stoker"
173	TON	0.5	0.039	lignite	all else
209	10^6FT^3	1000	0.969	natural gas	scc contains: "engine"
209	10^6FT^3	150	0.145	natural gas	scc contains: “engine” and “turbine”

209	10^6FT^3	400	0.388	natural gas	scc contains: “engine” and "reciprocating"
209	10^6FT^3	65	0.063	natural gas	all else
209	10^6FT^3	84	0.081	natural gas	all commercial nonpoint
209	10^6FT^3	84	0.081	natural gas	all industrial nonpoint
251	10^6FT^3	35	0.032	process gas	
553	10^6FT^3	35	0.032	refinery gas	
310	10^6FT^3	35	0.032	sour gas	
126	10^6FT^3	35	0.032	gas	
255	E^3GAL	2.55	0.028	propane	
832	E^3GAL	3	0.043	ethane	
256	E^3GAL	3	0.031	propane/butane	
675	E^3GAL	3	0.029	butane	
178	E^3GAL	2.625	0.028	LPG	
425	10^6FT3	2912	4.936	coke oven gas	scc is: 39000702, 39000789
425	10^6FT3	1054	1.786	coke oven gas	scc is: 10200707
425	10^6FT3	18.4	0.031	coke oven gas	all else
809	10^6FT3	511	5.110	coke oven gas or blast furnace gas	scc is: 39000701
809	10^6FT3	185	1.850	coke oven gas or blast furnace gas	scc is: 10200704
809	10^6FT3	13.7	0.137	coke oven gas or blast furnace gas	all else
44	E^3GAL	116	0.836	diesel	
822	E^3GAL	5	0.036	distillate	
56	E^3GAL	5	0.036	distillate oil	
57	E3GAL	130	0.929	distillate oil (diesel)	scc contains "engine” and “reciprocating"
57	E3GAL	113.5	0.811	distillate oil (diesel)	scc contain “engine”
57	E3GAL	130	0.929	distillate oil (diesel)	scc contains “reciprocating”
57	E3GAL	6.72	0.048	distillate oil (diesel)	scc contains “turbine”
57	E3GAL	6.72	0.048	distillate oil (diesel)	all else
823	E3GAL	5	0.036	distillate oil (no 1&2)	
824	E3GAL	5	0.036	distillate oil (no 1)	
58	E3GAL	5	0.036	distillate oil (no 2)	
825	E3GAL	5	0.036	distillate oil (no 4)	
818	E3GAL	130	0.949	diesel kerosene	scc contains "engine” and “reciprocating"
818	E3GAL	113.5	0.828	diesel kerosene	scc contain “engine”
818	E3GAL	130	0.949	diesel kerosene	scc contains “reciprocating”
818	E3GAL	6.72	0.049	diesel kerosene	scc contains “turbine”
818	E3GAL	6.72	0.049	diesel kerosene	all else
279	E3GAL	130	0.867	residual oil	scc contains "reciprocating"
279	E3GAL	5	0.033	residual oil	all else
922	E3GAL	130	0.867	residual oil (no 5)	scc contains "reciprocating"
922	E3GAL	5	0.033	residual oil (no 5)	all else
923	E3GAL	130	0.867	residual oil (no 6)	scc contains "reciprocating"
923	E3GAL	5	0.033	residual oil (no 6)	all else
924	E3GAL	130	0.867	residual crude oil	scc contains "reciprocating"
924	E3GAL	5	0.033	residual crude oil	all else
272	E3GAL	130	0.867	refined oil	using residual oil values
2	E3GAL	2.1	0.015	waste oil	scc contains: "space heaters"
2	E3GAL	1.9	0.014	waste oil	all else
216	E3GAL	5	0.036	oil	
374	E3GAL	5	0.032	crude oil	
181	E3GAL	5	0.036	lube oil	
127	E3GAL	7900	60.82	gasoline	
864	E3GAL	130	1.082	jet A fuel	scc contains "reciprocating"
864	E3GAL	113.5	0.944	jet A fuel	scc contains “engine”
864	E3GAL	6.72	0.056	jet A fuel	all else

159	E3GAL	130	1.082	jet fuel	scc contains "reciprocating"
159	E3GAL	113.5	0.944	jet fuel	scc contains “engine”
159	E3GAL	6.72	0.056	jet fuel	all else
865	E3GAL	130	1.082	jet kerosene	scc contains "reciprocating"
865	E3GAL	113.5	0.944	jet keosene	scc contains “engine”
865	E3GAL	6.72	0.056	jet kerosene	all else
160	E3GAL	130	1.040	jet naptha	scc contains "reciprocating"
160	E3GAL	113.5	0.908	jet naptha	scc contains “engine”
160	E3GAL	6.72	0.054	jet naptha	all else
162	E3GAL	5	0.037	kerosene	
724	TON	6.6	0.236	coke	scc is: 390000899
724	TON	0.6	0.021	coke	all else
226	TON	6.6	0.220	raw coke	scc is: 390000899
226	TON	0.6	0.020	raw coke	all else
142				heat	search scc desc for fuel then reference list

Default emission values are derived from the FIRE emissions factor database [*USEPA* 1997; *USEPA* 2006b; *WebFIRE* 2005].

Table A.2. Default fuel combustion category emission factors for ntirogen oxides (NOx)

Mat id	unit	lbs NOx/ unit	lbs NOx/ 10^6btu	material name	modifier
663	TON	10	0.416	bituminous coal	scc contains: "atmospheric fluidized bed"
663	TON	10	0.416	bituminous coal	scc contains: "cogeneration"
663	TON	12	0.499	bituminous coal	scc contains: "spreader stoker"
663	TON	7.5	0.312	bituminous coal	scc contains: "traveling grate"
663	TON	9.1	0.379	bituminous coal	scc contains: "underfeed stoker"
663	TON	9.1	0.379	bituminous coal	scc contains: "overfeed stoker"
663	TON	9.1	0.379	bituminous coal	scc contains: "hand-fired"
663	TON	30	1.248	bituminous coal	all else
323	TON	15	0.857	subbituminous coal	scc contains: "atmospheric fluidized bed"
323	TON	15	0.857	subbituminous coal	scc contains: "cogeneration"
323	TON	11	0.628	subbituminous coal	scc contains: "spreader stoker"
323	TON	7.5	0.428	subbituminous coal	scc contains: "traveling grate"
323	TON	13.7	0.782	subbituminous coal	scc contains: "underfeed stoker"
323	TON	13.7	0.782	subbituminous coal	scc contains: "overfeed stoker"
323	TON	13.7	0.782	subbituminous coal	scc contains: "hand-fired"
323	TON	25	1.428	subbituminous coal	all else
664	TON	12.5	0.636	bituminous/subbituminous	scc contains: "atmospheric fluidized bed"
664	TON	12.5	0.636	bituminous/subbituminous	scc contains: "cogeneration"
664	TON	11.5	0.564	bituminous/subbituminous	scc contains: "spreader stoker"
664	TON	7.5	0.370	bituminous/subbituminous	scc contains: "traveling grate"
664	TON	11.4	0.581	bituminous/subbituminous	scc contains: "underfeed stoker"
664	TON	11.4	0.581	bituminous/subbituminous	scc contains: "overfeed stoker"
664	TON	11.4	0.581	bituminous/subbituminous	scc contains: "hand-fired"
664	TON	27.5	1.338	bituminous/subbituminous	all else
717	TON	0.03	0.00145	coal	scc contains: “oven pushing”
717	TON	3	0.145	coal	
640	TON	9	0.361	anthracite	scc contains "traveling grate"
640	TON	3	0.120	anthracite	scc contains: "hand-fired"
640	TON	18	0.722	anthracite	all else
639	TON	1.8	0.075	anthracite culm	
173	TON	15	1.157	lignite	scc contains: "cyclone furnace"
173	TON	15	1.157	lignite	scc contains: "traveling grate"
173	TON	6	0.463	lignite	all else
209	10^6FT3	3000	2.907	natural gas	scc contains: "engine"
209	10^6FT3	400	0.388	natural gas	scc contains: “engine” and “turbine”
209	10^6FT3	2840	2.752	natural gas	scc contains: “engine” and "reciprocating"
209	10^6FT3	140	0.136	natural gas	all else
251	10^6FT3	140	0.126	process gas	
553	10^6FT3	140	0.126	refinery gas	
310	10^6FT3	140	0.126	sour gas	
126	10^6FT3	140	0.126	gas	
255	E3GAL	15	0.165	propane	
832	E3GAL	15	0.216	ethane	
256	E3GAL	15	0.154	propane/butane	
675	E3GAL	21	0.204	butane	
178	E3GAL	15	0.165	LPG	
425	10^6FT3	90.8	0.154	coke oven gas	scc is: 39000702, 39000789
425	10^6FT3	54	0.092	coke oven gas	scc is: 10200707
425	10^6FT3	80	0.136	coke oven gas	all else
809	10^6FT3	15.9	0.159	coke oven gas or blast furnace gas	scc is: 39000701

809	10^6FT3	9.35	0.094	coke oven gas or blast furnace gas	scc is: 10200704
809	10^6FT3	23	0.230	coke oven gas or blast furnace gas	all else
44	10^3GAL	425	3.064	diesel	
822	10^3GAL	20	0.144	distillate	
56	10^3GAL	20	0.144	distillate oil	
57	10^3GAL	604	4.355	distillate oil (diesel)	scc contains "reciprocating"
57	10^3GAL	98	0.707	distillate oil (diesel)	all else
823	10^3GAL	20	0.144	distillate oil (no 1&2)	
824	10^3GAL	20	0.144	distillate oil (no 1)	
58	10^3GAL	20	0.144	distillate oil (no 2)	
825	10^3GAL	20	0.144	distillate oil (no 4)	
818	10^3GAL	604	4.355	diesel kerosene	scc contains "reciprocating"
818	10^3GAL	98	0.707	diesel kerosene	all else
279	10^3GAL	604	4.035	residual oil	scc contains "reciprocating"
279	10^3GAL	55	0.367	residual oil	all else
922	10^3GAL	604	4.035	residual oil (no 5)	scc contains "reciprocating"
922	10^3GAL	55	0.367	residual oil (no 5)	all else
923	10^3GAL	604	4.035	residual oil (no 6)	scc contains "reciprocating"
923	10^3GAL	55	0.367	residual oil (no 6)	all else
924	10^3GAL	604	4.035	residual crude oil	scc contains "reciprocating"
924	10^3GAL	55	0.367	residual crude oil	all else
272	10^3GAL	55	0.367	refined oil	using residual oil values
2	10^3GAL	16	0.116	waste oil	scc contains: "space heaters"
2	10^3GAL	19	0.138	waste oil	all else
216	10^3GAL	55	0.367	oil	
374	10^3GAL	55	0.367	crude oil	
181	10^3GAL	55	0.367	lube oil	
127	10^3GAL	200	1.599	gasoline	
864	10^3GAL	604	4.474	jet A fuel	scc contains "reciprocating"
864	10^3GAL	98	0.726	jet A fuel	all else
159	10^3GAL	604	4.474	jet fuel	scc contains "reciprocating"
159	10^3GAL	98	0.726	jet fuel	all else
160	10^3GAL	604	4.834	jet naptha	scc contains "reciprocating"
160	10^3GAL	98	0.784	jet naptha	all else
162	10^3GAL	18	0.133	kerosene	
724	TON	14	0.466	coke	scc contains: "cogeneration"
724	TON	21	0.698	coke	all else
226	TON	14	0.466	raw coke	scc contains: "cogeneration"
226	TON	21	0.698	raw coke	all else
142				heat	search SCC desc for fuel then reference list

Default emission values are derived from the FIRE emissions factor database [*USEPA* 1997; *USEPA* 2006b; *WebFIRE* 2005].

Table A.3. Fuel combustion category emission factors for carbon dioxide (CO_2) and fuel heat content

mat id	tonnes $CO_2/10^6$btu	material name	modifier	heat content	units
663	0.0931[1]	bituminous coal		24.04[3]	10^6BTU/TON
323	0.0967[1]	subbituminous coal		17.51[3]	10^6BTU/TON
664	0.0949[1]	bituminous/subbituminous	Average of previous two	20.77[3]	10^6BTU/TON
717	0.0949[1]	Coal	Use previous row	20.77[3]	10^6BTU/TON
640	0.1032[1]	Anthracite		24.94	10^6BTU/TON
639	0.1032[1]	anthracite culm	Use previous row	24.94	10^6BTU/TON
173	0.0961[1]	Lignite		12.97[3]	10^6BTU/TON
209	0.0531	natural gas	“natural gas pipeline”	1032[3]	10^6BTU/10^6FT^3
251	0.0561	process gas	“refinery fuel gas” entry	1068.6[1]	10^6BTU/10^6FT^3
553	0.0561	refinery gas	“refinery fuel gas” entry	1068.6[1]	10^6BTU/10^6FT^3
310	0.0561	sour gas	“refinery fuel gas” entry	1068.6[1]	10^6BTU/10^6FT^3
126	0.0561	Gas	“refinery fuel gas” entry	1068.6[1]	10^6BTU/10^6FT^3
255	0.0625	Propane		90.42	10^6BTU/10^3GAL
832	0.0590	Ethane		69.43[1]	10^6BTU/10^3GAL
256	0.0635	propane/butane	Mix of propane and butane	93.82	10^6BTU/10^3GAL
675	0.0644	Butane		97.23	10^6BTU/10^3GAL
178	0.0620	LPG		94.0	10^6BTU/10^3GAL
425	0.0406[2]	coke oven gas	“coke (oven gas)”	574[4]	10^6BTU/10^6FT^3
809	0.2063[2]	coke oven gas or blast furnace gas	“blast furnace gas”	92[4]	10^6BTU/10^6FT^3
44	0.0735	Diesel	“diesel/gas oil” entry	137.06	10^6BTU/10^3GAL
822	0.0725	Distillate	“distillate fuel” entry	139.93	10^6BTU/10^3GAL
56	0.0725	distillate oil	“distillate fuel” entry	139.93	10^6BTU/10^3GAL
57	0.0735	distillate oil (diesel)	“diesel/gas oil” entry	137.06	10^6BTU/10^3GAL
823	0.0725	distillate oil (no 1&2)	“distillate fuel” entry	139.93	10^6BTU/10^3GAL
824	0.0725	distillate oil (no 1)	“distillate fuel” entry	139.93	10^6BTU/10^3GAL
58	0.0725	distillate oil (no 2)	“distillate fuel” entry	139.93	10^6BTU/10^3GAL
825	0.0754	distillate oil (no 4)	“fuel #4” entry	143.16	10^6BTU/10^3GAL
818	0.0725	diesel kerosene	Mix of diesel and kerosene	135.98	10^6BTU/10^3GAL
279	0.0780	residual oil		149.97	10^6BTU/10^3GAL
922	0.0772	residual oil (no 5)		149.97	10^6BTU/10^3GAL
923	0.0803	residual oil (no 6)		153.20	10^6BTU/10^3GAL
924	0.0780	residual crude oil	“residual oil” entry	149.97	10^6BTU/10^3GAL
272	0.0780	refined oil	“residual oil” entry	149.97	10^6BTU/10^3GAL
2	0.0735	waste oil	“unfinished oil” entry	138.69[1]	10^6BTU/10^3GAL
216	0.0725	Oil	“other oil” entry	138.69[1]	10^6BTU/10^3GAL
374	0.0737	crude oil		142.26	10^6BTU/10^3GAL
181	0.0735	lube oil	“lubricants” entry	138.1[1]	10^6BTU/10^3GAL
127	0.0702	Gasoline		129.88	10^6BTU/10^3GAL
864	0.0702	jet A fuel	“jet fuel” entry	120.19	10^6BTU/10^3GAL
159	0.0702	jet fuel		120.19	10^6BTU/10^3GAL
865	0.0709	jet kerosene	Mix of jet fuel and kerosene	120.19	10^6BTU/10^3GAL
160	0.0721	jet naptha	“special naptha” entry	120.19	10^6BTU/10^3GAL
162	0.0716	Kerosene		134.91	10^6BTU/10^3GAL
724	0.1011	Coke	“petroleum coke”	27.96	10^6BTU/TON
226	0.1011	raw coke	“petroleum coke”	27.96	10^6BTU/TON
696		Cement	scc contains: "wet" process		
696		Cement	all else		
715		Clinker	scc contains: "wet" process		
715		Clinker	all else		

729		Concrete	scc contains: "wet" process		
729		Concrete	all else		
142		Heat	search SCC desc for fuel then ref list		

Notes: CO_2 emission factors and heat content from API [2004] unless otherwise noted. This source was used for generating internal consistency across the many fuel categories encountered. The values are within 1.5% of other estimates (eg. DOE/EIA, 2007a, USEPA, 2008).

[1] CO_2 emissions factor from DOE/EIA [2007b].

[2] CO_2 emission factor from IPCC, [1996].

[3] Coal heat values from 2006 data contained within the Energy Information Administration, Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report" Federal Energy Regulatory Commission, FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants." US averages for coal types were used. Bituminous and anthracite coal types were reported in one category.

[4] http://www.engineeringtoolbox.com/heating-values-fuel-gases-d_823.html

Appendix B

Table B.1. Complete MOBILE6 Vehicle Classifications[1]

VClass	VClassAbbr	VClassDesc
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3750 lbs. LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3751-5750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5750 lbs. ALVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, 5751 lbs. and greater ALVW)
6	HDGV2B	Class 2b Heavy-Duty Gasoline Vehicles (8501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8A	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8B	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1 and 2 (0-6,000 lbs. GVWR)
16	HDDV2B	Class 2b Heavy-Duty Diesel Vehicles (8501-10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8A	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8B	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

[1] Reproduced here from USEPA [2005d], Table 5a.

Table B.2. Complete MOBILE6 Road Classifications

RoadType	RoadDesc
11	Interstate: Rural
13	Other Principal Arterial: Rural
15	Minor Arterial: Rural
17	Major Collector: Rural
19	Minor Collector: Rural
21	Local: Rural
23	Interstate: Urban
25	Other Freeways and Expressways: Urban
27	Other Principal Arterial: Urban
29	Minor Arterial: Urban
31	Collector: Urban
33	Local: Urban

Table B.3. The 18 Mobile6.2 vehicle class-road type combinations

Vehicle Types	Road Types	Mobile6.2 Ftype	Mean Travel Speed (MPH)
LDV	Rural Interstate	Freeway	60
LDT	Rural Interstate	Freeway	55
HDV	Rural Interstate	Freeway	40
LDV	Urban Interstate	Freeway	45
LDT	Urban Interstate	Freeway	45
HDV	Urban Interstate	Freeway	35
LDV	Urban Freeways & Expressways	Freeway	45
LDT	Urban Freeways & Expressways	Freeway	45
HDV	Urban Freeways & Expressways	Freeway	35
LDV, LDT	Rural Principal Arterial	Arterial	45
LDV, LDT	Rural Minor Arterial	Arterial	40
HDV	Rural Principal Arterial	Arterial	35
LDT, LDT	Rural Major Collector	Arterial	35
LDV, LDT	Rural Minor Collector, Rural Local	Arterial	30
HDV	Rural Minor Arterial	Arterial	30
LDV, LDT	Urban Principal Arterial, Urban Minor Arterial, Urban Collector	Arterial	20
HDV	Rural Major Collector, Rural Minor Collector, Rural Local	Arterial	25
HDV	Urban Principal Arterial, Urban Minor Arterial, Urban Collector	Arterial	15

LDV = Mobile6.2 vehicle types 1 and 16

LDT = Mobile6.2 vehicle types 2-5

HDV = Mobile6.2 vehicle types 6-15

Table B.4. Rural/Urban and Light/Heavy Duty Characterization

Category	Vehicle Type (Table B.1)	Road Type (Table B.2)
Light Duty Urban	1, 2, 3, 4, 5, 14, 15, 24, 28	23, 25, 27, 29, 31, 33
Light Duty Rural	1, 2, 3, 4, 5, 14, 15, 24, 28	11, 13, 15, 17, 19, 21
Heavy Duty Urban	6 - 13, 16 - 23, 25 – 27	23, 25, 27, 29, 31, 33
Heavy Dury Rural	6 - 13, 16 - 23, 25 – 27	11, 13, 15, 17, 19, 21

Table B.5. Sources of selected HPMS Data

HPMS Data	Rural Functional Systems					
	Interstate	Other Principal Arterials	Minor Arterial	Major Collector	Minor Collector	Local
Interstate Lane Miles	Universe					
Interstate VMT	Universe					
Non-Interstate PAS Lane Miles		Universe				
Non-Interstate PAS VMT		Universe				
FA Highway Lane Miles[1]	Universe	Universe	Universe	Universe		
FA Highway VMT[1]	Universe	Universe	Sample[2]	Sample[2]		
NHS Lane Miles	Universe	Universe	Universe	Universe	Universe	Universe
Miles	Universe	Universe	Universe	Universe	Universe	Universe
Lane Miles	Universe	Universe	Universe	Universe	Universe[3]	Universe[3]
VMT	Universe	Universe	Sample[2]	Sample[2]	Summary[4]	Summary[4]
Total Public Road Miles	Certified Mileage --					

HPMS Data	Urban Functional Systems					
	Interstate	Other Freeways & Expressways	Other Principal Arterial	Minor Arterial	Collector	Local
Interstate Lane Miles	Universe					
Interstate VMT	Universe					
Non-Interstate PAS Lane Miles		Universe	Universe			
Non-Interstate PAS VMT		Universe	Universe			
FA Highway Lane Miles[1]	Universe	Universe	Universe	Universe	Universe	
FA Highway VMT[1]	Universe	Universe	Universe	Sample[2]	Sample[2]	
NHS Lane Miles	Universe	Universe	Universe	Universe	Universe	Universe
Miles	Universe	Universe	Universe	Universe	Universe	Universe
Lane Miles	Universe	Universe	Universe	Universe	Universe	Universe[3]
VMT	Universe	Universe	Universe	Sample[2]	Sample[2]	Summary[4]
Total Public Road Miles	Certified Mileage --					

1 Universe data are used to estimate lane-miles and VMT for the few miles of NHS that are on the minor collector and local functional systems.
2 Expanded sample data are used.
3 Universe miles times 2 (lanes) are used. States are not required to report number of through lanes on these systems, except for any NHS sections.
4 Summary data are used. States are not required to report section level AADT on these systems, except for any NHS sections.

Table B.6. Census Bureau Regions and Divisions with State FIPS Codes

Region 1: Northeast			
Division 1: New England		***Division 2: Middle Atlantic***	
Connecticut	09	New Jersey	34
Maine	23	New York	36
Massachusetts	25	Pennsylvania	42
New Hampshire	33		
Rhode Island	44		
Vermont	50		
Region 2: Midwest			
Division 3: East North Central		***Division 4: West North Central***	
Indiana	18	Iowa	19
Illinois	17	Kansas	20
Michigan	26	Minnesota	27
Ohio	39	Missouri	29
Wisconsin	55	Nebraska	31
		North Dakota	38
		South Dakota	46
Region 3: South			
Division 5: South Atlantic		***Division 6: East South Central***	
Delaware	10	Alabama	01
District of Columbia	11	Kentucky	21
Florida	12	Mississippi	28
Georgia	13	Tennessee	47
Maryland	24	***Division 7: West South Central***	
North Carolina	37	Arkansas	05
South Carolina	45	Louisiana	22
Virginia	51	Oklahoma	40
West Virginia	54	Texas	48
Region 4: West			
Division 8: Mountain		***Division 9: Pacific***	
Arizona	04	Alaska	02
Colorado	08	California	06
Idaho	16	Hawaii	15
New Mexico	35	Oregon	41
Montana	30	Washington	53
Utah	49		
Nevada	32		
Wyoming	56		

Table B.7. Fractions converting VMT by HPMS 2002 vehicle type to VMT by MOBILE6 2002 vehicle type

HPMS 2002 VMT Fractions						2002 VMT Fractions by MOBILE6 Vehicle Type					
HPMS Vehicle Category	RInt	ROPA, RMinArt	RMajC, RMinC, RLoc	UInt	UOther	MOBILE6 Vehicle Type	RInt	ROPA, RMinArt	RMajC, RMinC, RLoc	UInt	UO
Passenger Cars	0.4947	0.5485	0.5622	0.5951	0.6111	LDGV	0.4939	0.5476	0.5613	0.5941	0.6
						LDDV	0.0008	0.0009	0.0009	0.0010	0.0
Motorcycles	0.0043	0.0037	0.0039	0.0041	0.0026	MC	0.0043	0.0037	0.0039	0.0041	0.0
Other 2-Axle 4-Tire Vehicles	0.3034	0.3474	0.3592	0.3181	0.3425	LDGT1	0.0476	0.0545	0.0564	0.0499	0.0
						LDGT2	0.1585	0.1815	0.1876	0.1662	0.1
						LDGT3	0.0482	0.0552	0.0571	0.0505	0.0
						LDGT4	0.0222	0.0254	0.0262	0.0232	0.0
						LDDT12	0.0001	0.0002	0.0002	0.0002	0.0
						LDDT34	0.0010	0.0011	0.0012	0.0010	0.0
						HDGV2B	0.0195	0.0223	0.0231	0.0205	0.0
						HDDV2B	0.0063	0.0072	0.0075	0.0066	0.0
Single-Unit 2-Axle 6-Tire or More Trucks	0.0312	0.0337	0.0361	0.0223	0.0216	HDGV3	0.0012	0.0013	0.0014	0.0008	0.0
						HDGV4	0.0006	0.0006	0.0007	0.0004	0.0
						HDGV5	0.0013	0.0014	0.0015	0.0009	0.0
						HDGV6	0.0028	0.0031	0.0033	0.0020	0.0
						HDGV7	0.0013	0.0014	0.0015	0.0009	0.0
						HDDV3	0.0032	0.0034	0.0037	0.0023	0.0
						HDDV4	0.0028	0.0030	0.0032	0.0020	0.0
						HDDV5	0.0012	0.0013	0.0014	0.0009	0.0
						HDDV6	0.0068	0.0073	0.0078	0.0048	0.0
						HDDV7	0.0101	0.0109	0.0117	0.0072	0.0
Combination Trucks	0.1630	0.0641	0.0340	0.0585	0.0206	HDGV8A	0.0000	0.0000	0.0000	0.0000	0.0
						HDGV8B	0.0000	0.0000	0.0000	0.0000	0.0
						HDDV8A	0.0357	0.0141	0.0075	0.0128	0.0
						HDDV9A	0.1273	0.0501	0.0265	0.0456	0.0
Buses	0.0034	0.0025	0.0046	0.0020	0.0016	HDGB	0.0006	0.0004	0.0008	0.0003	0.0
						HDDBT	0.0011	0.0008	0.0015	0.0006	0.0
						HDDBS	0.0017	0.0013	0.0023	0.0010	0.0
Total	1.0000	1.0000	1.0000	1.0000	1.0000	Total	1.0000	1.0000	1.0000	1.0000	1.0

Table B.8. Mapping of the 28 MOBILE6 vehicle classes to 12 SCC vehicle classes and 8 MOBILE5 vehicle classes

Mapping of MOBILE6 to MOBILE5 and SCC Vehicle Classes			
MOBILE6 Vehicle Class	MOBILE6 Vehicle Code	SCC-Level 12 Vehicle Classes	MOBILE5 Vehicle Class
LDGV	1	LDGV (2201001)	LDGV
LDGT1	2	LDGT1 (2201020)	LDGT1
LDGT2	3		
LDGT3	4	LDGT2 (2201040)	LDGT2
LDGT4	5		
HDGV2B	6	HDGV (2201070)	HDGV
HDGV3	7		
HDGV4	8		
HDGV5	9		
HDGV6	10		
HDGV7	11		
HDGV8A	12		
HDGV8B	13		
HDGB	25		
MC	24	MC (2201080)	MC
LDDV	14	LDDV (2230001)	LDDV
LDDT12	15	LDDT (2230060)	LDDT
LDDT34	28		
HDDV2B	16	2BHDDV (2230071)	HDDV
HDDV3	17	LHDDV (2230072)	
HDDV4	18		
HDDV5	19		
HDDV6	20	MHDDV (2230073)	
HDDV7	21		
HDDV8A	22	HHDDV (2230074)	
HDDV8B	23		
HDDBT	26	BUS (2230075)	
HDDBS	27		

Table B.9. Seasonal VMT Factors

Vehicle Type	***Road Type***	***Seasonal VMT Factors***			
		Winter	Spring	Summer	Fall
LDV, LDT, MC	Rural	0.2160	0.2390	0.2890	0.2560
LDV, LDT, MC	Urban	0.2340	0.2550	0.2650	0.2450
HDV	All	0.2500	0.2500	0.2500	0.2500

Table B.10. Monthly VMT Factors

Vehicle Type	***Road Type***	***Monthly VMT Factors***											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LDV, LDT, MC	Rural	7.44	6.72	8.05	7.79	8.05	9.42	9.74	9.75	8.44	8.72	8.44	7.44
LDV, LDT, MC	Urban	8.06	7.28	8.60	8.33	8.60	8.65	8.94	8.94	8.09	8.36	8.09	8.06
HDV	All	8.62	7.78	8.42	8.15	8.42	8.15	8.42	8.42	8.24	8.52	8.24	8.62

Table B.11. NONROAD Model Equipment Segments

Model
Recreational
Construction
Industrial
Lawn/Garden
Agriculture
Commercial
Logging
Airport Support
Underground Mining
Oil Field
Pleasure Craft
Railroad

Table B.12. State Description File Type

State		
Colorado	Oil production equipment allocations	oil
Delaware	Airport equipment allocations	air
Delaware	Golf equipment allocations	gc
Delaware	Household allocations	hou
Delaware	Logging equipment allocations	log
Delaware	Source populations	pop
Delaware	Recreational vehicle park allocations	rvp
Illinois	Nonroad activity	act
Illinois	Growth rates	grw
Illinois	Source populations	pop
Illinois	Seasonal allocations	sea
Illinois	Inboard watercraft allocations	wib
Illinois	Outboard watercraft allocations	wob
Indiana	Nonroad activity	act
Indiana	Growth rates	grw
Indiana	Source populations	pop
Indiana	Seasonal allocations	sea
Indiana	Inboard watercraft allocations	wib
Indiana	Outboard watercraft allocations	wob
Iowa	Nonroad activity	act
Iowa	Source populations	pop
Iowa	Seasonal allocations	sea
Iowa	Inboard watercraft allocations	wib
Iowa	Outboard watercraft allocations	wob
Michigan	Nonroad activity	act
Michigan	Growth rates	grw
Michigan	Source populations	pop
Michigan	Seasonal allocations	sea
Michigan	Inboard watercraft allocations	wib
Michigan	Outboard watercraft allocations	wob
Minnesota	Nonroad activity	act
Minnesota	Growth rates	grw
Minnesota	Seasonal allocations	sea
Minnesota	Snowmobile allocations	snm
Minnesota	Inboard watercraft allocations	wib
Minnesota	Outboard watercraft allocations	wob
Ohio	Nonroad activity	act
Ohio	Growth rates	grw
Ohio	Source populations	pop
Ohio	Seasonal allocations	sea
Ohio	Inboard watercraft allocations	wib
Ohio	Outboard watercraft allocations	wob
Rhode Island	Source populations	pop
Washington	Inboard watercraft allocations	wib
Washington	Outboard watercraft allocations	wob
Wisconsin	Nonroad activity	act
Wisconsin	Growth rates	grw
Wisconsin	Source populations	pop
Wisconsin	Seasonal allocations	sea
Wisconsin	Inboard watercraft allocations	wib
Wisconsin	Outboard watercraft allocations	wob

Table B.13. Crosswalk table for road types

Roadway Type	*Vulcan Roadway Type*	*Vulcan Road Classification*
Interstate: Rural	Interstate: Rural	1
Other Principal Arterial: Rural	Arterial: Rural	2
Minor Arterial: Rural		
Major Collector: Rural	Collector: Rural	3
Minor Collector: Rural		
Local: Rural		
Interstate: Urban	Interstate: Urban	4
Other Freeways and Expressways: Urban		
Other Principal Arterial: Urban	Arterial: Urban	5
Minor Arterial: Urban		
Collector: Urban	Collector: Urban	6
Local: Urban		