PDHonline Course C191 (2 PDH)

Environmental Action: Estimating Green House Gas Emissions from Manufacturing

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Course Content

Green House Gas emissions are linked to Global Warming and the potential for climate change. While there is some scientific uncertainty about the exact link, it is clear that there will be an increasing awareness and concern regarding increased Green House Gas emissions and their control/reduction. A basic skill learned in this course will be the ability to estimate Green House Gas emissions using readily available information. The engineer also will learn about the major sources of Green House Gases, why estimates at a specific facility may be needed, and techniques for reporting changes in emissions over time. At the completion of this course, the student should have sufficient understanding of Green House Gas Emissions to incorporate this concept into new project planning and to effectively communicate results to managers, employees, and the interested community.

1. Why Estimate Green House Gas Emissions (Reference 1)

Green House Gases such as water vapor and carbon dioxide, as well as clouds and small particles (called aerosols), trap some heat in the lower part of the Earth's atmosphere. This is called the greenhouse effect. There is increasing evidence that that Green House Gases are increasing in the atmosphere and concern that this increase can cause a climate change termed Global Warming.

Climate is controlled by the long-term balance of energy between the Earth and its atmosphere. Incoming radiation from the sun, mainly in the form of visible light, is absorbed at the Earth's surface and in the atmosphere above. On average, absorbed radiation is balanced by the amount of energy returned to space in the form of infrared "heat" radiation.

Winds and ocean currents redistribute heat over the surface of the Earth. The evaporation of surface water and its subsequent condensation and precipitation in the atmosphere redistribute heat between the Earth's surface and the atmosphere, and between different parts of the atmosphere. The natural redistribution process and results strongly influence weather but do not by themselves change climate.

Climate is the average weather, including seasonal extremes and variations, either locally, regionally, or across the globe. Climate is generally influenced by slow changes in features like the ocean, the land, the orbit of the Earth about the sun, and the energy output of the sun.

Natural events can cause changes in climate. For example, large volcanic eruptions put tiny particles in the atmosphere that block sunlight, resulting in a surface cooling of a few years' duration. Variations in ocean currents change the distribution of heat and precipitation. El Niño events (periodic warming of the central and eastern tropical Pacific Ocean) typically last one to two years and change weather patterns around the world, causing heavy rains in some places and droughts in others. Over longer time spans (tens or hundreds of thousands of years) natural changes in the geographical distribution of energy received from the sun and the amounts of Green House Gases and dust in the atmosphere have caused the climate to shift from ice ages to relatively warmer periods, such as the one we are currently experiencing.

Green House Gases are necessary for sustaining life on Earth as we know it. If there were no natural greenhouse effect and heat was not trapped in the lower part of the atmosphere, the average surface temperature of the Earth would be about 34°C (61°F) colder than it is today. On the other hand, uncontrolled increases in Green House Gases in the atmosphere could increase the greenhouse effect and change climate.

The sources of Green House Gases are many. The major sectors identified are (Reference 2):

- Energy use
- Industrial processes (including solvent and other product use)
- Agriculture
- Land use changes and forestry
- Waste management

The reasons a specific facility or corporation could choose to monitor Green House Gas emissions may include:

- Policy to attain ISO 14001 certification for the Environmental Management System. Aspects of the facility operations need to be identified (e.g., energy use, air emissions) and impacts estimated (e.g., Global Warming Potential). It is necessary to quantify these impacts, establish targets, and monitor these targets for improvements.
- Continual improvement policies and goals. One goal for a facility or corporation can be the reduction of environmental impacts which contribute to Green House Gas emissions and a method to assess reduction in the potential contribution to Global Warming

Quantifying the emission rate of known Green House Gases is the first step in setting these goals and is a needed element in tracking the progress of meeting such goals.

2. Green House Gas Sources in the US

The US total Green House Gas emissions are reported as Carbon Dioxide (CO_2) equivalents in Teragrams:

- 1 Teragram = 10^{12} grams
- 1 Teragram = one billion kilograms
- 1 Teragram = 2.2 billion pounds
- 1 Teragram = 1.1 million tons (2000 pounds/ton)
- 1,000 Teragram = 1.1 billion tons

- 1 ton (2000 pounds) = 2.27 x 10^{-7} Teragram
- 1 ton (2000 pounds) = 908 kilogram
- 1 pound = 4.545 x 10^{-10} Teragram
- 1 pound = 0.454 kilogram

In 2003, total US Green House Gas emissions were 6,900.2 Teragrams CO_2 Equivalent, which is equivalent to 7.6 billion tons of carbon dioxide emissions (See Tables A and B).

Table A: Recent Trends in US Green House Gas Emissions and Sinks by Sector (Reported as Teragram CO_2 Equivalent) (Reference 1)

SECTOR	1990 Teragrams CO_2 Eq. % of Total	2000 Teragrams CO_2 Eq. % of Total	2003 Teragrams CO_2 Eq. % of Total
Energy	5,141.7 84.5 %	5,985.3 86.1 %	5,964.4 86.4 %
Industrial Processes	299.9 4.9 %	332.1 4.8 %	308.6 4.5 %
Solvent and Other Product Use	4.3 < 0.1 %	4.8 < 0.1 %	4.8 < 0.1 %
Agriculture	426.5 7.0 %	444.1 6.4 %	433.3 6.3 %
Land-Use Change and Forestry (Emissions)	5.6 < 0.1 %	6.3 < 0.1 %	6.4 < 0.1 %
Waste	210.1 3.5 %	180.6 2.6 %	183.8 2.7 %
Total Green House Gas Emissions (All Sources)	**6,088.1** **100 %**	**6,953.2** **100 %**	**6,900.2** **100 %**
Agriculture and Forestry Net Flux (Sinks)	(1,042.0) 17.1 %	(822.4) 11.8 %	(828.0) 12.0 %
Net Emissions (Sources and Sinks)	**5,046.1** **82.9 %**	**6,130.8** **88.2 %**	**6,072.2** **88.0 %**

Table B: Key Source Categories for the United States (Reference 2)

Source Categories	Gas	2003 Emissions (Teragram CO_2 Equivalent)
Energy		
Emissions from Stationary Combustion – Coal	CO_2	2,013.8
Mobile Combustion: Road & Other	CO_2	1,538.5
Emissions from Stationary Combustion - Gas	CO_2	1,134.9
Emissions from Stationary Combustion - Oil	CO_2	635.3
Mobile Combustion: Aviation	CO_2	171.3
Fugitive Emissions from Natural Gas Operations	CH_4	125.9
Emissions from Non-Energy Use of Fuels	CO_2	118.0
International Bunker Fuels	Several	85.1
Mobile Combustion: Marine	CO_2	57.5
Fugitive Emissions from Coal Mining and Handling	CH_4	53.8
Mobile Combustion: Road & Other	N_2O	39.9
Fugitive Emissions from Oil Operations	CH_4	17.1
Industrial Processes		
Emissions from Substitutes for Ozone Depleting Substances	Several	99.5
Emissions from Iron and Steel Production	CO_2	53.8
Emissions from Cement Production	CO_2	43.0
Emissions from Ammonia Production and Urea Application	CO_2	15.6
Emissions from Electrical Equipment	SF_6	14.1
Emissions from HCFC-22 Manufacture	HFCs	12.3
Emissions from Adipic Acid Production	N_2O	6.0
Emissions from Aluminum Production	PFCs	3.8
Agriculture		
Direct Emissions from Agricultural Soils	N_2O	155.3
Emissions from Enteric Fermentation in Domestic Livestock	CH_4	115.0
Indirect Emissions from Nitrogen Used in Agriculture	N_2O	98.2
Emissions from Manure Management	CH_4	39.1
Waste		
Emissions from Solid Waste Disposal Sites	CH_4	131.2
Emissions from Wastewater Handling	CH_4	36.8
Emissions from Waste Incineration	CO_2	18.8
Subtotal of Key Source Emissions		**6,833.6**
Total Emissions		**6,900.2**

The major sources for these emissions include (Reference 1).

Energy Sector

Historically, energy-related activities have accounted for more than three-quarters of Global Warming Potential-weighted Green House Gas emissions. Most of these are carbon dioxide emissions; however, some emissions of methane and nitrous oxide also result from stationary and mobile combustion. Almost all emissions from the energy sector result from fossil fuel combustion, which includes the burning of coal, natural gas, and petroleum. Fossil fuel combustion from stationary sources, such as electricity generation, represents more than half of energy-related emissions, while combustion of fossil fuels by mobile sources, such as automobiles, represents approximately one-third. In addition to fossil fuel combustion-related activities, carbon dioxide is also emitted as a result of natural gas flaring and biomass burning. Methane is emitted through coal mining as well as the production, processing, transmission, and distribution of natural gas and petroleum.

Industrial Processes

Industrial processes emit Green House Gases as a by-product of various non-energy related industrial activities. Manufacture of cement, lime, soda ash, iron, steel, aluminum, ammonia, titanium dioxide, and ferroalloys produces carbon dioxide as a by-product. The consumption of limestone, dolomite, and carbon dioxide as raw materials in industrial applications also releases carbon dioxide emissions. The production of petrochemicals and silicon carbide result in small amounts of methane emissions, while producing nitric and adipic acid generates nitrous oxide emissions. Emissions of HFCs, PFCs, and SF_6 are particularly important as substitutes for ozone-depleting substances such as chlorofluorocarbons (CFCs). These gases may also be emitted as a result of aluminum and hydrochlorofluorocarbon (HCFC-22) production, semiconductor manufacturing, electrical transmission and distribution, and magnesium production and processing.

Agriculture

Agricultural activities contribute directly to emissions of methane and nitrous oxide. The majority of nitrous oxide emissions occur because cropping and fertilizer practices increase the quantity of reactive nitrogen in the soils. This occurs through application of commercial fertilizers, livestock manure, and sewage sludge; production of nitrogen-fixing crops and forages; retention of crop residues on the field; and the cultivation of soils high in organic matter. These activities make more nitrogen available for the generation of nitrous oxide through microbial activity. The normal digestive processes in ruminant livestock (known as enteric fermentation) account for the largest portion of methane emissions. The agriculture sector also emits methane and nitrous oxide from managed and unmanaged manure, rice cultivation, and the burning of agricultural residues.

Land Use Change and Forestry

The natural carbon fluxes between biomass, soils, and the atmosphere result in a net removal of carbon dioxide from the atmosphere. This natural flux can change when humans alter the terrestrial biosphere through land-use, changes in land-use, and forest management practices. Various forest, agricultural soil, and land management practices can result in the uptake (i.e., sequestration) or emission of carbon dioxide. Forestlands contribute the most to the net uptake of carbon dioxide, followed by agricultural soils.

Waste Management

Waste management and treatment activities are another source of Green House Gas emissions in the United States. Landfills are the nation's largest source of methane emissions from the activities of man. Wastewater treatment systems, including human sewage treatment, are also sources of methane and nitrous oxide emissions.

3. How to Estimate Green House Gas Emissions

Green House Gas emissions are not directly regulated in the US at this time. It is normal for a facility to have some emissions estimates in support of air permits or exemptions, but those estimates normally will not include sufficient information to estimate all Green House Gas emissions. For example, a furnace might be permitted for Natural Gas and Fuel Oil as back up fuel, but the emission calculations will not directly identify the Carbon Dioxide (CO_2) emissions from combustion. Also, Green House Gas emissions from a facility should include indirect emissions in order to fully evaluate the total impact of the facility (e.g., include Green House Gas emissions for the electricity used at the facility). Finally, the impact of all chemicals considered Green House Gases are not equal, so there is a need to present these chemical emissions on a common basis. As discussed below, Carbon Dioxide equivalent emissions are used for this reporting.

The procedure for estimating Green House Gas emissions is an extension of normal engineering principles. A simple method includes the steps:

Step 1 Determine the Period of Interest for the Estimate

Step 2 Determine Fuel Consumption and Direct Green House Gas Emissions

Step 3 Determine Electricity Consumption and Indirect Green House Gas Emissions

Step 4 Determine Other Chemical Emissions and Convert to Equivalent Green House Gas Units

Step 5 Putting It All Together

Tables C, D, and E referenced in the Steps are included at the end of this section.

Step 1 Determine the Period of Interest for the Estimate

The first issue to address is the time frame for an estimate, such as:

- Operating Hours – useful for standby equipment (backup generators) or other major energy consumption units that are infrequently used
- Operating Shifts – useful for a facility where variable shifts may be required
- Operating Week – useful for closely monitoring impact of changes and for routine operations reporting
- Calendar Month – useful for closely monitoring operating results and often consistent with management reporting
- Quarter – useful for summarizing seasonal changes and often consistent with management reporting

- Year – useful for longer-term monitoring and often consistent for setting goals and objectives
- Longer Periods – usually selected for evaluating trends, for example, comparing results to manufacturing output

It is important to understand how the data from the estimate may be used and considered when selecting a time frame for evaluation. A reasonable starting point is often Calendar Year because of the relative ease in obtaining summary data. However, for the evaluation to be most useful, the engineer is likely to need at least the detail from Calendar Monthly data and information on infrequently used equipment. The monthly approach is particularly useful for presenting results on a "month-over-month" basis since this normalizes operating changes for many facilities (e.g., seasons, shutdowns).

Step 2 Determine Fuel Consumption and Direct Green House Gas Emissions

Energy generation and fuel consumption are by far the largest component of Green House Gas emissions (**Table A and Reference 1**). The actual direct generation of Green House Gases for most facilities results from fuel fired equipment, such as boilers (steam, hot water), furnaces, heaters, manufacturing equipment, and facility transport such as forklifts. The main Green House Gas emitted from these sources will be Carbon Dioxide.

Direct Green House Gas estimates from fuel use are determined as follows:

- List all fuel fired items
- Identify fuel use within the selected time frame
- Estimate Carbon Dioxide emissions using an emission factor

Typical fuels used in a facility may include gases (natural gas (methane), propane, butane), liquids (fuel oils, gasoline), or solids (coal, wood or wood waste). Table C presents typical emission factors for Carbon Dioxide from these fuel sources (**Reference 3**). Note: these are typical factors, assuming essentially complete combustion.

Step 3 Determine Electricity Consumption and Indirect Green House Gas Emissions

Electricity generally is furnished to a facility without direct on-site generation, but the Green House Gases from the off-site generator represent indirect emissions for the facility. These indirect Green House Gas emissions are in proportion to the electricity consumed and the Green House Gas emissions per unit of electricity for the power generator. Based on reports by region and state, typical Carbon Dioxide emissions for electricity generation are reported in Table D (**Reference 3**).

Indirect Green House Gas estimates from electricity use are determined as follows:

- List all electricity consuming items
- Identify electricity use for the items
- Estimate Carbon Dioxide emissions using the appropriate state factor

In practice, a facility may measure only total electricity use, but some approaches to obtain the necessary information may include:

- Total electricity bill – it is necessary to get the actual use in Kilowatt hours (kWh) since the electric bill will usually include service cost, peak service charges, and possibly power factor charges
- Power draw and use estimates – major energy consuming equipment can be inventoried according to power consumption and use factor; this approach is useful for allocating power consumption to major uses within a facility but it is only an approximation
- Power meters within the facility – useful for more advanced evaluations when a higher confidence is desired for individual components of energy use

The Green House Gas estimate is made by multiplying electricity use (kWh) times the appropriate emission factor (pounds Carbon Dioxide per kWh).

Step 4 Determine Other Chemical Emissions and Convert to Equivalent Green House Gas Units

The major Green House Gas contributed by the activity of mankind is Carbon Dioxide, but there are several other common chemicals which contribute to Global Warming. The main chemicals considered to be Green House Gases include both those that are naturally occurring and those whose only source is the activity of mankind (**Reference 1**):

Naturally occurring Green House Gases

- Water vapor (H_20)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)

Industrial Sources of halogenated substances (fluorine, chlorine, or bromine)

- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- Bromofluorocarbons (Halons).

Stratospheric ozone depleting substances

- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- Bromofluorocarbons (Halons)

Other fluorine-containing substances that do not deplete stratospheric ozone

- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)

Chemicals that influence the formation or destruction of other Green House Gases, include:

- Carbon monoxide (CO)
- Oxides of nitrogen (NOx)
- Non-methane volatile organic compounds (NMVOCs)

Aerosols, which are extremely small particles or liquid droplets, such as those produced by sulfur dioxide (SO_2) or elemental carbon emissions, can also affect the absorptive characteristics of the atmosphere and therefore the net energy balance for the Earth.

Evaluating this wide range of chemicals to get a balanced assessment of their significance is accomplished using the concept of Global Warming Potential. The Global Warming Potential for a Green House Gas is defined as a dimensionless ratio:

> Global Warming Potential is the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas.

The reference gas selected for developing the Global Warming Potential is Carbon Dioxide (CO_2). The Global Warming Potential for other Green House Gases is determined by estimating the long-term effect on energy absorption considering factors such as persistence in the atmosphere and relative absorption over a long period of time. The Global Warming Potential is calculated as a dimensionless conversion factor to report the Green House Gas emissions as the CO2 equivalent emissions. The relationship between a gas and its CO_2 equivalent can be expressed as follows:

$$CO_2 \text{ Equivalent, grams} = (\text{Gas, grams}) \times (\text{Global Warming Potential})$$

Included in Table E is a list of the chemicals considered to be Green House Gases and their Global Warming Potential.

A Global Warming Potential factor is not defined for CO, NOx, NMVOCs, SO_2, and aerosols because these are short-lived in the atmosphere, spatially variable, or have only indirect effects on radiative forcing (**Reference 2**).

Engineers should use their knowledge of the facility raw materials, manufacturing processes, fuel and energy consuming activities, and waste management practices to identify any chemicals listed in Table E that are present at the facility. As is evident from the ratios, any halogenated chemical has an extremely high Global Warming Potential and therefore should be carefully considered in estimating emissions. Also note that Methane (Potential 21 times Carbon Dioxide) and Nitrous Oxide (Potential 310 times Carbon Dioxide) should be carefully assessed.

The Green House Gas emissions are all reported as Carbon Dioxide equivalent, by multiplying the chemical emission times the Global Warming Potential factor (Table E).

Step 5 Putting It All Together

Compiling the information from the above individual steps into a facility estimate is completed by using the selected time frame (Step 1) and then combining the direct Carbon Dioxide emissions (Step 2), the indirect Carbon Dioxide emissions (Step 3), and the direct Chemical Carbon Dioxide equivalent emissions (Step 4) into a representative total for the facility. It is often most instructive to present results showing the magnitude of each component. It is particularly important when presenting a total for the facility to clarify that it includes both "direct" and "indirect" Green House Gas emissions.

Table C Green House Gas Carbon Dioxide Emissions by Type of Fuel (Reference 3)

FUEL	Pounds CO_2 per Unit Volume or Mass	Pounds CO_2 per Million BTU
Petroleum Products		
Aviation Gasoline	18.355 per gallon 770.916 per barrel	152.717
Distillate Fuel (No. 1, No. 2, No. 4 Fuel oil and Diesel)	22.384 per gallon 940.109 per barrel	161.386
Jet Fuel	21.439 per gallon 900.420 per barrel	159.690
Kerosene	21.537 per gallon 904.565 per barrel	159.535
Liquefied Petroleum Gas (LPG)	12.200 per gallon 512.415 per barrel	138.846
Motor Gasoline	19.641 per gallon 824.939 per barrel	157.041
Residual Fuel (No. 6 Fuel oil)	26.033 per gallon 1,093.384 per barrel	173.906
Natural Gas and Other Gaseous Fuels		
Methane	116.376 per 1000 ft^3	115.528
Flare Gas	133.759 per 1000 ft^3	120.721
Natural Gas (Pipeline)	120.593 per 1000 ft^3	117.080
Propane	12.669 per gallon 532.085 per barrel	139.178
Electricity		
Varies depending on fuel used to generate electricity		SEE TABLE D
Coal		
Anthracite	3852.156 per ton	227.400
Bituminous	4921.862 per ton	205.300
Subbituminous	3723.952 per ton	212.700
Lignite	2733.857 per ton	215.400
Renewable Sources		
Geothermal Energy	0	0
Wind	0	0
Photovoltaic and Solar Thermal	0	0
Hydropower	0	0
Wood and Wood Waste	3814 per ton	221.943
Municipal Solid Waste	1999 per ton	199.854
Nuclear		
Nuclear	0	0

Table D Carbon Dioxide Emissions from Electricity Generation by State (Reference 3)

Region/State	Pounds CO_2 per kWh		Region/State	Pounds CO_2 per kWh
New England			**East-South Central**	
Connecticut	0.715		Alabama	1.369
Maine	0.966		Kentucky	1.930
Massachusetts	1.459		Mississippi	1.075
New Hampshire	0.852		Tennessee	1.335
Rhode Island	1.091		**West-South Central**	
Vermont	0.159		Arkansas	1.286
Mid Atlantic			Louisiana	1.388
New Jersey	0.774		Oklahoma	1.672
New York	1.036		Texas	1.552
Pennsylvania	1.286		**Mountain**	
East-North Central			Arizona	0.798
Illinois	0.866		Colorado	2.001
Indiana	2.171		Idaho	0.269
Michigan	1.576		Montana	1.553
Ohio	1.807		Nevada	1.875
Wisconsin	1.343		New Mexico	1.405
West-North Central			Utah	1.990
Iowa	1.686		Wyoming	2.194
Kansas	1.703		**Pacific (Contiguous)**	
Minnesota	1.627		California	0.756
Missouri	1.783		Oregon	0.235
Nebraska	1.288		Washington	0.306
North Dakota	2.303		**Pacific (Other)**	
South Dakota	0.912		Alaska	0.031
South Atlantic			Hawaii	0.031
Delaware	1.855			
District of Columbia	2.649		**US AVERAGE**	**1.291**
Florida	1.294			
Georgia	1.220			
Maryland	1.356			
North Carolina	1.350			
South Carolina	0.688			
Virginia	1.107			
West Virginia	2.005			

Table E Global Warming Potentials (100 Year Time Horizon) (Reference 2)

GAS	Chemical	Global Warming Potential Factors (Relative to CO_2)
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_20	310
Hydrofluorocarbons	HFC-23	11,700
"	HFC-32	650
"	HFC-125	2,800
"	HFC-134a	1,300
"	HFC143a	3,800
"	HFC-152a	140
"	HFC-227ea	2,900
"	HFC-236fa	6,300
"	HFC-4310mee	1,300
Chlorofluorcarbons	CF_4	6,500
"	C_2F_6	9,200
"	C_4F_{10}	7,000
"	C_6F_{14}	7,400
Sulfur Hexafluoride	SF_6	23,900

Source: **Reference 2**

4. Example of Estimating Green House Gas Emissions

In practice, estimating emissions is often performed by iteration, for example:

- First estimate – Green House Gases for one year
    - Energy consumption
        - Electricity = kWh
        - Gas Fuels (e.g., Natural Gas) = cubic feet or BTUs
        - Liquid Fuels (e.g., Diesel) = gallons, pounds, or BTUs
        - Solid (coal or wood waste)
    - Convert to Carbon Dioxide emissions equivalents
        - Calculate for Fuels using factors in Table C
        - Calculate for Electricity using factors in Table D
    - Determine other Chemicals and their emissions
        - Emissions by appropriate estimating method
        - Calculate Green House Gas emission as Carbon Dioxide equivalent using factors in Table E
    - Summarize total Annual Green House Gas Emissions as Carbon Dioxide equivalents
        - Direct from Fuels
        - Indirect from Electricity
        - Direct from Chemicals
    - Suggestions
        - Understand the major energy consumption items and the time frame for their use/operation; e.g., seasonal differences
            - Comfort heating/cooling
            - Seasonal manufacturing
        - Use spreadsheets to summarize information with Annual Total and capability to expand to Monthly data

- Second estimate – Green House Gases by major activity
    - Facility support
        - Offices
        - Manufacturing areas
        - Outside areas
        - Heating and air conditioning
    - Manufacturing support
        - Process furnaces and heaters
        - Energy consuming operations (e.g., electric and gas welding)
        - Steam and boilers
    - Chemical emissions
        - Halogenated chemicals
        - Methane or Nitrous Oxide

Example: Acme Widgets (Ohio)

STEP 1 Select Annual Monitoring Period

STEPS 2, 3 and 4 Collect Facility Energy and Chemical Information

Natural Gas for comfort heating: Annual 3,200,000 cu ft

Propane for Fork Lifts (three): Annual 6,000 pounds

Fuel Oil (No. 2) for Hot Water Boiler (Widget cleaning): Annual 26,000 gallons

Electricity for lighting, pumps, etc: Annual 360,000 kWh

Green House Gases chemicals used at facility: None

STEPS 2, 3 and 4 Estimates of Green House Gases

STEP 2 Carbon Dioxide Direct Sources (Fuel) (Table C)

Natural Gas = (120.593 lb/1000 cu ft) x (3,200,000 cu ft)
= 385,900 lb/yr (192.9 ton/year)

Propane = (12.669 lb CO_2 /gallon) x (6,000 lb/yr)
= 76,014 lb/year (38.0 ton/year)

Fuel Oil = (22.384 lb/gallon) x (26,000 gallon)
= 582,000 lb/yr (291.0 ton/yr)

STEP 3 Carbon Dioxide Indirect Sources (Electricity)
(Table D, Ohio Factor)

Electricity = (1.807 lb/kWh) x (360,000 kWh) [Using Ohio factor]
= 650,500 lb/yr (325.3 ton/year)

STEP 4 Other Chemicals -- None

STEP 5 Facility Summary

Source	**Green House Gas, Ton/year**	**Green House Gas, Teragram/year**
Direct, Fuel	**521.9**	**0.000 12**
Indirect, Electricity	**325.3**	**0.000 19**
Chemicals	**0**	**0**
TOTAL	**847.2**	**0.000 31**

Note – Total US Green House Gases in 2003 was 6,900 Teragram

5. Monitoring Emissions Over Time

It is estimated that human activities have changed the atmospheric concentration of direct Green House Gases since the pre-industrial era (i.e., since about 1750) (**Reference 2**):

- Carbon dioxide (CO_2) increased by 31 %
- Methane (CH_4) increased by 150 %
- Nitrous oxide (N20) increased by 16 %

Total US Green House Gas emissions have risen by 13 percent from 1990 to 2003, while the US gross domestic product has increased by 46 percent over the same period (**Reference 2**). Important factors in emissions from year to year include:

- Economic growth leading to increased demand for electricity and fossil fuels
- Energy prices (e.g., rising natural gas prices cause some electric power producers to switch to burning coal)
- Weather and comfort heating and cooling

An effective monitoring program should include several years of data, preferably presented on a "month over month" basis to improve understanding of seasonal variations. Where feasible, it also is useful to normalize emissions (e.g., emissions per unit of production) for the selected monitoring period as a method to relate Green House Gas emissions to the production factor. To get a program started, it may be possible to use old fuel bills and other records to back-calculate emissions from past years.

6. Implementing Controls with New Projects

Measure Baselines

One current national action to control Green House Gas emissions is the annual US inventory and the world-wide inventory. Much progress has been made in improving the techniques for these estimates. Approaches for developing and evaluating a specific facility Green House Gas emissions data are:

- Year over year comparisons (overall measurement) to US inventory
- Unit emissions (normalize to production)
- Benchmark (normalize to best practices)

Typically, reduction targets for Green House Gas emissions are based on measurements with annual and long term goals.

Energy Impact and Controls

The biggest opportunity for control of Green House Gas emissions is with energy management, including both fixed and mobile sources. Opportunities and approaches include:

- Reduce energy use (e.g., conservation methods)
- Improve energy use efficiency
- Change type of energy use to “non” Green House Gas sources (e.g., solar)
- Replace “fossil” fuels with renewable resources (e.g., replace oil with ethanol). [Although replacing oil with ethanol still results in Green House Gas emissions of CO_2, this approach does reduce carbon release from fossil sinks]

Managing Sinks

One strategy to increase the sequestration of carbon is by introducing new sinks:

- Plant trees
- Land use practices (don’t burn)
- Increase and/or manage forest areas, as well as a net accumulation of carbon stocks in harvested wood pools
- Develop urban forests
- Convert cropland to permanent pasture and hay production
- Increase adoption of conservation tillage practices
- Increase use of organic fertilizers (e.g., manure and sewage sludge applied to agriculture lands)
- Landfill yard trimmings and food scraps for the long-term accumulation of carbon in landfills.

Industrial Chemical Use and Substitution

Industrial practices present opportunities for reducing certain chemical use. Institutional controls are used to reduce Green House Gas emissions from chemicals with the highest Global Warming Potential (Table E). Current control focus includes:

- Classes of halogenated substances that contain fluorine, chlorine, or bromine
    - Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) (contain chlorine)
    - Halons are bromine containing chemicals (bromofluorocarbons)
- Stratospheric ozone depleting substances (i.e., Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs), and Bromofluorocarbons (Halons))
- Non-ozone depleting substances with high Global Warming Potential
    - Hydrofluorocarbons (HFCs)
    - Perfluorocarbons (PFCs)
    - Sulfur hexafluoride (SF_6)

Personal Choices

There also are common sense steps that people can take at home or at work to control and reduce Green House Gas emissions:

- Reduce, reuse, and recycle materials
- Use fuel-smart vehicles
- Use alternatives to personal vehicles (e.g., public transportation, car pools)
- Implement building and home energy savings
- Use non-Green House Gas energy sources (e.g., solar)
- Plant and maintain actively growing trees (carbon sinks)

7. Communicating Results

The reason for estimating Green House Gas emissions will determine the best way to present results. Essential findings can be summarized in charts, tables, or graphics. The findings should be compared to facility goals, unit production, or other activity meaningful to the audience for the information.

Results also can be used to increase awareness of the Green House Gas emissions issue and relate these emissions to daily activities. For example, one gallon of gasoline results in 19.6 pounds of equivalent Green House Gas emissions.

8. References and Information Sources

Reference 1

Common Questions about Climate Change, United Nations Environment Programme - World Meteorological Organization www.gcrio.org.

Reference 2

US Inventory of Greenhouse Gas Emissions and Sinks 1990-2003 (EPA 2005) EPA 430-R-05-003
yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html

Reference 3

Wise Rules for Industrial Efficiency; A Tool Kit for Estimating Energy Savings and Greenhouse Gas Emissions Reductions (EPA 231-R-98-014, September 2003)
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/JSAW62TQJV/$File/WiseRules_03.pdf

Additional References and Web Sites

Energy Star
www.energystar.gov/

Global Warming – Resource Center
yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterToolsGHGCalculator.html