Emission Factors and Calculations
September 15, 2008

Direct Emissions

- This presentation will cover methods to estimate the direct emissions of GHGs
- Indirect emissions will be discussed at a subsequent meeting
- Once a source determines it has direct emissions above 10,000 tonnes the source must also determine and report indirect emissions

What are Direct Emissions

- Direct emissions are those generated directly by the operation of a facility (aka source)
- Direct emissions can include:
  - Fuel combustion in industrial or commercial equipment
  - Emissions from the process
  - Fugitive emissions

How do you Determine Direct Emissions?

- Direct emissions can be determined:
  - Directly through measurements of how much is emitted
  - Through emission factors
  - Mass balance calculations
- For a single commercial or industrial facility, all of these methods may be necessary

What are Emission Factors?

The EPA document Compilation of Emission Factors (aka AP-42) describes an emission factor as:

An **emissions factor** is a value that attempts to relate the quantity of a chemical released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of chemical divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of CO_2 emitted per megagram of coal burned).

The Emission Factor Equation

The general equation for emissions estimation is:

$$E = A \times EF$$

where:
E = emissions;
A = activity rate;
EF = emission factor

Units of Emission Factors

- Emission factors can be in terms of:
  - lb/thousand gallons
  - lb/ton of product
  - lb/ton raw material
  - lb/million Btu (MMBtu)
  - lb/kWh (or MWh)
  - grams/mile
  - grams/Hp-mile

Why are Emission Factors Different?

- For fuels, they reflect the inherent variability of the fuel
- For industrial operations (i.e. lb/ton of product), they reflect the differences in actual operations and production efficiencies.

Choosing Emission Factors

- 2 types of emission factors
  - Generally accepted factors
  - Plant/process specific factors
- Plant process specific factors should be used when available and well documented on how derived
- Generally accepted factors should be used on common and relatively uniform processes i.e vehicle emissions, combustion of common fuels

Ecology's Preference on Use of Factors

- At this time, Ecology's preferences for generally accepted factors
  - TCR
  - IPCC or WRI where TCR doesn't have a factor
  - EPA where TCR or IPCC doesn't have a factor
  - EIA where TCR, IPCC, or EPA doesn't have a factor
- At this time, Ecology's preferences for plant specific factors
  - Plant specific emission factors based on source test information or continuous emission monitors
  - Mass balances for fugitive losses
  - Estimating equations that take several factors into account e.g. aluminum smelter PFC emissions

Terminology

- Carbon dioxide equivalent (CO_{2e}) – The universal unit for comparing emissions of different GHGs expressed in terms of the GWP of one unit of carbon dioxide
- Global Warming Potential - (GWP) The ratio of radiative forcing (degree of warming to the atmosphere) that would result from the emission of one unit of a given GHG compared to one unit of carbon dioxide (CO2)
- Metric Ton (tonne) = 2,204.6 lb

Global Warming Potentials

Chemical	GWP
CO_2	1
CH_4	21
N_2O	310
SF_6	23,900
HFCs	12-11,700
PFCs	6,500-9,200

Examples

- First example is a frozen potato products plant
- Second example is a vehicle fleet owned and operated by a local government
- Third example is a motor vehicle rental fleet

Frozen Potato Products Production Plant

The plant has the following operations that produce greenhouse gas emissions:

- Boiler operating on natural gas, digester gas, and #2 fuel oil
- Forklifts operating on propane
- Space heating equipment in the plant and the attached office buildings using natural gas
- Natural gas hot water heaters for worker sanitation purposes
- Fugitive methane from an on-site anaerobic digester
- Purchased electricity (this is an indirect emission source)

Other Information

- All natural gas goes through one meter,
- Digester gas is metered
- Propane comes from one supply tank, and
- #2 fuel oil tank content is measured monthly.
- Digester gas is 500 Btu/scf and 50% CO2 by volume

Information to Collect

- Annual cubic feet or therms of natural gas consumed
- Annual gallons of propane purchased
- Annual gallons of #2 fuel oil purchased or used
- Annual cubic feet of digester gas used in boiler
- Estimated loss of digester gas from
  - Valve and fittings leaks,
  - Digested waste solids removal and emission rate

Emissions from the boiler and other natural gas combustion

	Million cu. Ft natural gas	Million cu.ft digester gas	Natural gas emission factor, tonne/scf	Digester gas emission factor, tonne/scf	Tonne/yr	GWP	CO2e
CO_2 Emissions	200	50	0.000054	2.62E-05	12110	1	12,110
N_2O emissions	200	50	9.18E-10	4.59E-10	0.2066	310	64
CH_4 emissions	200	50	9.18E-10	4.59E-10	0.2066	21	4
				Natural and digester gas total			12,178

	Gallons #2 oil	Emission factor, tonne/gal	tonne/yr	GWP	CO2e
CO_2 Emissions	50,000	0.01013	506.5	1	507
N_2O emissions	50,000	4.23E-08	0.002115	310	1
CH_4 emissions	50,000	2.82E-08	0.00141	21	0
				Diesel total	507
		Boiler Emissions Total		12,686	tonnes CO2e

Emissions From Propane Usage

	Gallons propane	Emission factor, tonne/gal	tonne/yr	GWP	CO2e
CO_2 Emissions	1000	0.00579	5.79	1	6
N_2O emissions	1000		0.0004	310	0.12
CH_4 emissions	1000		0.00022	21	0.00
				Propane Total	6

Fugitive Digester Losses

- Fugitive methane losses are estimated to be 45.4 kg/yr (100 lb/year)
- Fugitive CO_2 from the digestion is 100 kg/yr (220 lb/yr)
- The total is a negligible amount of CO_{2e} at 1.05 metric ton
- CO_2 that passes through the boiler 1,294 metric tons

Purchased Electricity

- This is not a source of direct emissions
- Determination of indirect emissions from purchased electricity will be covered at a later time

Total Plant Emissions

Boiler fuel and natural gas combustion	**12,686**
Digester CO_2 emitted through Boiler	1,294
Propane usage	6
Fugitive Digester losses	1.05
Total CO2e, metric tons/year	13,987

Fleet Emission Calculations

- Ecology plans to use The Climate Registry's (TCR) General Reporting Protocol (GRP) as a framework
  - http://www.theclimateregistry.org/downloads/GRP.pdf
- GRP Chapter 13: Direct Emissions from Mobile Combustion (pg 82-96)
- Includes required data, calculations, and emission factors

Framework

- Greenhouse Gases – separate calculation methods
  - CO_2 – fuel use based
  - CH_4 & N_2O – mileage based
  - Other gases calculated like stationary sources (Chapter 16)
- Fuel use vs. mileage
  - Options for both
- Tiers
  - Tiered system with various degrees of accuracy
  - Encouraged, but not required to select higher tiers
  - Options for data types and level of complexity

Tiers

CO_2 Emissions

Tier	Data	Factor
A1	Fuel use	•Measured carbon content and fuel density or •Measured carbon content and heat content
A2	Fuel use	•Measured heat content and default carbon content or •Measured carbon content and default heat content
B	Fuel use	Default factors by fuel type
C	Fuel use estimated by mileage	Default factors by fuel type

CH_4 & N_2O Emissions

Tier	Data	Factor
A	Mileage	Default factors based on vehicle type and technology
B	Mileage	Default factors based on vehicle type and model year
C	Mileage estimated by fuel use	Default factors based on vehicle type and technology or model year

Aggregation

- Aggregation methods vary by tier
- Calculations are dependent on fuel and vehicle properties
- Necessary to perform separate calculations for different fuels and vehicles
- Can group similar sources together before calculating – does not have to be per individual vehicle

Data Options

- Fuel use:
  - Logs of vehicle fuel gauges and storage tanks
  - Fuel receipts
  - Purchase records
  - Includes bulk fueling facilities and other fueling locations
- Fuel properties
  - Fuel type
  - Carbon content
  - Fuel density
  - Heat content
  - % Oxidation (100% standard)
  - Biofuels reported separately – % blend
- Mileage
  - Odometer readings
  - Trip manifests
- Vehicle properties
  - Vehicle type
  - Control technology
  - Model year
- Fuel economy (mpg)
  - Listed on sticker when purchased
  - Manufacturer documentation
  - Company records
  - EPA website: www.fueleconomy.gov
  - Measured or standard city / highway ratio

Calculations

- Choose calculation method
- Gather and aggregate data
- Calculate CO_2 emissions
  - Fuel use or mileage x emission factor
- Calculate CH_4 & N_20 emissions
  - Mileage or fuel use x emission factor
- Calculate other emissions
  - same as stationary sources – mass balance and indirect
- Convert to MT CO_2e
- Total MT CO_2e emissions

Example 2: Local Government Fleet

- Tracks fuel purchases per vehicle
- Does not track mileage
- CO_2
  - Fuel use
  - Fuel type
  - Default factors – not measured
  - Tier B
- CH_4 & N_2O
  - Estimate mileage by fuel use per vehicle and mpg
  - Vehicle type
  - Model year factors
  - Tier C

Example 2: CO_2 Aggregation

Vehicle ID	Vehicle Model	Fuel Type	Annual Fuel Use (gal)
FT05-3	2005 Ford Taurus	gasoline	700
FT04-53	2004 Ford Taurus	gasoline	820
CT06-8	2006 Chevy Trailblazer	gasoline	930
HDT-4	Heavy-duty truck	diesel	1,536
CT07-5	2007 Chevy Trailblazer	gasoline	850
FT05-15	2005 Ford Taurus	gasoline	510
HDT-75	Heavy-duty truck	diesel	1,830
CT06-36	2006 Chevy Trailblazer	gasoline	975
HDT-42	Heavy-duty truck	diesel	1,780
FT03-7	2003 Ford Taurus	gasoline	800

Group by fuel type

Example 2: CO_2 Calculation

Fuel	Total gallons	Emission factor from Table 13.1 (kg CO_2 / gal)	CO_2 emissions (MT CO_2)
Gasoline	160,000	8.81	1,410
Diesel	170,500	10.15	1,731
Total			3,141

Total gallons x emission factor (kg CO_2 / gal) / 1,000 (kg / metric ton) = MT CO_2 emissions

Emission Factors

Table 13.1 U.S. Default CO_2 Emission Factors for Transport Fuels

Fuel Type	Tier A2 Method			Tier B/C Method
	Carbon Content (Per Unit Energy)	Heat Content	Fraction Oxidized	CO_2 Emission Factor (Per Unit Volume)
Fuels Measured in Gallons	**kg C / MMBtu**	**MMBtu / barrel**		**kg CO_2 / gallon**
Motor Gasoline	19.33	5.218	1.00	8.81
Diesel Fuel No.1 and 2	19.95	5.825	1.00	10.15
Aviation Gasoline	18.87	5.048	1.00	8.32
Jet Fuel (Jet A or A-1)	19.33	5.670	1.00	9.57
Kerosene	19.72	5.670	1.00	9.76
Residual Fuel Oil (#5,6)	21.49	6.287	1.00	11.80
Crude Oil	20.33	5.80	1.00	10.29
Biodiesel (B100)*	NA	NA	1.00	9.46
Ethanol (E100)*	17.99	3.539	1.00	5.56
Methanol**	NA	NA	1.00	4.10
Liquefied Natural Gas (LNG)*	NA	NA	1.00	4.46
Liquefied Petroleum Gas (LPG)*	17.23	3.849	1.00	5.79
Propane	17.20	3.824	1.00	5.74
Ethane	16.25	2.916	1.00	4.14
Isobutane	17.75	4.162	1.00	6.45
n-Butane	17.72	4.328	1.00	6.70
Fuels Measured in Standard Cubic Feet	**kg C / MMBtu**	**Btu / Standard cubic foot**		**kg CO_2 / Standard cubic foot**
Compressed Natural Gas (CNG)*	14.47	1,027	1.00	0.054

Source: U.S. EPA, *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005* (2007), Annex 2.1, Tables A-31, A-34, A-36, A-39, except those marked * (from EPA Climate Leaders, Mobile Combustion Guidance, 2007) and ** (from California Climate Action Registry *General Reporting Protocol* Version 2.2, 2007, Table C.3). A fraction oxidized value of 1.00 is from the IPCC, *Guidelines for National Greenhouse Gas Inventories* (2006). Note: Default CO_2 emission factors are calculated using Equation 12d: Heat Content × Carbon Content × Fraction Oxidized × 44/12 × Conversion Factor. Heat content factors are based on higher heating values (HHV). NA = data not available.

Example 2: CH_4 & N_2O Aggregation

Vehicle ID	Vehicle Model	Fuel Type	Annual Fuel Use (gal)
FT05-3	2005 Ford Taurus	gasoline	700
FT04-53	2004 Ford Taurus	gasoline	820
CT06-8	2006 Chevy Trailblazer	gasoline	930
HDT-4	Heavy-duty truck	diesel	1,536
CT07-5	2007 Chevy Trailblazer	gasoline	850
FT05-15	2005 Ford Taurus	gasoline	510
HDT-75	Heavy-duty truck	diesel	1,830
CT06-36	2006 Chevy Trailblazer	gasoline	975
HDT-42	Heavy-duty truck	diesel	1,780
FT04-7	2004 Ford Taurus	gasoline	800

Group by model

Example 2: CH_4 Calculation

Model	Total gallons	Mpg city	Mpg hwy	% City miles	Total miles	CH_4 model year factor Table 13.4	MT CH_4
2005 Ford Taurus	70,000	18	25	50%	1,505,000	0.0147	0.022
2006 Chevy Trailblazer	90,000	14	20	55%	1,503,000	0.0152	0.023
Heavy-duty truck	170,500	5.8	5.8	55%	988,900	0.0051	0.005
Total							0.050

Total gallons x ((mpg city x % city miles) + (mpg hwy x % hwy miles)) = total miles

Total miles x CH_4 model year emission factor (g / mi) / 1,000,000 (g / metric ton) = MT CH_4 emissions

Example 2: N_2O Calculation

Model	Total gallons	Mpg city	Mpg hwy	% City miles	Total miles	N_2O model year factor Table 13.4	MT N_2O
2005 Ford Taurus	70,000	18	25	50%	1,505,000	0.0079	0.012
2006 Chevy Trailblazer	90,000	14	20	55%	1,503,000	0.0132	0.020
Heavy-duty truck	170,500	5.8	5.8	55%	988,900	0.0048	0.005
Total							0.036

Total gallons x ((mpg city x % city miles) + (mpg hwy x % hwy miles)) = total miles

Total miles x N_2O model year emission factor (g / mi) / 1,000,000 (g / metric ton) = MT N_2O emissions

Example 2: Total Emissions

Total gas	MT gas	IPCC Global Warming Potential (GWP) pg 168	MT CO_2e
CO2	3,141	1	3,141
CH4	0.050	21	1.1
N2O	0.036	310	11.3
Total			3,153

MT CO_2e = MT gas x IPCC GWP

Example 3: Rental Vehicle Fleet

- Tracks mileage per vehicle
- Does not track fuel use
- CO_2
  - Estimate fuel use by mileage per vehicle and mpg
  - Fuel type
  - Default factors – not measured
  - Tier C
- CH_4 & N_2O
  - Mileage
  - Vehicle type
  - Control technology factors
  - Tier A

Example 3: CO_2 Aggregation

Vehicle ID	Vehicle Model	Fuel Type	Annual mileage
FT05-3	2005 Ford Taurus	gasoline	15,050
FT04-53	2004 Ford Taurus	gasoline	17,630
CT06-8	2006 Chevy Trailblazer	gasoline	15,531
HDT-4	Heavy-duty truck	diesel	8,909
CT07-5	2007 Chevy Trailblazer	gasoline	14,195
FT05-15	2005 Ford Taurus	gasoline	10,965
HDT-75	Heavy-duty truck	diesel	10,614
CT06-36	2006 Chevy Trailblazer	gasoline	16,283
HDT-42	Heavy-duty truck	diesel	10,324
FT04-7	2004 Ford Taurus	gasoline	17,200

Group by model

Example 3: CO_2 Calculation

Model	Total miles	Mpg city	Mpg hwy	% City miles	Total gallons	Emission factor from Table 13.1 (kg CO_2 / gal)	CO_2 emissions (MT CO_2)
2005 Ford Taurus	2,000,000	18	25	50%	93,023	8.81	820
2006 Chevy Trailblazer	1,500,000	14	20	55%	89,820	8.81	791
Heavy-duty truck	1,000,000	5.8	5.8	55%	172,414	10.15	1,750
Total							3,361

Total miles / ((mpg city x % city miles) + (mpg hwy x % hwy miles)) = total gallons

Total gallons x emission factor (kg CO_2 / gal) / 1,000 (kg / metric ton) = MT CO_2 emissions

Example 3: CH_4 & N_2O Aggregation

Vehicle ID	Vehicle Model	Vehicle Type	Control Technology	Annual mileage
FT05-3	2005 Ford Taurus	gas passenger car	EPA Tier 2	15,050
FT04-53	2004 Ford Taurus	gas passenger car	EPA Tier 2	17,630
CT06-8	2006 Chevy Trailblazer	gas light truck	EPA Tier 2	15,531
HDT-4	Heavy-duty truck	diesel heavy-duty	moderate	8,909
CT07-5	2007 Chevy Trailblazer	gas light truck	EPA Tier 2	14,195
FT05-15	2005 Ford Taurus	gas passenger car	EPA Tier 2	10,965
HDT-75	Heavy-duty truck	diesel heavy-duty	moderate	10,614
CT06-36	2006 Chevy Trailblazer	gas light truck	EPA Tier 2	16,283
HDT-42	Heavy-duty truck	diesel heavy-duty	moderate	10,324
FT03-7	2003 Ford Taurus	gas passenger car	EPA Tier 2	17,200

Group by vehicle type and control technology

Example 3: CH_4 Calculation

Vehicle type and control technology	Total miles	CH_4 control technology factor Table 13.4	MT CH_4
Passenger cars – Tier 2	2,000,000	0.0173	0.035
Light trucks – Tier 2	1,500,000	0.0163	0.024
Heavy-duty trucks – moderate	1,000,000	0.0051	0.005
Total			0.064

Total miles x CH_4 control technology emission factor (g / mi) / 1,000,000 (g / metric ton) = MT CH_4 emissions

Example 3: N_2O Calculation

Vehicle type and control technology	Total miles	N_2O control technology factor Table 13.4	MT N_2O
Passenger cars – Tier 2	2,000,000	0.0036	0.106
Light trucks – Tier 2	1,500,000	0.0066	0.146
Heavy-duty trucks – moderate	1,000,000	0.0048	0.071
Total			0.323

Total miles x N_2O control technology emission factor (g / mi) / 1,000,000 (g / metric ton) = MT N_2O emissions

Example 3: Total Emissions

Total gas	MT gas	IPCC Global Warming Potential (GWP) pg 168	MT CO_2e
CO2	3,361	1	3,361
CH4	0.064	21	1.3
N2O	0.323	310	6.8
Total			3,369

MT CO_2e = MT gas x IPCC GWP

Questions?