CHARACTERIZATION OF CRITERIA AIR POLLUTANT AND GREENHOUSE GAS EMISSION FACTORS ASSOCIATED WITH ENERGY USE IN THE USA:

Sources, Assumptions, Methodology

Prepared for:

Ralph Torrie Associates

Prepared by:

Alison Bailie, Steve Bernow, Rachel Cleetus, Bill Dougherty,
Charlie Heaps, and Benjamin Runkle

Tellus Institute
11 Arlington Street
Boston, MA 02116

February 2002

Table of Contents

page

List of Tables

Introduction

As part of the project "Strategic Planning Software for Harmonized Strategies for Greenhouse Gas and Criteria Pollutant Reduction", STAPPA/ALAPCO and ICLEI are developing an easy-to-use software tool intended to assist in the development of harmonized strategies for criteria air pollutant (CAP) and greenhouse has (GHG) reduction at the state, air quality management district and local government levels. The tool is initially intended for users in the USA, but could be readily adapted for users in other countries.

The new tool is based on the existing "Cities for Climate Protection" Greenhouse Gas Emissions software system (CCP) developed by Torrie-Smith Associates (TSA). Existing versions of the CCP software are primarily focused on accounting for greenhouse gas emissions. Thus, a major task in the current project is to add to the software the ability to account for criteria air pollutants (CAPs). The targeted audiences for this tool are primarily analysts and policymakers in state and local pollution control agencies and in municipalities.

In this report, we characterize emission factors for both CAPs and GHGs for a variety of processes across the industrial, commercial, residential, transport, and electric sectors. Emission factors are distinguished between "baseline-based" and "measure-based." Baseline-based emission factors represent average, sector-wide emission factors based on the existing and projected equipment vintage, and expected future emission regulations. Measure-based emission factors represent average lifetime emission factors for new technology.

This report documents the sources, assumptions, and methodology used in characterizing these emission factors. Key references include the EIA's energy projections, as well as the EPA's emission inventories, life cycle emission models, and emission factor databases. For technologies where emission factor information is unavailable from these sources, alternative sources are used and documented. Where applicable, this report also provides a step-by-step description of the calculations made to develop final emission factors. Excerpts of the results are also included. A zip disk, provided as an attachment to this report, contains spreadsheet models and databases that were constructed to develop the emission factor estimates.

This report is divided into 2 major parts, one for baseline-based emission factors, and the other for measure-based emission factors. Each major part is further divided into three major sections that address the electric sector, the transport sector, and collectively the residential, commercial, and industrial sectors.

1. Baseline Emission Factors

Baseline-based emission factors are system average emission factors that apply to sectors as a whole. They were developed relative to specifications developed in discussions with TSA (Bailie, et al, 2001 and Tellus, 2001). The following table summarizes the specifications for the emission factors collected.

Table 1-1.1 Summary of specifications for baseline emission factors

	Pollutants					GHGs							
Sector	NO_x	SO_2	VOC	CO	PM_{10}	CO_2	CH_4	N_2O	Units	Fuel Type	Mode	Yrs	Region
Electric	✓	✓	✓	✓	✓	✓	✓	✓	ton/ GWh	NA	• System average • System margin	1990 2000 2010 2020	By NERC region (13)
Transport	✓	✓	✓	✓	✓	✓	✓	✓	gm/ mile; lb/ mmbtu	• Gasoline • Diesel • LPG • CNG, • Ethanol • Methanol	• Cars • light duty trucks • heavy duty trucks • trains • buses	1990 1999 to 2020	National
Residential	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Natural Gas • diesel • Biomass	NA	1990 2000 2010 2020	National
Commercial	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Coal • natural gas • diesel, Biomass	NA	1990 2000 2010 2020	National
Industrial	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Coal • natural gas • residual oil • diesel Biomass	NA	1990 2000 2010 2020	National

The subsections that follow describe the sources, assumptions, and methods used to characterize emission inputs in the five sectors. **A summary of baseline emission factors is provided in the attached zip drive in a spreadsheet file entitled: BASELINE 25 JAN.XLS**.

1.1 Electric Sector

Two types of emission factors were developed for the electric sector, average and marginal. Average emission factors represent the system average emission factor of the regional baseline electricity demand. Marginal emission factors represent the system average emission factor corresponding to reduction in dispatch of power stations on the margin. These latter emission factors are most applicable to the evaluation of measures that impact electricity generation on the system margin, such as the small perturbations that are associated with improvements in end-use efficiency.

1.1.1 Sources

There are several sources that were used in the development of average system and marginal electric emission factors, as follows:

1. **Carbon Dioxide, Sulfur Dioxide, and Nitrogen Oxides:** Annual emission levels associated with electricity generation for these pollutants were obtained directly from regional outputs of the AEO2001 reference case NEMS model run.[1]
2. **Carbon Monoxide, Particulates (< 10 µ), and Volatile Organic Compounds.** Regional average emission factors for these pollutants were developed from a combination of the U.S. EPA's National Air Quality and Emissions Trends Report, 1999 (U.S. EPA, 2001c), and energy data from regional outputs of the AEO2001 reference case NEMS model run.
3. **Methane and Nitrous Oxide.** Average emission factors for these greenhouse gases are obtained from the Intergovernmental Panel on Climate Change (IPCC, 1996).

1.1.2 Major Assumptions

There are several assumptions that are embedded in the determination of emission factors, as follows:

1. The reference case NEMS model run for the AEO2001 was assumed to represent a reasonable projection of electric sales and primary energy consumption by electric generators.
2. National emission factors for CO, PM10, and VOCs, determined using historical emission and energy use levels, are appropriate for use at the regional level.
3. In the determination of system average emission factors, the NEMS model assumes region-wide characteristics. Data does not necessarily reflect the particular mix of electric generation technologies in a given city.
4. In the determination of average marginal emission factors, the NEMS model assumes which types of generation technologies would be dispatched less due to electric demand reductions, on the basis of differences in variable operating costs for the plants in the particular region.

1.1.3 Average System Emission Factors

Emission factors for a baseline analysis need to reflect the likely **average** mix of generating technologies and fuels purchased by end-users in the city. Ideally, emission factors should also reflect the regional variations in fuels and technologies used to generate power, and the likely future trends in emission factors over time from the present to 2020. National average emission factors will also be provided to support those users who do not wish to use region-specific values. For each pollutant, emission factors have been developed for all years between 1999 and 2020, and for the 13 NERC regions. Average emission factors for the United States as a whole are also presented. These emission factors are presented in units of short tons per MWh.

1.1.3.1 CO2, SO2, and NOx

Regional average emission factors for carbon dioxide, sulfur dioxide, and nitrogen oxides were determined using a three-step process, as follows:

---

[1] The NEMS model (National Energy Modeling System) is used by the US Energy Information Agency (USEIA) to develop annual projections of energy production and consumption in the USA (see EIA, 2001). The "reference case NEMS model run" represents AEO2001's base case projection.

1. Total emissions (in short tons) of carbon dioxide, sulfur dioxide, and nitrogen oxides associated with electricity generation were obtained directly from regional outputs of the AEO2001 reference case NEMS model run.
2. Total electric sales of electricity (in MWh) were obtained directly from regional outputs of the AEO2001 reference case NEMS model run.
3. Final emission factors, in units of short tons per MWh, for each NERC region were determined by dividing total annual emissions by total annual electric sales.

1.1.3.2 CO, PM10, and VOC

Regional average emission factors for other criteria air pollutants including carbon monoxide, non-methane volatile organic compounds, and particular matter smaller than 10 microns in diameter were determined using a five-step process, as follows:

1. Emission inventory data was collected for the base year of 1999 at the national level from the U.S. EPA's National Air Quality and Emissions Trends Report (U.S. EPA, 2000)
2. Primary energy use data was collected by fuel type at the national level for the base year of 1999 from the outputs of the AEO2001 reference case NEMS model run.
3. Emission factors by fuel type (in units of pounds per mmbtu) were determined for the base year by dividing emissions (Step #1) by primary energy consumption (Step #2). This emission factor was assumed to be constant through the period 2000-2020.
4. Total annual, regional emissions for the years 2000-2020 were determined by multiplying the fuel based emission factors generated in Step #3 above by primary consumption of these fuels in each of the 13 NERC regions, as projected by the AEO2001 reference case NEMS model run.
5. Final annual emission factors, in units of short tons per MWh, for each NERC region were determined by dividing total annual emissions in Step #4 above by total annual electric sales, as projected by the AEO2001 reference case NEMS model run.

1.1.3.3 CH4 and N2O

Regional average emission factors for methane (**CH_4**) and nitrous oxide (**N_2O**) were determined using a three-step process, as follows:

1. Since emission inventory levels for these pollutants are not tracked in the U.S. EPA's National Air Quality and Emissions Trends Report (U.S. EPA, 2000), we used "Tier 1" fuel-specific emission factors, as recommended by the Intergovernmental Panel on Climate Change (IPCC, 1996).
2. Total annual average emissions for the years 2000-2020 were determined by multiplying the fuel-based emission factors from Step #1 above by primary consumption of these fuels in each of the 13 NERC regions, as projected by the AEO2001 reference case NEMS model run.
3. Final annual emission factors, in units of short tons per MWh, for each NERC region were determined by dividing total annual emissions in Step #2 above by total annual electric sales, as projected by the AEO2001 reference case NEMS model run.

1.1.4 Average Marginal Emission Factors

Conservation measures are one major mitigation category for which electric sector emission factors are required. Reducing electric consumption also reduces air pollutant and GHG emissions depending on which generating technologies are dispatched less. These **marginal** (i.e., avoided) emissions reflect two changes, the effect on expansion of power supplies (the type, size and timing of new power plants) and the dispatch of the fleet of plants to meet loads. Average marginal emission factors can differ substantially from average system emission factors. The baseline marginal emission factors are calculated for years 2000-2020.

1.1.4.1 CO2, SO2, and NOx

Regional average marginal emission factors for carbon dioxide, sulfur dioxide, and nitrogen oxides were determined using a three-step process, as follows:

1. The NEMS model was run with an electricity demand set slightly lower than the base case electricity demand. To reflect the situation where a city/region acts alone in its actions to decrease electricity consumption, the model was run with 1% decrease in electricity demand in one region at a time, while holding it constant in the remaining 12 regions (hereafter called the "NEMS 1% decrement run").[2] [3]
2. The change in the annual emission level in the region with decreased electricity consumption was determined by subtracting "decrement case" emission levels from reference case emission levels.
3. The marginal emission factor was determined as the change in the annual emission level divided by the change in annual electricity generation, as projected by the NEMS 1% decrement run

1.1.4.2 CO, PM10, and VOCs

Regional average marginal emission factors for other criteria air pollutants including carbon monoxide, non-methane volatile organic compounds, and particular matter smaller than 10 microns in diameter were determined using a five-step process, as follows:

1. The change in annual primary fuel use by type was determined by subtracting fuel consumption levels in the NEMS 1% decrement run from fuel consumption levels from reference case fuel consumption levels.
2. Total annual, marginal emissions for the years 2000-2020 were determined by multiplying fuel-specific **average** system emission factors by the change in annual primary consumption of these fuels in each of the 13 NERC regions, as projected by the NEMS 1% decrement run.
3. Annual marginal emission factors, in units of short tons per MWh, for each NERC region were determined by dividing total annual marginal emissions in Step #2 above by the change in annual electricity generation, as projected by the NEMS 1% decrement run.

---

[2] To calculate **national** marginal emission factors for these pollutants, and unlike the regional marginal emission factors, electricity demand is reduced by 1% in *all* regions. Therefore, the national marginal emission factors are not a weighted average of the regional marginal emission factors.
[3] See Annex A for a discussion of the effects of SO2 and NOx emission trading.

1.1.4.3 CH4 and N2O

Regional average marginal emission factors for methane (**CH_4**) and nitrous oxide (**N_2O**) were determined using a three-step process, as follows:

1. The change in annual primary fuel use by type was determined by subtracting fuel consumption levels in the NEMS 1% decrement run from fuel consumption levels from reference case fuel consumption levels.
2. Total annual, marginal emissions for the years 2000-2020 were determined by multiplying fuel-specific **average** system emission factors by the change in annual primary consumption of these fuels in each of the 13 NERC regions, as projected by the NEMS 1% decrement run.
3. Annual marginal emission factors, in units of short tons per MWh, for each NERC region were determined by dividing total annual marginal emissions in Step #2 above by the change in annual electricity generation, as projected by the NEMS 1% decrement run.

1.1.5 Results

Average baseline emission factors over the 1999-2020 period for the electric sector are included in the attached zip disk in the following annotated files:

1. Input data and worksheets:
    - RESULTS COMPARISON.XLS: raw AEO2001 data and calculation of average system and average marginal emission factors.
    - HISTORICFACTORS.XLS: emission factors from electric utilities in the base year developed from historic emission and energy use data
2. Summary worksheet:
    - ELEC-ALLYEARS.XLS: summary of average system and average marginal emission factors.

1.2 Transport Sector

Emission factors in the transportation sector are provided for light duty vehicles (i.e., passenger cars and light-duty trucks), heavy-duty vehicles, and rail for each major transportation fuel as detailed in Table 1.1.

For light and heavy-duty vehicles, emission factors are denominated in units of grams per vehicle mile traveled (grams/mile). Equivalent emission factors are also provided in units of pounds per million BTU (lb/MMBtu). For rail, emission factors are denominated in units of lb/MMBtu only.

Average emission factors for the existing fleet of vehicles depend on the likely mix of vehicle technologies, fuels, and age vintage. Criteria air pollutant emission factors, as well as nitrous oxide and methane emission factors depend not only on the amount and type of fuel consumed or avoided, but also on the technology characteristics, operational parameters, and emission control equipment of vehicles. Carbon dioxide emission factors are more straightforward as they depend only on the amount and type of fuel consumed or avoided.

Average emission factors (CAPs, N2O, CH4) for new vehicles depend on fuel type and the regulatory standard to which they are certified. Carbon dioxide emission factors are more straightforward as they depend only on the amount and type of fuel consumed or avoided.

1.2.1 Sources

The transport sector emission factors were derived from a variety of sources, as follows:

1. **Criteria air pollutant emissions levels** are from the USEPA's annual report of air pollution emission trends (USEPA, 2001c). Specialized reports from this database are developed from USEPA (2001b).
2. **On-highway vehicle miles traveled (VMT) in 1990 and 1999:** This data is from the Annex D of USEPA (2001a).
3. **On-highway vehicle miles traveled and fleet average fuel economy for the years 2000 through 2020:** National Energy Modeling System (NEMS) output for the reference case (USEIA, 2001)
4. **Emissions Standards** are from published USEPA federal and California-specific tailpipe standards (USEPA, 2000).
5. **Off-road (rail) emission factors** are from published USEPA emission factors for locomotives (USEPA, 1997).
6. **Greenhouse Gas Emissions and Fuel Use Data** are from the USEPA's national greenhouse gas inventory (USEPA, 2001a).
7. **On-Road Stock Turnover Values** are from Oak Ridge National Laboratory's transportation data book (Davis, 2001).
8. **VMT Data Determination Methodology** is from the USEPA (2001d).
9. **IPCC GHG emission inventory guidelines** are from IPCC (1996)
10. **On-road deterioration rates for LDVs and HDVs for criteria air pollutants** are from USEPA (2001e).

1.2.2 Assumptions

To determine baseline fleet-wide emission factors, the following simplifying assumptions were made:

1. VMT per year per age vintage is assumed constant. In other words, old and new cars alike are presumed to drive the same number of miles per year.
2. The model also assumes that the stock turnover and deterioration rates stay constant with time. In reality, economic factors and quality improvements may cause these rates to change.

1.2.3 Base Year (1990, 1999) Emission Factors for LDVs and HDVs: Gasoline and Diesel

The approach used to determine historical emission factors for the years 1990 and 1999 is described below. For each pollutant or greenhouse gas identified in Table 1.1, emission factors have been developed in units of grams per mile and lbs per mmbtu.

1.2.3.1 CO, NOx, VOC, SO2, PM10: gm/mile

Historic emission factors (gm/mile) for the above pollutants were determined for the years 1990 and 1999 by fuel, by vehicle type using a three-step process, as outlined below:

1. The **actual levels of pollution** for each mode of transport were obtained from the EPA's National Inventory in 1990 and 1999 (USEPA, 2001b).
2. VMT data was obtained for the vehicle fleet, as follows:
   - **1990 VMT** data for each mode of transport for California and the rest of the country were obtained from Annex D of USEPA (2001a).[4]
   - **1999 VMT** data for each mode of transport for California and the rest of the country was also obtained from Annex D of USEPA (2001a). See the table below for a check against EIA (2001) showing:
     - there is good agreement for gasoline LDV VMT. This is the dominat category, accounting for about 90%of all on-road VMT.
     - EPA's gasoline and diesel HDV VMT estimates are higher than the EIA estimate because the EPA includes bus VMT whereas only HDV freight vehicles are included in the EIA estimate.
     - There is poor agreement for diesel LDVs. However, this is a small category, accounting for less than 1% of total VMT.
     - EIA does not report motorcycle VMT.

Table 1.2: VMT (billion miles) comparison between EPA and EIA estimates for 1999

	EPA (2001a)	EIA (2001)	% diff from EPA
Gasoline LDVs	2366	2329	-1.6%
Gasoline HDVs	82	21	-74.5%
Diesel LDVs	9	35	294.2%
Diesel HDVs	211	182	-13.4%
Motorcycles	10.5	NA	NA

3. Emission factors in grams per mile were calculated by dividing total emissions (Step #1) by total VMT (Steps #2).

1.2.3.2 CO, NOx, VOC, SO2, PM10: lb/mmbtu

To calculate emission factors in units of lbs/mmbtu, one additional variable was needed – average fleet fuel economy by vehicle class. Historic fuel economy was determined for the years 1990 and 1999 using a two-step process, as outlined below:

1. **Fuel economy in 1990 and 1999** was determined from data provided by the EPA (2001a). No data was readily available from the EIA for 1990. This involved the following as per assumptions in USEPA (2001a):

[4] The VMT reported in this document is based on the methodology described in EPA (2001d). Note in particular section 4.6.3 (p. 4-193), which shows how the EPA's VMT data estimation has changed over time.

- Identify the VMT profile by vehicle age (years) and fuel type for highway vehicles (From Table D-5)
- Identify control technology shares (% of VMT) within and outside California (from Table D-7 for gasoline, from Table D-11 for diesel)[5]

2. Identify average fuel economy for each control technology. The USEPA uses gm CO2 per km as a proxy for fuel economy. This is provided in Table D-12 (and converted to km/liter using standard conversion factors). The source for these values is IPCC (1997), which provides fuel economy values for each vehicle type and control technology, as shown in the table below

Table 1.3:Vehicle Fuel Economy (source IPCC, 1997)

Fuel/Control Technology	**Fuel Economy (mpg)**		
GASOLINE	**Passenger Cars**	**Light-Duty Trucks**	**Heavy-Duty Trucks**
LEV	20.0	14.1	
Tier 1	19.5	14.1	
Tier 0	18.8	11.3	5.4
Oxidation Catalyst	14.6	11.3	5.4
Non-Catalyst	10.6	9.4	4.2
Uncontrolled	11.1	9.6	4.2
DIESEL			
Advanced	23.5	16.9	5.6
Moderate	22.6	16.9	5.6
Uncontrolled	17.6	13.4	5.2

3. Fuel economy is then run through the stock turnover model in the same way as the N_2O and CH_4 emission factors. While it is true that control technology may not directly change fuel economy, the typical manufacturing year of vehicles with each control type weighs in the assumption about its efficiency.

4. Combine the fuel economy for each control technology to compute an adjusted fuel economy for each vehicle model year, as follows:

$$FE_{MY} = \sum \left(Control_k \times FE_k \right)$$

Where:

FE_{MY} is the adjusted fuel economy for that model year (mpg)

$Control_k$ = control technology assignment portion,

k = range of control technology options (in the example above, k would be the set: {non-catalyst, oxidation, tier 0})

FE_k = emission factor for control technology type k

5. Calculate weighted average fuel economy across all years and control technology shares for each vehicle class (nation, California, non-California) as per the following formula:

[5] Technology shares refer to the level of pollution control equipment, i.e., uncontrolled, non-catalyst, oxidation catalyst, Tier 0, Tier 1, and LEV.

$$Fleet\ Average\ FE_k = \sum_{k-MY=0}^{1990,1999} \left(t_{k-MY} \times FE_{MY}\right)$$

Where:

MY = model year

k = present year (year for which one is determining the fleet average fuel economy)

EF_{MY} *= adjusted fuel economy for a certain model year (mpg)*

t_i *= percentage of VMT in cars of age (i)*

6. Details of these calculations are provided on a spreadsheet in the attached CD-ROM entitled FUEL ECONOMY BASELINE CALCULATIONS.XLS.
7. **Emission factors** in units of pounds per mmbtu were calculated by multiplying gm/mile by the fleet average fuel economy (in miles/gallon), and applying appropriate conversion factors.

Fuel economies using EPA data were determined for all years from 1990 to 2020, which allowed for consistently derived average fuel economies for all years. These values were compared with EIA projections of on-road average fuel economy, as provided in EIA (2001). Typically, the EIA projections are higher than the EPA projections, as shown in the table below, with the largest differences for gasoline vehicles, and minor differences for diesel vehicles. These differences are likely due to different assumptions regarding fuel economy by technology type.[6] The use of the EPA results has the effect of producing emission factors (lb/mmbtu) which are lower than what they would be using the EIA results.

Table 1.4: Comparison between EPA and EIA Projections for Average fleet fuel economy

Year	1990	1999	2000	2001
EPA-derived results (mi/gge)				
Cars	17.2	19.0	19.1	19.2
LDTs	10.9	12.8	13.0	13.2
Gas HDV	4.2	4.8	4.8	4.8
Diesel HDV	5.2	5.6	5.6	5.6
EIA results (mi/gge)				
Cars	NA	23.53	23.75	23.74
LDTs	NA	16.83	16.89	16.88
Gas HDV	NA	8.15	8.16	8.16
Diesel HDV	NA	5.84	5.90	5.95
Difference relative to EPA (%)				
Cars	NA	19%	19%	19%
LDTs	NA	24%	23%	22%
Gas HDV	NA	41%	41%	41%
Diesel HDV	NA	4%	5%	6%

[6] EPA-derived results use IPCC fuel economy data and an EPA fleet turnover model. The EIA-derived data is taken directly from the EIA's AEO projections.

1.2.3.3 N2O and CH4: gm/mile

Historic emission factors (gm/mile) for the above pollutants were determined for the years 1990 and 1999 using a three-step process (based on USEPA, 2001a), as outlined below:

1. Identify the VMT profile by vehicle age (years) and fuel type for highway vehicles. Table D-5 provides data for the age profile by vehicle type (cars, LDTs, HDVs, and motorcycles) for both diesel and gasoline fueled vehicles. These tables show the percentage of VMT driven by vehicles of each age, from one to twenty-five years old.
2. Identify control technology shares (% of VMT) within and outside California. Tables D-7 (gasoline) and Table D-11 (diesel) provide control technology assignments for each vehicle's model year. These assignments are separated between California standards and rest-of-country standards for cars and LDTs. For example, gas cars made between 1980 and 1982 are assigned to non-catalyst, oxidation, or Tier 0 technology controls as shown on the excerpt in the table below.

Table 1.5: Excerpt from Control Technology Assignments Worksheet (USEPA, 2001a)

Model Year	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV	Total
1980	5%	88%	7%	0	0	100%
1981	0	15%	85%	0	0	100%
1982	0	14%	86%	0	0	100%

3. Identify average N2O and CH4 emission factor for each control technology (gm N2O per km and gm CH4 per km provided in Table D-12, and converted to gm of each pollutant per mile).:
4. Combine N2O and CH4 emission factor for each control technology to compute an adjusted emission factor for each vehicle model year, as follows:

$$EF_{MY} = \sum \left(Control_k \times EF_k \right)$$

Where:

EF_{MY} *is the adjusted emission factor for that model year (MY)*

$Control_k$ *= control technology assignment portion,*

k = range of control technology options (in the example above, k would be the set: {non-catalyst, oxidation, tier 0})

EF_k *= emission factor for control technology type k*

5. Calculate weighted average emission factor across all years and control technology shares for each vehicle class (nation, California, non-California) as per the following formula:

$$Fleet\ Average\ EF_k = \sum_{k-MY=0}^{1990,1999} \left(t_{k-MY} \times EF_{MY} \right)$$

Where:

MY = model year

k = present year (year for which one is determining the fleet average emission factor)

EF_{MY} *= adjusted emission factor for a certain model year*

t_i *= percentage of VMT in cars of age (i)*

1.2.3.4 N2O and CH4: lb/mmbtu

To convert emission factors from units of grams per mile to units of lbs/mmbtu, average fleet fuel economy by vehicle class (in miles per gallon, as described in Section 1.2.3.2) was multiplied by emission factors (in grams per mile), and appropriate conversion factors applied.

1.2.3.5 CO2: lb/mmbtu

Carbon dioxide emission factors by fuel type was obtained from the IPCC (1996) in units of tonnes carbon per TJ, and converted to lb CO2/mmbtu by applying appropriate conversion factors.

1.2.3.6 CO2: gm/mile

Carbon dioxide emission factors in units of lb CO2/mmbtu were converted to units of gm/mile by dividing by average fleet fuel economy by vehicle class (in miles per gallon, as described in Section 1.2.3.2).

1.2.4 Baseline (2000-2020) Emission Factors for LDVs and HDVs: Gasoline and Diesel

Baseline emission factors for the vehicle fleet should also incorporate the effect of gradually more stringent emission reduction requirements, as reflected by federal regulations. The approach used to determine historical emission factors for the years 2000 through 2020 is described below. For each pollutant or greenhouse gas identified in Table 1.1, emission factors have been developed in units of grams per mile and lbs per mmbtu.

1.2.4.1 CO, NOx, VOC, SO2, PM10: gm/mile

Emission factors (gm/mile) for the above pollutants were determined for the years 2000 through 2020 by fuel, by vehicle type using a seven-step process, as outlined below:

1. Establish the emission standard in year, t as per USEPA (2000).
2. Determine an average VMT per year based on USEIA (2001) for LDVs and HDVs.
3. Take account of emission factor deterioration rates (gm/mi per 1000 miles) as per assumptions in USEPA (2001e). These rates are given in the table below in two parts: deterioration before and after 50,000 miles.

Table 1.6: Transport Deterioration Factors (g/mi per 1000 miles)

	CO <50k mi	CO >50k mi	NO_x <50k mi	NO_x >50k mi	VOC <50k mi	VOC >50k mi	PM-10 <50k mi	PM-10 >50k mi	SO_2 <50k mi	SO_2 >50k mi
Gasoline cars	0.145	0.343	0.008	0.020	0.007	0.027	0.002	0.001	0	0
Gasoline LDTs	0.145	0.343	0.008	0.019	0.007	0.027	0	0	0	0
Diesel cars	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.001	0	0
Diesel LDTs	0.004	0.004	0.003	0.003	0.004	0.004	0.002	0.001	0	0
Gasoline HDVs	0.064	0.064	0.004	0.004	0.009	0.009	0	0	0	0
Diesel HDVs	0.008	0.008	0	0	0	0	0	0	0	0

4. Use a representation of the age vintage of vehicles in the fleet based on Table 6.6 of Davis, 2001. These values are specific to 1999, and give percent of vehicles in operation for each age up to 15 years. To make these values relevant to all years, a quadratic best-fit equation was found based on the 1999 values. This equation was taken to 20 years and applied to all years in question, from 1999 to 2020.[7]

5. Emission standards (from step #1) were combined with deterioration factors (from step #2) and on-road stock turnover values (from step #3) to estimate emission factors for 1999 in units of gm/mile. The formula used is as follows:

$$Emission\ Factor = \sum_{k=1979}^{1999} Percent\ of\ Stock_k \times \left(EF_k + Annual\ VMT \times Deterioration\ Factor_k\right)$$

Where: k = year between 1979 and 1999,

EF_k = EPA emission standard for model year k,

Annual VMT = 12,508 miles for LDVs and 31, 358 miles for HDVs

Deterioration factor in year k (in units of g/mi per 1000 miles)

6. The estimated emission factor (Step #5) was then compared to the actual emission factor as determined in Section 1.2.3.1. Ratios were developed and used as a calibrating benchmark for subsequent years. Benchmark factors are calculated for each pollutant and vehicle category. These benchmark factors are therefore very important, and assume that EPA and EIA data are compatible: that the fleets measured in each are similar; and that vehicles are classified in the same manner. A summary of the ratios is shown in the table below.

Table 1.7: Benchmark factors used in the period 2000 through 2020

Vehicle type	CO	NOX	VOC	PM-10	SO2
Gasoline cars	0.57	0.72	0.78	3.30	1.00
Gasoline light trucks	0.55	0.63	0.79	0.18	1.00
Diesel cars	0.37	1.07	0.76	0.35	1.00
Diesel light trucks	0.13	0.77	0.46	0.69	1.00
Gasoline HDVs	1.35	0.67	1.26	0.31	1.03
Diesel HDVs	0.63	2.33	1.09	2.09	1.00

7. Finally, emission factors for years 2000 through 2020 were estimated using the formula in Step #5 multiplied by the benchmark factors in Table 1.7.

[7] A useful refinement to this approach would be to predict changes in stock turnover with time, rather than using the same values for each year.

1.2.4.2 CO, NOx, VOC, SO2, PM10: lb/mmbtu

To convert emission factors from units of grams per mile to units of lbs/mmbtu, average fleet fuel economy by vehicle class (in miles per gallon, as described in Section 1.2.3.2) was multiplied by emission factors (in grams per mile).

1.2.4.3 N2O and CH4: gm/mile

Emission factors (gm/mile) for the above pollutants were estimated for the years 2000 through 2020 using the same process (based on USEPA, 2001a), as was used to calculate 1990 and 1999 emission factors (see Section 1.2.3.3), with the following modifications:

1. Outside California, it was assumed that 100% of the new fleet would meet Tier1 standards for the years 2000 through 2020.
2. Inside California, it was assumed that 20% of the new fleet would meet LEV standards and the remainder would meet Tier1 standards for the years 2000 through 2020.

1.2.4.4 N2O and CH4: lb/mmbtu

To convert emission factors from units of grams per mile to units of lbs/mmbtu, average fleet fuel economy by vehicle class (in miles per gallon, as described in Section 1.2.3.2) was multiplied by emission factors (in grams per mile).

1.2.4.5 CO2: lb/mmbtu

Carbon dioxide emission factors by fuel type were obtained from the IPCC (1996) in units of tonnes carbon per TJ, and converted to lb CO2/mmbtu by applying appropriate conversion factors.

1.2.4.6 CO2: gm/mile

Carbon dioxide emission factors in units of lb CO2/mmbtu were converted to units of gm/mile by dividing by average fleet fuel economy by vehicle class (in miles per gallon, as described in Section 1.2.3.2).

1.2.5 Baseline Emission Factors for Buses: Gasoline and Diesel

In the development of the national inventory of pollutants emissions by mobile source, the USEPA (2001b) includes buses in the HDV category. That is, the emission factor for HDV's - both diesel- and gasoline-fueled - represents an aggregate emission factor that incorporates bus emissions. Since the same emission standards apply to both for HD freight vehicles and buses (see USEPA, 1997a), this seems like a reasonable approach. Therefore, the methodology described previously for determining emission factors for HDVs also applies to buses.

1.2.6 Baseline Emission Factors for LDVs, HDVs, and Buses: Alternative Fuels

As shown in Table 1.1, alternative fuels include LPG, CNG, ethanol, and methanol. The estimation methods applied for conventional fuels (i.e., gasoline and diesel) can not be applied due to the lack of data. That is, the USEPA does not identify CAP emissions from AFV fleet. Furthermore, regulatory standards apply to gasoline- and diesel-fueled vehicles only.

It was assumed therefore that average lifetime emission factors for new AFVs would represent an adequate proxy for fleetwide emissions. Since AFVs are likely to be considered as a mitigation measure relative to conventional vehicles (as opposed to relative to other AFVs), this assumption is reasonable. Average lifetime emission factors for new AFVs are described in a later section.

1.2.7 Baseline Emission Factors (1990, 1999-2020) for Rail

This section addresses rail emissions associated with rail powered by diesel and residual oil. For electric rail, electric sector emission factors should be applied.

1.2.7.1 CO, NOx, VOC, PM10: lb/mmbtu

Emission factors (in grams per gallon) for these pollutants are provided **directly** from EPA (1997). The EPA provides fleet average emission factors for all locomotives from 1999 to 2040 for VOCs, CO, NO_x, and PM. These emission factors were converted to (lb/mmbtu) using standard conversion factors.[8] These emission factors account for:

- Different locomotive service categories (i.e. National Freight Line Haul, National Freight Switching, Local and Regional Freight, Passenger),
- Emission control categories (i.e. Tier 0, Tier 1, and Tier 2),
- Stock turnover.

1.2.7.2 SO2: lb/mmbtu

Sulfur dioxide emission factors for locomotives are found using a four-step process, as described below:

1. Obtain total rail emissions of SO2 from USEPA (2001b).
2. Obtain fuel use data for locomotives from USEPA (2001a) for years 1990 and 1999. Sum across residual and diesel oil categories.
3. For 1990 and 1999 emission factors, divide SO2 emissions by total rail fuel use.
4. For the 2000 to 2020 period, use the 1999 emission factor. This is considered a reasonable assumption since SO_2 levels depend mostly on the sulfur level of the oil rather than a control technology.[9]

1.2.7.3 CO_2, CH_4, and N_2O: lb/mmbtu

Greenhouse gas emission factors for locomotives are found using a four-step process, as described below:

1. Obtain fuel use data for locomotives from USEPA (2001a) for years 1990 and 1999. Sum across residual and diesel oil categories.
2. Obtain total rail emissions of each greenhouse gas from USEPA (2001a).

---

[8] Gallons to mmBTU taken from EPA/STAPPA/ALAPCO, 1999

[9] See, for example, the EPA's 40 CFR Parts 85, 89 and 92, as cited in: http://www.epa.gov/otaq/regs/nonroad/locomotv/loconprm.pdf).

3. For 1990 and 1999 emission factors, divide GHG emissions by total rail fuel use.
4. For the 2000 to 2020 period, use the 1999 emission factor.

1.2.8 Results

Average baseline emission factors over the period 1999-2020 for the transport sector are included in the attached zip disk in the following annotated files:

1. Input data and summary worksheets:
   - EIA PETROL CONSUMPTION IN TRANSPORT 1949TO2000.XLS: historic energy use in the transport sector
   - N2O BASELINE CALCULATIONS.XLS: input data and stock turnover modeling to estimate nitrous oxide emission factors.
   - CH4 BASELINE CALCULATIONS.XLS: input data and stock turnover modeling to estimate methane emission factors.
   - CO2 BASELINE CALCULATIONS.XLS: input data and fuel economy modeling to estimate carbon dioxide emission factors.
   - TRANSPORT BASELINE 5FEB.XLS: input data and stock turnover modeling to estimate CO, NOX, VOC, PM-10, AND SO2 emission factors
   - BUS TRANSPORT BASELINE.XLS: summary of CO, NOX, VOC, PM-10, SO2, CH4, N2O, and CH4 emission factors.

1.3 Residential, Commercial, and Industrial Sectors

Emission factors for the residential, commercial, and industrial sectors (RCI) are provided by fuel and by sector.

1.3.1 Sources

There are several sources used to develop RCI emission factors:

1. **Criteria air pollutant emissions levels** are from the USEPA's annual report of air pollution emission trends (USEPA, 2001c). Specialized reports from this database are developed from USEPA (2001b).
2. **Fuel consumption for 1990:** National Energy Modeling System (NEMS) internal data (USEIA, 2001a).
3. **Fuel consumption for the years 1999 through 2020:** National Energy Modeling System (NEMS) output for the reference case (USEIA, 2001).
4. **Greenhouse gas emission factors** by fuel type are taken from IPCC, 1996.

1.3.2 Assumptions

1. The EPA and EIA use the same classification guidelines to determine sector-based characteristics (i.e. the two databases define which energy uses and correlated emissions fall into "residential," "commercial," and "industrial" sectors in the same manner).

2. Emission factors calculated for 1999 are presumed to hold true through 2020.

1.3.3 Baseline (1990, 1999-2020) Emission Factors

1.3.3.1 CO, NOx, VOC, SO2, PM10: lb/mmbtu

Emission factors for the above pollutants were determined for the years 1999 through 2020 by fuel and sector using a three-step process, as outlined below:

1. Obtain total emissions by sector and fuel type from USEPA (2001b) for the years 1990 and 1999.
2. Obtain energy consumption data by sector and fuel type from USEIA (2001a) for 1990.
3. Obtain energy consumption data by sector and fuel type from USEIA (2001) for 1999.
4. For 1990 and 1999 emission factors, divide emissions by fuel use.
5. For 2000 through 2020 emission factors, use the 1999 value.

Note: emission factors for the residential sector for natural gas and oil for CO, VOCs, and PM10 were set equal to commercial sector emission factors due to a lack of specification in the pollutant emission data.

1.3.3.2 CO_2, CH_4, and N_2O: lb/mmbtu

IPCC (1996) GHG emission factors for each sector were converted from units of kg/TJ to lb/mmbtu and applied to 1990 and 1999 through 2020.

1.3.4 Results

Average baseline emission factors over the period 1999-2020 for the RCI sectors are included in the attached zip disk in the following annotated files:

1. Input data and summary worksheets:
    - RCI BASELINE.XLS: input assumptions and summary calculations.

2. Measure-based Emission Factors

Measure based emission factors apply to specific, new control technologies that can be used to reduce sector emissions of both criteria air pollutants and greenhouse gases. They were developed relative to specifications developed in discussions with TSA (Bailie, et al, 2001 and Tellus, 2001). The following table summarizes the specifications for the emission factors collected.

Table 2.1 Summary of specifications for measure-based emission factors

	Pollutants					GHGs						
Sector	NO_x	SO_2	VOC	CO	PM_{10}	CO_2	CH_4	N_2O	Units	Fuel Type	Mode	Region
Electric	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Coal • NG • Residual oil • Distillate • Biomass	Boilers	National
Transport	✓	✓	✓	✓	✓	✓	✓	✓	gm/ mile; lb/ mmbtu	• Gasoline • Diesel • LPG • CNG, • Ethanol • Methanol	• Cars • light duty trucks • heavy duty trucks • trains • buses	CA, Rest-of-Country
Residential	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Coal • NG • Residual oil • Distillate • Biomass	Boilers	National
Commercial	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Coal • NG • Residual oil • Distillate • Biomass	Boilers	National
Industrial	✓	✓	✓	✓	✓	✓	✓	✓	lb/ mmbtu	• Coal • NG • Residual oil • Distillate • Biomass	Boilers	National

The subsections that follow describe the sources, assumptions, and methods used to characterize emission inputs in the five sectors. **A summary of measure-based emission factors is provided in the attached zip drive in a spreadsheet files entitled: RCEI MEASURES 4JAN02.XLS and TRANS MEASURES 7FEB02.XLS**.

2.1 Electric Sector

Measures in the electric sectors are likely to be either efficiency-based (e.g., a more efficient prime mover), fuel switching (e.g., switching from oil to natural gas), or pollution control based (e.g., adding a scrubber to a coal steam power station). The first two measures (i.e., efficiency and fuel switching) will result in changes in emissions that can be tracked using the baseline-based emission factors developed in the previous section. However, the last measure (i.e., pollution control) will lead to significant variation in air pollution emission factors. This section describes the sources, assumptions, and methods to determine the emission factors of electric generation facilities subject to a range of pollution control equipment.

2.1.1 Sources

A variety of sources used in the determination of emission factors:

1. **Emission Factors** were obtained from USEPA (2001f)
2. **Fuel specifications** were obtained from USEPA (2001f). For those fuels not included in the AP-42 Appendix, values from the LEAP model program were used.

3. **Low-Sulfur Coal** data was obtained from a number of sources from the USEIA (2001b) USEIA (low-sulfur coal forms), FERC (2001), the US Department of Commerce (2001), and Hong and Slater (1995).
4. **CH4 and N2O emission factors** are provided from ICF (1999), IPCC (1994) and De Soete (1993).

2.1.2 Assumptions

1. Most values come from directly or are derived from the EPA Compilation of Air Pollutant Emission Factors (AP-42). Preference is given to AP-42 values over other data sources.
2. The processes that control pollutant emissions are described and quantified in the text and tables within AP-42. Values for pollution control efficiency relative uncontrolled emission factors were assumed to be representative.
3. Not all fuels have data for each process (e.g. anthracite and coke have no data available for AFBC boiler types). We have assumed that these categories are not applicable.
4. The USEPA's AP-42 database is given precedence over the IPCC values. For some process/fuel combinations, AP-42 provides N_2O and/or CH_4 emission factors. For those that the AP-42 does not cover, the IPCC values are used. Converting from the generic "coal" emission factor for nitrous oxide (as given by IPCC) to specific types of coal, it was assumed that nitrous oxide emissions would be relative to the percentage nitrogen content in the fuel.
5. It is assumed that the controls do not change N_2O or CH_4 emissions, due to the lack of available data and lack of actual influence, respectively.

2.1.3 NO_x, VOC, PM-10, SO_2, and CO Emission factors

There are several generalized steps for calculating these emission factors:

1. **Obtain uncontrolled emission factors:** Uncontrolled process emission factors are taken directly from the EPA's AP-42 FIRE database.
2. **Convert to units of lb per mmbtu:** Emission factors from the FIRE database are provided in units of pounds per ton. To convert to pounds per mmBTU, the emission factor was divided by the heating value (mmBTU/ton) of the fuel.
3. **Split emission factors into two groups: coal and non-coal fuels**. These groups are described in the next subsections, along with the case of low-sulfur coal.
4. **Determine controlled Emission Factors:** Emission factors for processes with emission controls were provided in one of two ways.
   - **Provided**: If emission factors for the controls are provided by AP-42 or in the FIRE database, then these are used.
   - **Calculated**: The FIRE database does not provide factors for every control for each process and fuel type, so in some cases controlled emission factors needed to be calculated. Based on descriptions of the control types in the text and tables within the AP-42 document, control efficiency values can be determined (for example,

electrostatic precipitators (ESP's) are 97.7% effective at reducing particulate matter). These efficiency values were used to calculate controlled emission factors as a reduction in emissions relative to the uncontrolled case for the pollutant in question. Pollutants not affected by the control technologies have the same emission factors as in the uncontrolled case. Most controls are measures applied to the boiler itself, and are described within the AP-42 document. Efficiency values for particulate matter were derived from tables showing size specific emission factors for different control types. Values for particle size 10 μm were compared for each control against the uncontrolled factor to find the control efficiency.

2.1.3.1 Coal Fuels

Coal fuels have four specific types of scrubbers used to control SO_2 (lime/limestone, dual alkali, magnesium oxide/hydroxide, and sodium carbonate), as well as a generic label "scrubbers". Each of these scrubber-types was assigned a value for controlling PM10 as well as SO_2. The other controls affect the emission factors of only one pollutant (i.e. ESP's, baghouses, and multiple cyclones control PM10 emissions; low NO_x burners (LNB), overfire air (OFA), reburning, selective catalytic reduction (SCR), and selective non-catalytic reduction (SNCR) control NO_x emissions).

The table below summarizes scrubber control efficiency for sulfur oxides and particulate emissions. Sulfur control efficiency data is from the AP42 database.[10] Particulate control efficiency data is also from the AP42 database.[11] Assumed values for the generic scrubber category also based on AP42.

Table 2.2: Wet scrubbers for coal fueled technologies (Control for both SO_x and PM10).

	SO_x Controls for Coal			**PM10 Controls for Coal**
Scrubber Type	Average Value	Minimum Control Efficiency	Maximum Control Efficiency	Derived value
Wet				
Lime/limestone	87.5%	80.0%	95.0%	81.7%
Sodium Carbonate	89.0%	80.0%	98.0%	81.7%
Magnesium oxide/hydroxide	87.5%	80.0%	95.0%	81.7%
Dual alkali	93.0%	90.0%	96.0%	81.7%
Generic	95.0%	n/a	n/a	95.0%

[10] (www.epa.gov/ttn/chief/ap42/ch01; from section 1.1 - supplement E, Bituminous and Sub-bituminous coal combustion, table 1.1-1).

[11] (Table 1.1-6. Cumulative Particle Size Distribution and Size-Specific Emission Factors for Dry Bottom Boilers Burning Pulverized Bituminous and Sub-bituminous Coal; www.epa.gov/ttn/chief/ap42/ch01/final/c01s01.pdf; ap42, 5th ed, vol. 1; ch 1.1 Bituminous and Sub-bituminous Coal Combustion; Supplement E., Sept 98.)

The table below summarizes control efficiency for particulates by type of control equipment. The data is from the AP42 database.[12]

Table 2.3 Particulate Matter Controls for Coal Fueled Technologies

Control	Assumed Control Efficiency
ESP	97.7%
Baghouse	99.1%
Multiple Cyclone	74.8%

The table below summarizes control efficiency for nitrogen oxides by type of control equipment. The data is from the AP42 database.

Table 2.4 NO_x Controls for Coal Fueled Technologies

Control Type	Control	Min	Max	Value
Combustion	Overfire Air (OFA)	20%	30%	25%
	Low NOx burners (LNB)	35%	55%	45%
	Low NOx burners with overfire air (LNB+OFA)	40%	60%	50%
Flue Gas Treatment	Reburning	50%	60%	55%
	Selective Non-catalytic reduction	30%	60%	45%
	Selective catalytic reduction	75%	85%	80%

2.1.3.2 Low Sulfur Coal

A fuel-based, rather than control equipment-based approach to achieving sulfur emission reductions is the use of low sulfur coal. Rather than being a change made to the boiler facility, low sulfur coal has a different chemical content, and could be subject to additional controls (most likely for other emissions such as NO_x or PM10). This fuel type was determined in two steps:

1. The **emission factors** (in lb/ton) for this type of coal were taken as the average of the values for bituminous and sub-bituminous coal for each of the different boiler types.
2. These were **converted** to factors with units of lb/mmBTU using a heating value of 19.43 mmBTU /ton, which is derived from data from the Energy Information Administration (1995). The sulfur value of this coal (0.3 lb S/ mmBTU coal) is also taken from the Energy Information Administration (2001).

Because the low sulfur coal emission factors are averages, values for each pollutant will be different from the uncontrolled case using a fuel with normal sulfur content. To apply additional controls to this coal, the sulfur value should be taken from this fuel and the controlled pollutant should be taken from the normal-fuel case.

2.1.3.3 Non-Coal Fuels

Non-coal fuels include natural gas, oil, and biomass. These fuels have different controls from coal, primarily focusing on NO_x rather than SO_x emissions. Fuel oils (distillate oil and residual

[12] Derived from Table 1.1-6. Cumulative Particle Size Distribution and Size-Specific Emission Factors for Dry Bottom Boilers Burning Pulverized Bituminous and Sub-bituminous Coal; www.epa.gov/ttn/chief/ap42/ch01/final/c01s01.pdf; ap42, 5th ed, vol. 1; ch. 1.1 Bituminous and sub-bituminous coal combustion; supplement E., Sept 98.

oil) have a large number of control options. Their NO_x emissions can be controlled to varying degrees by the following types of pollution control technologies:

- Flue gas recirculation (FGR)
- Burners out of service (BOOS)
- Selective non-catalytic reduction (SNCR)
- Selective catalytic reduction (SCR)
- Low excess air (LEA)
- Staged combustion (SC)
- FGR + SC
- Reduced Air Preheat (RAP)
- Air Heater (SCR)
- Duct SCR
- Low NOx burners (LNB) and FGR

Particulate matter control technologies are the same as for coal (i.e. cyclones, ESP, and baghouse filters) and there is also a single scrubber option that controls both PM10 and SO_x emissions. The range of fuel oil control efficiency for NOx, PM-10,and SOx are summarized in the table below.[13]

The midrange value is a calculated simple average, and was used to represent average emission factors from the implementation of these technologies. For the LNB and FGR category, the average value is as specified in AP42. Values for specific fuel oil grades (e.g. distillate oil grade 4; distillate oil grades 1 and 2; residual oil grade 5; and residual oil grade 6), computed using the control efficiencies provided below, are also provided when possible (i.e., uncontrolled emission factors estimates provided in AP42).

[13] Data is taken from AP42 database: NO_x controls from Table 1.3-14; PM-10 controls from Table 1.3-4; SO_x controls from text section 1.3.4.1-2.

Table 2.5 Fuel Oil Control Efficiency

	Control Efficiency					
	Residual Oil			Distillate Oil		
NO_x controls	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**
Low NO_x burners (LNB)	20%	50%	35%	20%	50%	35%
Flue gas recirculation (FGR)	15%	30%	23%	58%	73%	66%
Burners out of service (BOOS)	10%	30%	20%	n/d	n/d	n/d
Selective Non-catalytic reduction	40%	70%	55%	40%	70%	55%
Selective catalytic reduction	75%	90%	83%	75%	90%	83%
Low excess air (LEA)	0%	28%	14%	0%	24%	12%
Staged combustion (SC)	20%	50%	35%	17%	44%	31%
FGR + SC	25%	53%	39%	73%	77%	75%
Reduced Air Preheat (RAP)	5%	16%	11%	n/d	n/d	n/d
Air Heater (SCR)	40%	65%	53%	40%	65%	53%
Duct SCR	30%	30%	30%	30%	30%	30%
LNB and FGR			50%			78%
PM-10 Controls						
Cyclones (mechanical collectors)	80%					
ESP	99%					
Baghouse	99%					
Scrubbers	94%					
SO_x Controls						
Scrubbers	93%					

Natural gas, a generally clean-burning fuel with negligible PM10 and SO_x emissions, applies controls equipment only for the reduction in NO_x emissions, as well as nitrous oxide emissions. The types are control equipment include low NO_x burners, selective non-catalytic reduction, selective catalytic reduction, and flue-gas recirculation. Control efficiency estimates are provided in the table below.[14]

Table 2.6 Natural Gas Control Efficiency

NO_x Controls	**Min**	**Max**	**Average**
LNB and FGR	60%	90%	75%
LNB	40%	85%	50%
SNCR	25%	40%	33%
SCR	80%	90%	85%
FGR			55%
N_2O Control			
SCR	60%		

Liquid petroleum gas (i.e. butane and propane) has only two NO_x control options: FGR and FGR in combination with LNB Control efficiency estimates are provided in the table below.[15]

[14] NO_x data taken from AP42 Database: FGR, LNB data from FIRE database (or Table 1.4-1) rather than averaging min and max values. Other data comes from AP-42, text section 1.4.4. N_2O data from Radian, 1990, as cited in: http://www.epa.gov/ttn/chief/eiip/techreport/volume08/viii14.pdf.
[15] Data from AP-42, text section 1.5.4.

Table 2.7 LPG Control Efficiency (Includes both butane and propane)

NO_x Controls	Value
FGR	50%
LNB and FGR	60%

2.1.4 CO_2, CH_4, and N_2O Emission factors

These emission factors are determined in two steps:

1. **Obtain uncontrolled emission factors:** Uncontrolled process emission factors are taken directly from the EPA's AP-42 FIRE database,where possible.
2. **Convert to units of lb per mmbtu:** Emission factors from the FIRE database are provided in units of pounds per ton. To convert to pounds per mmBTU, the emission factor was divided by the heating value (mmBTU/ton) of the fuel.
3. **Use IPCC data for missing data:** Process/fuel combinations not represented in AP42 apply IPCC data, adjusted according to the particular fuel's nitrogen content.

2.1.5 Results

Average measure-based emission factors for the electric sector are included in the attached zip disk in the following annotated files:

1. Input data and summary worksheets:
    - COAL 4JAN02.XLS: input assumptions and summary emission factor calculations for coal.
    - NON-COAL 4JAN02.XLS: input assumptions and summary emission factor calculations for natural gas, oil, and biomass.

2.2 Transport Sector

Measure-based emission factors for criteria air pollutants are supplied on a grams per mile and lb per mmbtu basis. Emission factors represent average lifetime values relative to California and rest-of-the-country standards.

Measure-based emission factors associated with alternative fuels are provided for each of the eight pollutants of interest (CO, NO_x, VOC, PM-10, SO_2, N_2O, CH_4, CO_2). These emission factors represent four alternative fuel types: compressed natural gas (CNG), liquid pressurized gas (LPG), ethanol (E85), and methanol (M85).

2.2.1 Sources

A variety of sources used in the determination of emission factors, as identified below.

1. **Emissions Standards** are from published USEPA federal and California-specific tailpipe standards (USEPA, 2000).
2. **Fuel economy** of cars, LDTs, Medium HDVs, and heavy HDVs are from EIA (2001).
3. Emission factors for **gasoline fueled light duty vehicles**:
    - NO_x and VOC: EPA (2001g).

- PM-10: DeCicco and Kliesch (2001)
- CO: USEPA (1999).
- SO2: derived from the EPA (1995)
- N2O and CH4: USEPA (2001a)

4. Emission factors for **gasoline fueled heavy duty vehicles**
   - NO_x, VOC, CO: EPA (2001e, Appendix H).
   - PM-10:
   - SO2: derived from the EPA (1995)
   - N2O and CH4: USEPA (2001a)
5. Emission factors for **diesel fueled light duty vehicles**
   - NO_x, VOC, CO, PM-10: DeCicco and Kliesch (2001)
   - SO2: derived from the EPA (1995)
   - N2O and CH4: USEPA (2001a)
6. Emission factors for **diesel fueled heavy duty vehicles**
   - NO_x, VOC, CO: EPA (2001e, Appendix H).
   - PM-10:
   - SO2: derived from the EPA (1995)
   - N2O and CH4: USEPA (2001a)
7. Criteria air pollutant and GHG emission factors for alternative-fueled for light duty vehicles are based on ANL (2001).

2.2.2 Assumptions

1. Average lifetime emission factors are based on the following assumptions for lifetime VMT per vehicle:
   - Gasoline and diesel LDVs: 120,000 miles
   - Gasoline and diesel HDVs: 300,000 miles
2. For pollutant categories where there is no TLEV standard (i.e., CO), the TLEV emission factor is assumed to be an average of Tier 1 and LEV emission factors.
3. On and off-cycle emissions are included for LDV emission factors
4. Fuel economy of new LDVs scales with vehicle weight. A summary of fuel economy assumptions is as follows:
   - Cars: 22.5 mpg (directly from EIA, 2001)
   - LDT1: 22.5 mpg (scaled with respect to weight)
   - LDT2: 17.5 mpg (scaled with respect to weight)
   - LDT3: 14.9 mpg (scaled with respect to weight)
   - LDT4: 13.1 mpg (scaled with respect to weight)

5. Fuel economy of new HDVs scales with vehicle weight. A summary of fuel economy assumptions is as follows:
    - Light HDVs (LHDVs): 10.8 (scaled with respect to weight)
    - Medium HDVs (MHDVs): 9.2 mpg (directly from EIA, 2001)
    - Heavy HDVs (HHDVs): 7.8 mpg (directly from EIA, 2001)
6. Emission factors of CO, NOx, and VOCs scales with vehicle weight. A summary of assumptions is as follows:
    - Light HDVs (LHDVs) median weight: 14,750 lbs: Scale = 0.56
    - Medium HDVs (MHDVs): median weight: 26,250 lbs: Scale = 1.00
    - Heavy HDVs (HHDVs): median weight: +33,000 lbs: Scale = 1.26
7. NOX and VOC emission factors for gasoline LDVs are based on location as follows:
    - Outside California: based on SFTP control, conventional gasoline, on-board diagnostics only for I/M, and average sulfur content of 80 ppm.
    - In California: based on SFTP control, reformulated gasoline, on-board diagnostics only for I/M, and average sulfur content of 30 ppm.
8. SO2 emission factors for LDVs and HDVs correspond to the gaseous SO2 fraction of total SOx emissions. Sulfates are accounted for in the particulate emission factor.
9. In the calculation of emission factors for AFV LDTs, 50-50 split of LDT1s and LDT2s in the fleet and same VMT/yr for each class was assumed.

2.2.3 NO_x and VOC Emission factors for gasoline LDVs outside California

Emission factors for these pollutants are determined using the process outlined below:

1. **Input assumptions into the TIER1FER.XLS** model that reflect non-CA assumptions for fuel use, sulfur content, inspection regime, and emissions control.
2. **Run the TIER1FER.XLS** model for each standard (i.e., TIER1, LEV, ULEV, SULEV) to obtain emission factor deterioration rates and flex points.
3. **Use the outputs of the above model runs** to calculate average lifetime emission factors by the following equation:

$$FER = ZML + DR2 \times \frac{D2}{2} + \left(DR2 - DR1\right) \times \left(1 - \frac{D1}{2 \times D2}\right) \times D1$$

Where:

FER is the final average lifetime emission rate (gm/mile)

ZML is the emission rate (gm/mile) at zero mileage

DR1 is the degradation factor in Zone 1

DR2 is the degradation factor in Zone 2

D1 is the end mileage for Zone 1 in units of E5 miles

D2 is the end mileage for Zone 2 in units of E5 miles (assuming a 120,000-mile vehicle lifetime)

2.2.4 NO_x and VOC Emission factors for gasoline LDVs in California

Emission factors for these pollutants are determined using the process outlined below:

1. **Input assumptions into the TIER1FER.XLS** model that reflect CA assumptions for fuel use, sulfur content, inspection regime, and emissions control.
2. **Calculate** average lifetime emission factors as per the approach and equation described above.

2.2.5 CO Emission factors for gasoline LDVs

Emission factors for these pollutants are determined using the process outlined below:

1. **Codify the approach of USEPA (1999) into a spreadsheet model.** Note: this approach only includes on-cycle emissions.
2. **Incorporate off-**cycle emissions into the model from DeCicco (2001) assumptions
3. **Run the model** for each standard (i.e., TIER1, LEV, ULEV, SULEV) to obtain emission factor deterioration rates and flex points.
4. **Calculate average lifetime emission factors** by using the equation cited in section 2.2.3.

2.2.6 PM-10 Emission factors for gasoline LDVs

These emission factors are taken directly from DeCicco and Kliesch (2001), Appendix A, for Tier 1, LEV, ULEV and SULEV standards.

2.2.7 SO2 Emission factors for gasoline LDVs

These emission factors were computed using the process outlined below.

1. Compute fraction of the percent of fuel that is directly converted into sulfate as per the following equation:

$$FCNVRC = DSULFC * FE \; / (13.6078 * (1.+ WATER) * FDNSTY * SWGHT$$

Where:

FCNVRC is the fraction of the percent of fuel that is directly converted into sulfate

DFSULFC is direct sulfate from catalyst vehicles = 0.016

FE is the fuel economy

WATER is weight ratio of seven water molecules to sulfate, 7.18 / 98 = 1.2857

FDNSTY is fuel density in lb/gal = 6.09 lb/gal gasoline

SWGHT is weight percent of sulfur content in gasoline = 0.0138

13.6078 is a constant

2. Compute the gaseous sulfur emission factor (gm/mile) as follows:

$$EFSO2 = 9.072 * FDNSTY * SWGHT * (1.0 - FCNVRC) / FE$$

2.2.8 N2O and CH4 Emission factors for gasoline LDVs

These emission factors are taken directly from Table D-12 of USEPA (2001a) for Tier 1 control technology.

2.2.9 CO2 Emission factors for gasoline LDVs

Carbon dioxide emission factors for gasoline was obtained from the IPCC (1996) in units of tonnes carbon per TJ, and converted to lb CO2/mmbtu by applying appropriate conversion factors.

2.2.10 CO, VOC, NOx,and PM-10 Emission factors for diesel LDVs

These emission factors are taken directly from DeCicco and Kliesch (2001), Appendix A. Only Tier 1 standards apply.

2.2.11 SO2 Emission factors for diesel LDVs

The gaseous sulfur emission factor (gm/mile) was computed as per the following equation:

$$EFSO2 = 9.072 * FDNSTY * SWGHTD * (1.0 - DCNVRT) / FE$$

Where:

FE is the fuel economy

FDNSTY is fuel density in lb/gal = 7.11 lb/gal gasoline

SWGHTD is weight percent of sulfur content in diesel = 0.05

DCNVRT is percent of sulfur in diesel that in converted directly into sulfates = 2%

9.072 is a constant

2.2.12 N2O and CH4 Emission factors for diesel LDVs

These emission factors are taken directly from Table D-12 of USEPA (2001a) for Tier 1 control technology.

2.2.13 CO2 Emission factors for diesel LDVs

Carbon dioxide emission factors for diesel fuel was obtained from the IPCC (1996) in units of tonnes carbon per TJ, and converted to lb CO2/mmbtu by applying appropriate conversion factors.

2.2.14 $NO_{x,}$ VOC, and CO Emission factors for gasoline HDVs

Emission factors for these pollutants are determined using the process outlined below:

1. **Obtain the emission factor** at 150,000 miles at low and high altitudes.
2. **Take a simple average** as the average lifetime emission factor for medium HDVs
3. **Scale the emission factor relative to MHDVs by weight** to obtain the average lifetime emission factor for light and heavy HDVs

2.2.15 PM-10 Emission factors for gasoline HDVs

Emission factors for these pollutants are determined using the process outlined below:….

2.2.16 SO2 Emission factors for gasoline HDVs

The average lifetime SO2 emission factor was computed using the process as outlined in section 2.2.7, using HDV fuel economy.

2.2.17 N2O and CH4 Emission factors for gasoline HDVs

These emission factors are computed from Table D-12 of USEPA (2001a) for Tier 1 control technology assuming 25% of the vehicle fleet use Tier 0 control technology, 30% use an oxidation catalyst, and the balance non-catalyst.

2.2.18 CO2 Emission factors for gasoline HDVs

Carbon dioxide emission factors for gasoline was obtained from the IPCC (1996) in units of tonnes carbon per TJ, and converted to lb CO2/mmbtu by applying appropriate conversion factors.

2.2.19 NO_x,VOC, and CO Emission factors for diesel HDVs

Emission factors for these pollutants are determined using the process outlined below:

1. **Obtain the zero mile emission factor** at low and high altitudes.
2. **Obtain the deterioration rate** in units of gm per 10,000 miles at low and high altitudes.
3. **Compute the emission rate at 150,000 miles.** This is the average lifetime emission factor (assumes a 300,000 miles lifetime)
4. **Scale the emission factor relative to MHDVs by weight** to obtain the average lifetime emission factor for light and heavy HDVs

2.2.20 PM-10 Emission factors for diesel HDVs

Emission factors for these pollutants are determined using the process outlined below:….

2.2.21 SO2 Emission factors for diesel HDVs

The average lifetime SO2 emission factor was computed using the process as outlined in section 2.2.11, using HDV fuel economy.

2.2.22 N2O and CH4 Emission factors for diesel HDVs

These emission factors are taken directly from Table D-12 of USEPA (2001a) for Tier 1 control technology.

2.2.23 CO2 Emission factors for diesel HDVs

Carbon dioxide emission factors for diesel was obtained from the IPCC (1996) in units of tonnes carbon per TJ, and converted to lb CO2/mmbtu by applying appropriate conversion factors.

2.2.24 Alternative-Fueled LDVs

Emission factors for AFVs were computed using the GREET model (see Annex B for a description of the model). The GREET model produces both near-term and long-term emission factors. The long-term emission factors were used as a proxy for “measure-based” factors, while the near-term factors could be (but were not) used as baseline emissions. The GREET model produces emission factors for each of the eight pollutants of interest (CO, NO_x, VOC, PM-10, SO_2, N_2O, CH_4, CO_2). It gives emission factors for four alternative fuel types: compressed natural gas (CNG), liquid pressurized gas (LPG), ethanol (E85), and methanol (M85). Emission factors were computer as per the process outlined below:

1. Emission factors for alternative-fueled vehicles were calculated as percent reductions from conventional gasoline-fueled vehicles. Use the GREET model's default values for percent reductions.
2. Replace the GREET model's emission factor assumptions for gasoline-fueled cars, LDT1s and LDT2s for CO, NOx, VOCs, and PM-10 with the computed average lifetime emission factors as described elsewhere in this Section. The table below summarizes the changes.

Table 2.8 Tellus Modifications to the GREET Model

		Gasoline Car	Gasoline LDT1	Gasoline LDT2
Original GREET default values	VOC	0.080	0.091	0.629
	PM-10	0.012	0.015	0.015
	CO	5.517	8.247	16.846
	NOx	0.275	0.381	1.173
Tellus Modifications	VOC	0.243	0.252	0.303
	PM-10	0.020	0.020	0.020
	CO	4.848	4.848	5.358
	NOx	0.612	0.627	0.96

3. Run the model to compute average lifetime emission factors (in gm/mile) for long-term technology.

2.2.25 Alternative-Fueled HDVs

Emission factors for AFV HDVs were computed using the GREET model's default values for percent reductions from conventionally fueled vehicles. Only one heavy-duty vehicle category, medium heavy-duty diesel vehicles, was assessed.

2.2.26 Results

Average measure-based emission factors for the trasport sector are included in the attached zip disk in the following annotated files:

1. Input data and summary worksheets for gasoline emission factors:
   - Carbon monoxide calculations are in the following files: CO LEV.XLS, CO LDLLEV.XLS, CO TIER1.XLS, CO ULEV, CO SULEV.XLS, and CO HDV[GASOLINE].XLS. A summary for LDVs is provided in CO SUMMARY.XLS
   - Nitrogen oxide and volatile organic compound calculations for California are in the following files: CA LEV.XLS, CA LDLLEV.XLS, CA TIER1.XLS, CA ULEV, and CA SULEV.XLS. A summary is provided in CA SUMMARY.XLS
   - Nitrogen oxide and volatile organic compound calculations for the rest of the country are in the following files: NON CA LEV.XLS, NON CA LDLLEV.XLS, NON CA TIER1.XLS, NON CA ULEV, NON CA SULEV.XLS, NOX

HDV[GASOLINE].XLS, and VOC HDV[GASOLINE]..XLS. A summary for LDVs is provided in NON CA SUMMARY.XLS.

- Particulate matter calculations for LDVs are in: PM-10 LDV.XLS
- Sulfur dioxide calculations are in: SO2 LDV.XLS and SO2 HDV.XLS
- Methane calculations for LDVs and HDVs are in: CH4.XLS
- Nitrous oxide calculations for LDVs and HDVs are in: N2O.XLS

2. Input data and summary worksheets for diesel emission factors:
   - Carbon monoxide, volatile organic compounds, nitrogen oxides, and particulate matter calculations for LDVs are in: CO VOC NOX PM.XLS.
   - Sulfur dioxide emission factors for LDVs are in SO2 LDV.XLS
   - Particulate matter emission factors for LDVs are in PM-10 LDV.XLS
   - Methane calculations for LDVs and HDVs are in: CH4.XLS
   - Nitrous oxide calculations for LDVs and HDVs are in: N2O.XLS
   - Carbon monoxide, volatile organic compounds, nitrogen oxides, and particulate matter calculations for HDVs are in: CO HDV[DIESEL].XLS, VOC HDV[DIESEL].XLS, and NOX HDV[DIESEL].XLS.
   - Sulfur dioxide emission factors for HDVs are in SO2 HDV.XLS
3. Input data and summary worksheets for alternative fuel emission factors:
   - All CAPs and GHGs for LDVs are in ADAPTED GREET1_5A.XLS.
   - All CAPs and GHGs for HDVs are in AFV HDV.XLS.

2.3 Residential, Commercial, and Industrial Sectors

Measures in these demand sectors are likely to be either efficiency-based (e.g., a more efficient boiler in the industrial sector), fuel switching (e.g., replacing an oil furnace with a natural gas furnace in the residential sector), or pollution control based (e.g., adding a scrubber to a coal steam power station). The first two measures (i.e., efficiency and fuel switching) will result in changes in emissions that can be tracked using the baseline-based emission factors developed in the baseline emission factors. However, the last measure (i.e., pollution control) will lead to significant variation in air pollution emission factors. This section describes the sources, assumptions, and methods to determine the emission factors of RCI technologies subject to a range of pollution control equipment.

2.3.1 Sources

A variety of sources used in the determination of emission factors:

1. **Emission Factors** were obtained from USEPA (2001f)
2. **Fuel specifications** were obtained from USEPA (2001f). For those fuels not included in the AP-42 Appendix, values from the LEAP model program were used.

3. **Low-Sulfur Coal** data was obtained from a number of sources from the USEIA (2001b) USEIA (low-sulfur coal forms), FERC (2001), the US Department of Commerce (2001), and Hong and Slater (1995).
4. **CH4 and N2O emission factors** are provided from ICF (1999), IPCC (1994) and De Soete (1993).

2.3.2 Assumptions

1. Most values come from directly or are derived from the EPA Compilation of Air Pollutant Emission Factors (AP-42). Preference is given to AP-42 values over other data sources.
2. The processes that control pollutant emissions are described and quantified in the text and tables within AP-42. Values for pollution control efficiency relative uncontrolled emission factors were assumed to be representative.
3. Not all fuels have data for each process. We have assumed that these categories are not applicable.
4. The USEPA's AP-42 database is given precedence over the IPCC values. For some process/fuel combinations, AP-42 provides N_2O and/or CH_4 emission factors. For those that the AP-42 does not cover, the IPCC values are used. Converting from the generic "coal" emission factor for nitrous oxide (as given by IPCC) to specific types of coal, it was assumed that nitrous oxide emissions would be relative to the percentage nitrogen content in the fuel.
5. It is assumed that the controls do not change N_2O or CH_4 emissions, due to the lack of available data and lack of actual influence, respectively.

2.3.3 NO_x, VOC, PM-10, SO_2, and CO Emission factors

There are several generalized steps for calculating these emission factors:

1. **Obtain uncontrolled emission factors:** Uncontrolled process emission factors are taken directly from the EPA's AP-42 FIRE database.
2. **Convert to units of lb per mmbtu:** Emission factors from the FIRE database are provided in units of pounds per ton. To convert to pounds per mmBTU, the emission factor was divided by the heating value (mmBTU/ton) of the fuel.
3. **Split emission factors into two groups: coal and non-coal fuels**. These groups are described in the next subsections, along with the case of low-sulfur coal.
4. **Determine controlled Emission Factors:** Emission factors for processes with emission controls were provided in one of two ways.
    - **Provided**: If emission factors for the controls are provided by AP-42 or in the FIRE database, then these are used.
    - **Calculated**: The FIRE database does not provide factors for every control for each process and fuel type, so in some cases controlled emission factors needed to be calculated. Based on descriptions of the control types in the text and tables within the AP-42 document, control efficiency values can be determined (for example,

electrostatic precipitators (ESP's) are 97.7% effective at reducing particulate matter). These efficiency values were used to calculate controlled emission factors as a reduction in emissions relative to the uncontrolled case for the pollutant in question. Pollutants not affected by the control technologies have the same emission factors as in the uncontrolled case. Most controls are measures applied to the boiler itself, and are described within the AP-42 document. Efficiency values for particulate matter were derived from tables showing size specific emission factors for different control types. Values for particle size 10 μm were compared for each control against the uncontrolled factor to find the control efficiency.

2.3.3.1 Coal Fuels

Coal fuels used in industrial boilers have potentially four specific types of scrubbers that could be used to control SO_2 (lime/limestone, dual alkali, magnesium oxide/hydroxide, and sodium carbonate), as well as a generic label "scrubbers". Each of these scrubber-types was assigned a value for controlling PM10 as well as SO_2. The other controls affect the emission factors of only one pollutant (i.e. ESP's, baghouses, and multiple cyclones control PM10 emissions; low NO_x burners (LNB), overfire air (OFA), reburning, selective catalytic reduction (SCR), and selective non-catalytic reduction (SNCR) control NO_x emissions). The control efficiencies are the same as those summarized in various tables in the Electric Sector section.

2.3.3.2 Low Sulfur Coal

As with the electric sector, a fuel-based, rather than control equipment-based approach to achieving sulfur emission reductions is the use of low sulfur coal. Rather than being a change made to the boiler facility, low sulfur coal has a different chemical content, and could be subject to additional controls (most likely for other emissions such as NO_x or PM10). This fuel type was determined in two steps:

1. The **emission factors** (in lb/ton) for this type of coal were taken as the average of the values for bituminous and sub-bituminous coal for each of the different boiler types.
2. These were **converted** to factors with units of lb/mmBTU using a heating value of 19.43 mmBTU /ton, which is derived from data from the Energy Information Administration (1995). The sulfur value of this coal (0.3 lb S/ mmBTU coal) is also taken from the Energy Information Administration (2001).

Because the low sulfur coal emission factors are averages, values for each pollutant will be different from the uncontrolled case using a fuel with normal sulfur content. To apply additional controls to this coal, the sulfur value should be taken from this fuel and the controlled pollutant should be taken from the normal-fuel case.

2.3.3.3 Non-Coal Fuels

Non-coal fuels for the RCI sectors include natural gas, oil, and biomass. These fuels have different controls from coal, primarily focusing on NO_x rather than SO_x emissions. Fuel oils (distillate oil and residual oil) have a large number of control options. Their NO_x emissions can be controlled to varying degrees by the following types of pollution control technologies:

- Flue gas recirculation (FGR)
- Burners out of service (BOOS)

- Selective non-catalytic reduction (SNCR)
- Selective catalytic reduction (SCR)
- Low excess air (LEA)
- Staged combustion (SC)
- FGR + SC
- Reduced Air Preheat (RAP)
- Air Heater (SCR)
- Duct SCR
- Low NOx burners (LNB) and FGR

Particulate matter control technologies are the same as for coal (i.e. cyclones, ESP, and baghouse filters) and there is also a single scrubber option that controls both PM10 and SO_x emissions. The range of control efficiencies by fuel for NOx, PM-10, and SOx are the same as those summarized in the tables in the electric sector Section.

2.3.4 CO_2, CH_4, and N_2O Emission factors

These emission factors are determined in two steps:

1. Obtain uncontrolled emission factors: Uncontrolled process emission factors are taken directly from the EPA's AP-42 FIRE database, where possible.
2. Convert to units of lb per mmbtu: Emission factors from the FIRE database are provided in units of pounds per ton. To convert to pounds per mmBTU, the emission factor was divided by the heating value (mmBTU/ton) of the fuel.
3. Use IPCC data for missing data: Process/fuel combinations not represented in AP42 apply IPCC data, adjusted according to the particular fuel's nitrogen content.

2.3.5 Results

Average measure-based emission factors for the RCI sectors are included in the attached zip disk in the following annotated files:

1. Input data and summary worksheets:
    - COAL 4JAN02.XLS: input assumptions and summary emission factor calculations for coal.
    - NON-COAL 4JAN02.XLS: input assumptions and summary emission factor calculations for natural gas, oil, and biomass.

3. List of references

Argonne NationalLaboratory (ANL), 2001. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model,* developed by Michael Wang, http://www.transportation.anl.gov/ttrdc/greet/

Bailie, A., Bernow, S., Dougherty, W., Heaps, C., 2001. *Emission Factor Specifications for the 2001 Version of the CCP Model,* May.

Davis, S., 2001. *Transportation Energy Data Book, Edition 21*; Center for Transportation Analysis, Energy Division, Oak Ridge National Lab, for Office of Transportation Technologies, U.S. Department of Energy; October, ORNL-6966 (Edition 21 of ORNL-5198); Table 6.6 http://www-cta.ornl.gov/data/tedb21/Index.html.

De Soete, G.G. 1993. *Nitrous oxide from Combustion and Industry: Chemistry and Emissions Control*, In A.R. van Amstel (ed.), Proceedings of an International IPCC Workshop on Methane and Nitrous Oxide: Methods in National Emissions Inventories and Options for Control. RIVM Report No. 481507003, Bilthoven, The Netherlands.

DeCicco, J and Kliesch, J., 2001. *Rating the Environmental Impacts of Motor Vehicles: ACEEE's Gree Book Methodology, 2001 Edition*, May,

Federal Energy Regulatory Commission (FERC), 2001. Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants"

Hong, B.D. and Slatick E.R., 1995. *Carbon Dioxide Emission Factors for Coal*, Energy Information Administration, Quarterly Coal Report, January-March 1994, DOE/EIA-0121 (94/Q1) (Washington, DC, August).

ICF Incorporated, 1999. *Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion*; Vol. 8: Ch. 14; October, Prepared for the Greenhouse Gas Committee's Emission Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/viii14.pdf)

Intergovernmental Panel on Climate Change (IPCC). 1996. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 3: Reference Manual.* http://www.iea.org/ipcc/invs1.html

IPCC, 1994. *IPCC Guidelines for national Greenhouse Gas Inventories, 3 volumes: Vol. 1, Reporting Instructions; Vol. 2, Workbook; Vol. 3, Draft Reference Manual*. Intergovernmental Panel on Climate Change, Organization for Economic Co-Operation and Development. Paris, France.

Long-Range Energy Alternatives Planning System (LEAP). http://www.sei.se/red/red9703b.html

Tellus Institute, 2001. *Emission Factor Specifications For The 2001 Version Of The CCP Model* August.

United States Department of Commerce, Bureau of the Census, 2001. "Monthly Report EM-545.

United States Energy Information Agency (USEIA), 2001. *Annual Energy Outlook 2001 (AEO2001),* DOE/EIA-0383(2001), December.

United States Energy Information Agency (USEIA), 2001a. *National Energy Modeling System (NEMS),* version used producing the Annual Energy Outlook 2001 (AEO2001), from internal NEMS RESTART file.

United States Energy Information Agency (USEIA), 2001b.*Coal Receipts and Prices by Sulfur Content at Electric Utility Plants, by State of Origin and Imports*, January-March (http://www.eia.doe.gov/cneaf/coal/quarterly/html/t27p01p1.html).

United States Energy Information Agency (USEIA), (low sulfur coal forms):

Form EIA-3, "Quarterly Coal Consumption Report Manufacturing Plants",

Form EIA-3A, "Annual Coal Quality Report - Manufacturing Plants",

Form EIA-5, "Coke Plant Report Quarterly",

Form EIA-5A, "Annual Coal Quality Report - Coke Plants",

Form EIA-860B, "Annual Electric Generator Report – Non-utility",

Form EIA-6A, "Coal Distribution Report - Annual", and

Form EIA-7A, "Coal Production Report";

United States Environmental Protection Agency (USEPA), 2000. *National Air Quality and Emission Trends Report, 1999* US-EPA. http://www.epa.gov/oar/aqtrnd99/

United States Environmental Protection Agency (USEPA), 1995. *Draft User's Guide To Part5: A Program For Calculating Particle Emissions From Motor Vehicles*, Appendix: Particulate Emission Factors For Mobile Sources As Calculated In The Model Part5.

United States Environmental Protection Agency (USEPA), 1997. *Emission Factors for Locomotives*, Air and Radiation, Office of Mobile Sources; EPA420-F-97-051, http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/42097051.htm

United States Environmental Protection Agency (USEPA), 1997a. Emission Standards Reference Guide for Heavy-Duty and Nonroad Engines, EPA420-F-97-014, September, http://www.epa.gov/oms/cert/hd-cert/stds-eng.pdf

United States Environmental Protection Agency (USEPA), 1999. *Determination of CO Basic Emission Rates, OBD and I/M Effects for Tier 1 and Later LDVs and LDTs (DRAFT)*, EPA420-P-99-017, http://www.epa.gov/otaq/models/mobile6/m6exh009.pdf

United States Environmental Protection Agency (USEPA), 2001a. *Inventory of US Greenhouse Gas Emissions and Sinks* (1990-99); EPA 236-R-01-001; April, Annex D www.epa.gov/globalwarming/publications/emissions/us2001/index.html

United States Environmental Protection Agency (USEPA), 2001b AIRDatabase, EPA Office of Air Quality Planning and Standards, AIRData – NET Tier Report (http://www.epa.gov/air/data/)

United States Environmental Protection Agency (USEPA), 2001c. Air Pollutant Emission Trends Report, Average Annual Emissions, All Criteria Pollutants, Years Including 1970, 1975, 1980, 1985, 1989, 1990-1999, available at http://www.epa.gov/ttn/chief/trends/trends99/tier3_yrsemis.pdf .

United States Environmental Protection Agency (USEPA), 2001d. *Procedures Document For National Emission Inventory, Criteria Air Pollutants, 1985-1999*, EPA-454/R-01-006, March, Office of Air Quality Planning and Standards, Research Triangle Park, NC. http://www.epa.gov/ttn/chief/trends/trends99/neiproc_99.pdf

United States Environmental Protection Agency (USEPA), 2001e. *AP-42: Compilation of Air Pollutant Emission Factors*, http://www.epa.gov/otaq/ap42.htm

United States Environmental Protection Agency (USEPA), 2001f. *Compilation of Air Pollutant Emission Factors (AP-42)* (http://www.epa.gov/ttn/chief/ap42) obtained through the Factor Information REtrieval (FIRE) Data System (http://www.epa.gov/ttn/chief/software/fire).

United States Environmental Protection Agency (USEPA), 2001g. *TER1FER.XLS Spreadsheet Model*, developed in support of EPA's TIER2/Sulfur Analysis http://www.epa.gov/OMS/regs/ld-hwy/tier-2/nprm/t2models.htm.

United States Environmental Protection Agency (USEPA). 2000. *California and Federal Tailpipe Standards,*' Office of Transportation and Air Quality, EPA420-B-00-001, February.

Annex A: Emission Trading and SO_2 and NO_x Emission Factors

NEMS models the electricity sector through a linear programming model (LP) that is optimized by meeting a number of constraints at the lowest cost. One of the constraints is the required electricity generation; another constraint is total SO_2 emissions, based on the Clean Air Act requirements (which sets a national cap of 8.95 million tons). When we change the electricity generation constraint in one region at a time, the LP model optimizes to find the new mix of technologies to meet the constraints at lowest cost. In this case, the system produces less electricity (new constraint) but emits the same national level of SO_2 (i.e. still meeting the 8.95 million tons cap). How might this occur? As electricity demand decreases, utilities may purchase less low sulfur coal, and increase generation from their coal plants (for sale to other regions) or purchase and utilize less sulfur-removing scrubbers.

In economic terms, since the emissions cap per kWh produced is less of a constraint in situations where electricity demand is reduced, the demand for emissions permits and hence their cost will decrease. Regions that had reduction strategies costing the same or just lower than the permit price in the base case, will now find it less expensive to purchase credits and hence emit more SO_2 rather than pursue SO_2 reduction policies. The result will be negative marginal emission factors for some regions, reflecting increasing SO_2 emissions as electricity demand decreases. These negative emissions factors for SO_2 may seem perverse, but they reflect the reality of a national cap and trade regime. We recommend including the negative emission factors in CCP but having the software warn the users prior to applying them in any analysis.

NO_x emissions, like those for SO_2, are also subject to caps and trading. However, unlike SO_2 emissions, these arrangements are not national: they are expected to be implemented in 6 of the 13 NERC regions. In some of these regions, marginal NO_x emission factors are negative, reflecting the same considerations noted above for SO_2.

The NO_x emission factors from NEMS reflect the “NO_x SIP Call” rules initially promulgated by the EPA to limit NO_x emissions in 22 eastern and Midwestern states by capping summer season NO_x emissions from electric power plants from 2004 onwards. The factors reflect only those 19 States in which rules have been finalized, and include the effects of the revisions to the rules ordered in March 2000, which removed facilities in Wisconsin and required review of facilities in Georgia and Missouri. For more information, refer to the Annual Energy Outlook, 2001 (EIA, 2000).

In six regions subject to the NO_x cap, marginal emission factors for SO_2 are positive, while those for NO_x are negative. This reflects the fact that NEMS can choose among a range of measures to reduce emissions including fuel switching and pollution control options.

Annex B: A Description of The GREET Model

The GREET web page (http://greet.anl.gov/) describes the model's functionality:

To fully evaluate energy and emission impacts of vehicle technologies, the fuel cycle from wells to wheels and the vehicle cycle through material recovery and vehicle disposal need to be considered. Sponsored by the U.S. Department of Energy's Office of Transportation Technologies, Argonne has developed a fuel-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers to evaluate various engine and fuel combinations on a consistent fuel-cycle basis.

GREET was developed as a multidimensional spreadsheet model in Microsoft Excel. This public domain model is available free of charge for anyone to use (download information). The first version of GREET was released in 1996. Since then, Argonne has continued to update and expand the model.

For a given engine and fuel system, GREET separately calculates the following:

- Consumption of total energy (energy in non-renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal), and petroleum
- Emissions of CO_2-equivalent greenhouse gases - primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
- Emissions of five criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO_x), particulate matter with size smaller than 10 micron (PM10), and sulfur oxides (SO_x).

GREET includes more than 30 fuel-cycle pathways. It also includes the following vehicle technologies

- Conventional spark- ignition engines
- Direct-injection, spark- ignition engines
- Direct injection, compression ignition engines
- Grid-connected hybrid electric vehicles
- Grid-independent hybrid electric vehicles
- Battery-powered electric vehicles
- Fuel-cell vehicles.

To address technology improvements over time, GREET separates fuels and vehicle technologies into near- and long-term options. The latter are assumed to have improved energy and emission performance compared with the former.