

AUSTRALIAN Greenhouse Office

AGO Factors and Methods Workbook

For use in Australian Greenhouse Office Programs including Greenhouse Challenge

Version 3 - March 2003

Supercedes Greenhouse Challenge Factors and Methods Workbook Version 2 - December 2002

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Introduction

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Section A - Introduction

1 Workbook rationale

The *AGO Factors and Methods Workbook* (AGO F&M W/B) was developed to provide AGO program managers and program participants, including Greenhouse Challenge Program participants with a single source of current greenhouse gas emission factors (EFs). These are to be used as inputs to calculating greenhouse gas emissions related to their programs. The Workbook also contains the methods to be used in calculating greenhouse gas emissions and sinks. It is based on the Workbook entitled, *Greenhouse Challenge, Factors and Methods Workbook, Version 2 – December 2002.*

The objective of the AGO F&M W/B is to ensure consistency in the application of EFs and methods across AGO programs. It was developed in response to the AGO Data and Methods Working Group's finding that the different sources of information used across the AGO, particularly in terms of EFs, could result in the application of out of date or inconsistent EFs in the various programs.

The factors in this Workbook should be used in preference to those in other publications. This will allow for the review of emissions and abatement calculations in a simple and transparent manner. Should there be a need to use other sources or EFs please contact the Manager, Reporting, Analysis and Verification Team for further advice.

This Workbook will be updated periodically and notification of the most current version will be provided through the Greenhouse Challenge Program and AGO web sites and newsletters. Appendix 2 documents EF changes from the previous (December 2001) version.

It should be noted that when EFs are changed there is no requirement to recalculate emissions unless there was an error in the previous factor.

EFs are based on, among other inclusions, the composition of the fuel and the fuel mix (eg the proportion of gas and coal a particular state may use to generate electricity) which may change from year to year. Recalculation of previous year estimates based on the most current EFs will thus introduce errors into estimates especially with regard to emission and abatement trends.

2 AGO contact

The Manager Reporting, Analysis and Verification Team Partnerships and Market Policies Group Australian Greenhouse Office

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The Greenhouse Challenge Program Industry Adviser contact details are:

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Information Sources

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3 Information sources

The sources of information used in developing this workbook are:

- 1. Greenhouse Challenge Program Workbooks;
- 2. Australian Methodology for the Estimation of Greenhouse Gas Emission and Sinks Workbooks, Reprinted Revisions 1998, 1.1 to 1.8;
- 3. National Greenhouse Gas Inventory (NGGI) and analyses based on the NGGI (1999 and 2000);
- 4. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories;
- 5. IPCC Report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories; and
- 6. End Use Allocation of Emissions, a Report to the Australian Greenhouse Office by George Wilkenfeld and Associates Pty Ltd (2002).

This document is intended to be compatible with the Intergovernmental Panel on Climate Change (IPCC) publications and other publications of a similar nature including the WBCSD/WRI **The Greenhouse Gas Protocol: a corporate accounting and reporting standard* (<u>http://www.ghgprotocol.org/</u> * World Business Council for Sustainable Development/World Resources Institute).

The AGO Emissions Analysis Team was responsible for vetting the EFs used in this publication.

The EFs in this publication are usually state or national **averages**. Average EFs are derived from historical data only and do not necessarily indicate the increase or decrease in emissions to be expected from a change in, for example, energy use at a particular point in time. **Marginal EFs** may also be used depending on details required by a user and the information available. Marginal EFs are calculated using historical data, projections and other analyses intended to indicate the increase or reduction in emissions from a change in energy use or production sources at a particular point in time. In general they reflect the emissions associated with the last unit of energy used. They also reflect short cycle changes in fuel use and may be higher or lower than average EFs depending on the conditions relating to the system at that time. Marginal factors are, however, difficult to determine without good real time system monitoring capabilities. The AGO provides estimates of marginal EFs and these may be found at <u>http://www.greenhouse.gov.au/ggap</u>. For more information contact the Reporting, Analysis and Verification Team (see above for contact details).

4 Workbook structure

This Workbook is divided into two sections. Section A provides an introduction to the Workbook and information on key definitions and terms. Section B contains the EFs and methods to be used, in the absence of detailed site specific factors, in calculating greenhouse gas emission estimates.

For users of the previous *Greenhouse Challenge, Factors and Methods Workbook, Version 3 – December 2001*, of which this workbook is a more generalised, expanded update intended for wider use, Appendix 2 provides an indication of the changes in EFs from that publication, indicating the EFs that have been changed.



Key definitions

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5 Key definitions and terms

5.1 Direct and indirect emissions

5.1.1 Direct emissions

These are the emissions from sources generally within the boundary of the organisation, and represent emissions, at the point of final fuel combustion in most cases. The emissions mainly arise from the following activities:

- production of energy;
- manufacturing processes themselves (example, cement manufacture);
- transportation of materials, products, waste and employees; for example, use of mobile combustion sources, such as trucks and cars but not those owned and operated by another entity; and
- fugitive emissions: intentional or unintentional GHG releases (such as methane emissions from coal mines).

5.1.2 Indirect emissions

These are the emissions from sources generally outside the boundary of the organization and represent emissions associated with the consumption of fossil fuel derived energy but not at the point of final fuel combustion or use. Indirect emissions also include emissions associated with waste disposed off site (excluding sewerage) that are a consequence of the activities of a reporting company or project, but generated outside the organisational boundary by another company.

These emissions are mainly associated with the generation of imported electricity (not generated on site), heat, steam, gas and the production and distribution of petroleum products.

5.2 Emission factors

An emission factor is the quantity of a given GHG emitted per unit of energy (kg CO_2/GJ), fuel (t CH_4/t coal) or other such measure. EFs are used to calculate GHG emissions by multiplying the factor (eg kg $CO_2/litre$ petrol) with activity data (eg litres of petrol used). EFs can be categorised as point-source EFs or full fuel cycle EFs.

5.2.1 Point-source emission factors

A point-source emission factor is the quantity of a given GHG emitted per unit of energy, fuel etc., at the point of consumption. Combustion emissions occurring at the point of final fuel consumption (eg emissions from the combustion of petrol in a motor vehicle) or methane escaping from a coal seam during mining (fugitive emissions) constitute point-source emissions.

5.2.2 Full fuel cycle emission factors

A full fuel cycle emission factor is the quantity of GHG emissions emitted per unit of energy or activity for the entire production and consumption chain. For example, in the case of petroleum products full fuel cycle emissions include emissions of other fuels used in the production and transportation of the fuel as well as emissions at the final point of consumption. For the Greenhouse Challenge Program, full fuel cycle EFs are applied to electricity and gas consumption only but not to petroleum products consumption. This is due to internal accounting requirements, particularly in relation to double counting.



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NOTE

In calculating emissions, as a minimum the following are required:

- a. Raw data (eg litres of automotive fuel used, electricity use in kWh or GJ, etc etc);
- b. Point source emission estimates; and
- c. Full fuel cycle emission estimates.

6 References and web sites

- 1. AGO Emissions and Data Workbook (including use by Greenhouse Challenge Program members) in html mode. http://www.greenhouse.gov.au/challenge/html/member- tools/factorsmethod.html
- 2. AGO Emissions and Data Workbook (including use by Greenhouse Challenge Program members) in pdf mode. http://www.greenhouse.gov.au/challenge/html/member-tools/fmw_v3.pdf
- 3. Greenhouse Challenge Program. <u>http://www.greenhouse.gov.au/challenge</u> <u>http://www.greenhouse.gov.au/challenge/publications.html</u>
- 4. Australian National Greenhouse Gas Inventory and related topics. http://www.greenhouse.gov.au/inventory/index.html
- 5. Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventories Program. http://www.ipcc-nggip.iges.or.jp
- 6. IPCC web site. http://www.ipcc.ch/
- 7. United Nations Convention on Climate Change and relate topics including the Kyoto Protocol. http://unfccc.int
- The GHG Protocol Initiative (initiative convened by the <u>World Business Council for Sustainable Development (WBCSD</u>) & the <u>World Resources Institute (WRI</u>). <u>http://www.ghgprotocol.org/</u>
- 9. Greenhouse effect information site (Bad Greenhouse)— highly recommended reading http://www.ems.psu.edu/~fraser/Bad/BadGreenhouse.html
- 10. Solar radiation Michael J. Pidwirny, Ph.D., <u>Department of Geography</u>, <u>Okanagan University College</u> <u>http://www.geog.ouc.bc.ca/physgeog/contents/7f.html</u>



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Section B: Factors, Methods and Calculations

1 Energy

1.1 Stationary Energy Emissions (non transport)

1.1.1 Fuel combustion emissions

If your organisation uses coal or other fuels for combustion, the following formula can be used to estimate GHG emissions from the combustion of each type of fuel. Emissions are generally expressed in tonnes of CO_2 -equivalent (CO_2 -e), which includes the global warming effect of CO_2 as well as the relatively small quantities of CH_4 and N_2O emitted. Most of the emissions occur at the point of final fuel combustion ("point-source"), but there are also emissions associated with the production and transport of the fuel ("full fuel cycle").

Formula: GHG emissions (t CO_2 -e) = Q x EC x EF/1000

Where: Q (Activity) is the quantity of fuel in tonnes (sourced from inventory or supplier invoices or production records).

EC (Energy Content) of fuel in GJ/tonne, in Table 1.

EF (Emission Factor) is the point-source emission factor in kg CO_2 -e/GJ in Table 1, excluding non- CO_2 gases. Division by 1000 converts kg to tonnes.

Separate calculations should be carried out for each fuel type

This formula may be used by Electricity Generators with limited data related to EFs and calculation methods. Most generators, however, would have access to better EFs and methods. They are urged to pass these data to the AGO as soon as possible to allow verification and use by other Challenge members, where appropriate.



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Table 1 Fuel combustion emission factors				
Fuel combusted	Energy content of fuel GJ/t; MJ/L; GJ/kL	Point-source emissions factor kg CO ₂ /GJ	Full fuel cycle emissions factor kg CO ₂ -e/GJ	
Black coal	 default washed 27.0 GJ/t default unwashed 23.0 GJ/t NSW 23.2GJ/t QLD 21.9GJ/t 	90.0	NSW generation98.1NSW other uses96.9Queensland gen92.7Queensland other94.8	
Brown coal	10.0 GJ/t	88.3.0 ¹	93.9	
Coal used in steel industry	30.0 GJ/t	91.8 ²	112.8	
Coal by-products (gaseous)	37.0	48.5		
Coal by-products (coal tar and	1 BTX)	81.0	92.5	
Brown Coal Briquettes	22.1 GJ/t	105.0	115.7	
Coke	27.0 GJ/t	119.5	131.0	
LPG: non transport	49.6 GJ/t	59.4	67.1	
Naphtha	31.4 MJ/L	66.0	73.7	
Lighting kerosene	36.6 GJ/kL	69.7	77.4	
Power kerosene		69.7	77.4	
Heating Oil	37.3 GJ/kL	69.7	77.4	
Refinery Fuel		68.1	75.8	
Automotive diesel (ADO)	38.6 GJ/kL	69.7	77.6	
Industrial/marine diesel fuel	39.6 GJ/kL	69.7	77.7	
Fuel oil	Refer specifications of actual fuel default 40.8 GJ/kL	73.6	81.5	
Natural Gas (e) – see Table 15, CH_4 energy potential	consumption measured in GJ	Refer Tables 7 & 8	Refer Tables 7 & 8	
Town Gas	consumption measured in GJ	59.4 ¹		
Waste Methane (CH ₄) emissions not counted if used for energy or flared ³ (only vented waste methane counted)	consumption measured in GJ combustion engine)	51.0	56.0 (if used in internal	
Wood and wood waste CO ₂ missions not counted ³		94.0 (d)	95.4 (if used in boiler) 1.4 (if CO ₂ not counted)	
Bagasse CO ₂ emissions not counted ³		96.8 (d)	98.2 (if used in boiler) 1.4 (if CO ₂ not counted)	
Bitumen		80.7		
Tyres shredded with majority of steel removed ⁴	32 GJ/t	2391 kg CO ₂ /t	$75 \text{ kg CO}_2/\text{GJ}^5$	
Whole tyres ⁴	27 GJ/t	2080 kg CO ₂ /t	$77 \text{ kg CO}_2/\text{GJ}^5$	
Wood dry (boiler)	16.2 GJ/t ⁶			
Cotton trash	18 GJ/t ⁶			
Bagasse (boiler)	9.6 GJ/t ⁶			



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- ¹ from working paper (refer to source e).
- $^2\,$ from working paper and the 2000 NGGI (2002) and based on advice from BHP (refer to source e)
- ³ The CO₂ generated from bagasse, wood and wood waste, and the combustion of recovered CH₄ from waste dumps is not counted as a GHG emission, as it is regarded as part of the natural cycle of carbon in plants. (see IPCC Good Practice Report p 5.10). The same applies to flaring of CH₄. Emission factors are provided to record, for information purposes, the quantity of CO₂ released to the atmosphere. CH₄ captured and vented must be counted (x21 for CO₂ equivalent). Bagasse and wood waste are renewable fuels if harvested sustainably, in which case the CO₂/GJ coefficient is zero and the full fuel cycle coefficient is 1.4 (full fuel cycle factor without direct combustion).
- ⁴ Rubber in tyres is about 30% natural rubber no net greenhouse impact. Values do not take in full life cycle impacts.
- $^{5}\;$ Estimate only based on carbon content of the constituents of tyres.
- ⁶ Energy content from IOR Energy http://www.ior.com.au/ecflist.htm only non-CO₂ emissions included see Table 2 below.

Source:

- a. ABARE 1999, Australian Energy: Market Developments and Projections to 2014 15.
- b. Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Workbook for Fuel Combustion Activities (Stationary Sources), 1.1 1996. Although these factors are for CO_2 emissions only, they can be used as default CO_2 -e EFs except for equipment with high CH_4 or N_2O emissions notably internal combustion engines, wood-fuelled boilers and bagasse-fuelled boilers.
- c. National Greenhouse Gas Inventory 1990, 1995 and 1999: Cross Sectoral Analysis of Emissions. George Wilkenfeld and Associates, 2002. The full fuel cycle EFs include fuel used in mining/production and transport.
- d. CSIRO, *Lifecycle Emissions Analysis of Alternative Fuels for Heavy Vehicles: Stage 1*, March 2000 (also see GGAP Table 3: Emission factors transport fuels).
- e. 2000 NGGI (2002), Project Report for the Stationary Energy Sector of the 2000 NGGI (Energy Strategies), NGGIC Workbook 1.1 and the Working Paper on Data Sources and Methods for the review of the Energy (Stationary) Sector (2002).
- f. A National Approach to Waste Tyres, Prepared by Atech Group, June 2201.

The following non-CO₂ point-source EFs, Table 2, reflect the emissions associated with different fuels and equipment types used for fuel combustion in various sectors.



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Table 2 Equipment weighted sectoral emission factors for non-CO ₂ GHG (Mg/PJ) ⁷				
ANZSIC Category—Fuel	Equipment Weighted Emission Factor (Mg/PJ)			
	CH4	N ₂ O		
11 Coal mining				
Black coal	1.1	1.4		
LPG	0.1	0.6		
ADO	0.1	0.6		
Fuel oil	0.1	0.6		
1103 Briquette manufacturing				
Brown coal	1.3	0.8		
12 Oil and gas mining				
LPG	4.0	0.6		
ADO	4.0	0.6		
Petroleum products nec	4.0	0.6		
Natural gas	7.3	0.1		
14 All other mining				
Black coal	1.0	0.8		
Coke	1.0	0.8		
Coal byproducts	3.9	0.1		
LPG	1.1	0.6		
Aviation turbine fuel	1.1	0.6		
Heating oil	1.1	0.6		
ADO	0.8	0.6		
IDF	1.1	0.6		
Fuel oil	0.8	0.6		
Petroleum products nec	1.1	0.6		
Natural gas	1.1	0.1		
21 Food, beverages, tobacco				
Black coal	1.3	0.8		
Brown coal	1.3	0.8		
Coal byproducts	1.2	0.1		
Brown coal briquettes	1.3	0.8		
Wood, woodwaste	4.2	4.1		
Bagasse	9.3	4.1		
LPG	0.6	0.6		
ADO	0.6	0.6		
IDF	0.6	0.6		
Fuel oil	0.6	0.6		
Petroleum products nec	0.6	0.6		
Natural gas	1.2	0.1		
Town gas	1.2	0.1		

Source: Appendix C, National Greenhouse Gas Inventory 2000, p C-10.

⁷ See <u>http://www.greenhouse.gov.au/inventory/about.html</u> for full set of factors.



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Table 3 Pc	Table 3 Point-source emissions factors for flaring of gas at oil refineries			
	CO ₂	CH₄	CO ₂ -e	
kg/t gas flared	2695	6.8	2838	
kg/GJ energy flared	47.2	0.12	49.7	

Source: Australian Methodology for the Estimation of Greenhouse Gases and Sinks, Workbook for Fugitive Fuel Emissions (Fuel Production, Transmission, Storage and Distribution), Workbook 2.1, Reprinted Revision 1 With Supplements, 1998 (page 57)

1.1.2 Electricity End Use

If your organisation **consumes electricity**, you will need to calculate the greenhouse gas emissions associated with the quantity that you use. To determine the GHG emissions in tonnes of carbon dioxide equivalent (t CO_2 -e), the following formula and EFs should be used.

Formula: GHG emissions (t CO_2 -e) = Q x EF/1000

Where: Q (Activity) is the electricity used expressed in kWh, (sourced from supplier invoices or meters).

EF (Emission Factor) is the full fuel cycle EF in kg CO₂-e/kWh for the State or Territory in which your business operates, in Table 2 (and includes fugitive emissions). Other indirect emissions are excluded (see GWA report August 2002). Division by 1000 converts kg to tonnes.

Table 4 Emission factors for electricity purchased/used/delivered per kWh ⁸			
Locality	kg CO ₂ -e/kWh ⁸ Full fuel cycle emissions factors		
NSW, ACT	1.012		
VIC	1.444		
QLD	1.079		
SA	1.186		
WA	1.114		
TAS	0.002		
NT	0.654		

Source: George Wilkenfeld and Associates November 2002. Greenhouse Gas Coefficients for Electricity, Australia

⁸ Retail supply includes transmission and distribution losses



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Locality	Table 5 Emission factors for electricity purchased/used/delivered per GJ ality kg C0,-e/GJ (Gg C0,-e/PJ)Full fuel cycle emissions factors		
NSW, ACT	281		
VIC	401		
QLD	300		
SA	329		
WA	309		
TAS	0.6		
NT	182		

Source: Table 4 above: 3.6 x 10⁻³ GJ in 1 kWh. To convert kg/kWh to kg/GJ divide by 0.0036

Example: Calculation of Emissions Generated from Electricity Consumption

A Queensland based manufacturing facility uses 1,051,000 kWh of electricity per annum. The GHG in tonnes would be calculated as follows:

GHG emissions (t CO_2 -e) = Q x EF/1000

= 1,051,000 x 1.079/1000

= 1134

Where: Q (Activity) is the electricity used expressed in kWh, (sourced from supplier invoices or meters).

EF (Emission Factor) is the point-source EF in kg CO₂-e/kWh for the State or Territory in which your business operates, in Table 5.

1.1.3 Production of Coal, Gas and Petroleum

If your organisation produces coal, gas or petroleum products, there should be sufficient data about the production process to estimate or calculate emissions. If this is not the case, the following formula should be used in conjunction with the default emissions factors in Table 5. The general formula for each process is:

GHG Emissions (tCO₂-e) = Q x EF/1000 x 21

Where: Q (Activity) is the mass of fuel produced (tonnes) (sourced from supplier invoices or meters).

EF (Emission Factor) is the point-source EF in kg /tonne in Table 6 below. Division by 1000 converts kg to tonnes. Multiplication by 21 converts CH_4 to CO_2 -e.



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Table 6 Coal, Petroleum and Gas Production Point-source emission factors (Fugitive)				
	kg emissions/tonne product			
	CO2	CH ₄		
COAL	kg/tonne	kg/tonne		
Gassy underground mines - NSW	NA	18.6		
Gassy underground mines - Queensland	NA	16.1		
Less gassy underground mines	NA	0.56		
Open cut mines - NSW	NA	2.17		
Open cut mines – Queensland	NA	0.81		
Open cut mines - Tasmania	NA	0.68		
PETROLEUM		g/tonne		
Crude oil production	NA	0.005		
Crude oil transport: domestic	NA	0.016		
Crude oil refining and storage	6.50	0.027		
NATURAL GAS		g/tonne		
Production and processing	NA	0.02		
Transmission	0.03	0.18		
Distribution	0.96	6.77		
PETROLEUM AND GAS COMBINED		kg/tonne		
Venting at gas processing plant	126.55	4.37		
Flaring	46.90	0.57		

Source: Average derived from 1999 NGGI.

1.1.4 Gas Consumption (Non-Transport)

1.1.4.1 Natural gas

If your organisation uses natural gas for stationary energy (ie non-transport) purposes, you will need to calculate the greenhouse emissions (in tonnes) associated with the quantity that you use. Natural gas is usually supplied at either high or low pressure depending on the scale of use. Major users are those with an annual usage of more than 0.1 PJ.

To calculate emissions, please select the point-source EF from either Table 7 or Table 8 as appropriate, for use in the following formula.



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Formula: GHG Emissions (t CO_2 -e) = Q x EF/1000

Where: Q (Activity) is the quantity of natural gas consumed and expressed in GJ and sourced from supplier invoices / meters.

EF (Emission Factor) is the point-source emission factor kg CO_2 -e/GJ coefficient for the state or territory in which your business operates (see Table 7 and Table 8). Division by 1000 converts kg to tonnes.

Example: Calculation of Emissions Generated from Natural Gas Consumption

A Victorian Hotel uses 9000 GJ of natural gas per annum. Its greenhouse gas emissions (GHG) are calculated as follows:

GHG Emissions = Q x EF/1000

= (9000 x 51.7)/1000

 $= 465 \text{ t } \text{CO}_2\text{-e}$

Table 7 Emissions from combustion of natural gas - smaller users (a)				
Locality	Point-source emission factor (b) kg CO ₂ -e/GJ	Full fuel cycle emission factor kg CO ₂ -e/GJ		
NSW & ACT	51.7	71.9		
Victoria	51.7	64.2		
Queensland	53.1	74.8		
SA	51.7	74.4		
WA	53.2	62.7		
TAS	NA	NA		
NT	51.8	53.4		

(a) Consuming less than 100 TJ (TJ= 10^{12} J) per year (lower pressure)

(b) Includes allowance of 0.14 kg/GJ for non-CO₂ emissions at point of combustion.



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Table 8 Emissions from combustion of natural gas - larger users (a)			
Locality	Point-source emission factor (b) kg CO ₂ -e/GJ	Full fuel cycle emission factor kg CO ₂ -e/GJ	
NSW & ACT	51.7	70.8	
Victoria	51.7	63.7	
Queensland	53.1	66.5	
SA	51.7	72.2	
WA	53.2	61.6	
TAS	NA	NA	
NT	51.8	53.3	

(a) Consuming 100,000 GJ per year or more.

(b) Includes allowance of 0.14 kg/GJ for non-CO $_2$ emissions at point of combustion.

1.1.4.2 Liquid Petroleum Gas – LPG (non transport)

If you use liquid petroleum gas (LPG) for stationary energy (for non-transport purposes), you will need to calculate the greenhouse emissions associated with the quantity that you use. To determine these emissions, the following formula and EFs from Table 9 or Table 10 should be used:

Formula: GHG Emissions (t) = $Q \times EC \times EF/1000$

Where: Q (Activity) is the quantity of LPG gas consumed and expressed in tonnes and sourced from supplier invoices / meters.

EC (Energy Content) is the EC of the Fuel in GJ/tonne (see Table 9 and Table 10).

EF (Emission Factor) is the LPG point-source EF in kg CO_2/GJ given in Table 9 and Table 10. Division by 1000 converts kg to tonnes.

Example: Calculation of Emissions Generated from LPG (non-transport)

An island resort located off the coast of Queensland uses 200 tonnes of LPG for non-transport purposes per annum. The greenhouse gas direct combustion emissions are calculated as follows:

GHG Emissions = Q x EC x EF /1000

- = Q x (EC x EF)/1000
- = 200 x 2.9
- $= 580 \text{ t } \text{CO}_{2}$



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	Table 9 LPG (non-transport) combustion emission factors per GJ ⁹			
Fuel combusted	Energy content of fuel GJ/t GJ/t	Point-source factor kg CO ₂ /GJ	Full fuel cycle emission factorkg CO ₂ -e/GJ (c)	
LPG (non -transport)	49.6	59.4	67.1	

	Table 10 LPG (non-transport) combustion emission factors per kg fuel ⁹			
Fuel combusted	kg CO ₂ /kg LPG Direct combustion emissions	kg CO ₂ -e/kg LPG LPG Full fuel cycle emissions		
LPG (non transport)	2.9	3.4		

⁹ Derived from Table 1

1.2 Non-Stationary Energy Emissions (transport)

1.2.1 Fuel used and kilometres travelled

1.2.1.1 Fuel used

If your organisation uses transport fuels such as LPG, petrol (gasoline), or automotive diesel oil you will need to calculate the greenhouse emissions associated with the quantity that you use. To determine these emissions, you have a choice of two different formulae that could be used in conjunction with the EFs contained in Table 11. Your choice of formula will be determined by the information you have available. Separate calculations should be carried out for each fuel type.

Formula: GHG Emissions (t CO_2 -e) = Q x EC x EF/1000

Where: Q (Activity) is the quantity of each particular transport fuel consumed expressed in kL, sourced from supplier invoices.

EC (Energy Content) is the EC of the Fuel in GJ/kL for each fuel consumed and contained in Table 8.

EF (Emission Factor) is the point-source EF in kg CO₂-e /GJ for each transport fuel consumed and contained in Table 11.



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Table 11 Emission Factors for Transport Fuels ¹⁰						
		Point Source		Full fuel cycle		
	(1) Energy content GJ/kL	(2) Point-source emission factor CO ₂ , CH ₄ , N ₂ O kg CO ₂ -e/GJ	(3) Point-source emission factor t CO ₂ -e/kL (kg/L) (1)*(2)	(4) Full Fuel Cycle Emission factor kg CO ₂ -e/GJ	(5) FFC emission factor t CO ₂ -e/kL (kg/L) (1)* (4)	
Automotive Gasoline	34.2	73.911	2.5	80.3	2.7	
ADO(current fuel)	38.6	70.4	2.7	78.1	3.0	
ADO low sulfur (<500ppm)	38.6	70.4	2.7	78.1	3.0	
ADO ultra low sulfur (<50pp	m) 38.6	70.4	2.7	78.1	3.0	
Aviation Gasoline	33.1	69.5	2.3	77.2	2.6	
Aviation Turbine	36.8	70.4	2.6	78.1	2.9	
IDF	39.6	70.5	2.8	78.2	3.1	
Fuel Oil	40.8	74.3	3.0	82.0	3.3	
LPG	25.7	60.5	1.6	68.2	1.8	
Natural Gas 13	39.5 MJ/	m ³ 60.2 (LDV)	2.4 kg CO ₂ -e/m ³	74.1 ¹²	2.9 kg CO ₂ -e/m ³	
		56.8 (HDV)	2.2 kg CO ₂ -e/m ³	70.0 ¹²	2.8 kg CO_2 -e/m ³	
Electricity for traction				See Table 4		

¹⁰ Australian average, large users

¹¹ Using ATF 1998 and NGGI, derived fleet-weighted EF of 73.9; this accounts for all gasoline fuel used by either a passenger car or a bus

 $^{\rm 12}$ adjusted for new LDV, HDV figures

¹³ EFs from combustion of natural gas differ from year to year. LDV, HDV light duty vehicles, heavy duty vehicles

Example: Calculation of Emissions Generated from Transport Fuels

A New South Wales freight company consumes 2400 kL of LPG (transport), 2400 kL of petrol and 2400 kL automotive diesel (transport) per annum. The GHG emissions are calculated as follows:

GHD Emission	s (t CO ₂ -e)	= (Q x EC x EF)/1000
LPG	= 2400 x 1.6	= 3840 t CO ₂ -e
Petrol	= 2400 x 2.5	= 6000 t CO ₂ -e
Diesel	= 2400 x 2.7	= 6480 t CO ₂ -e

Total GHG emissions = 3840 + 6000 + 6480 $= 16,320 \text{ t CO}_2\text{-e}$



Industrial processes

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1.2.1.2 Kilometres travelled

If only fleet records which detail kilometres (km) travelled but not total quantity of fuel purchased are available, please contact the *Reporting, Analysis and Verification Team* to discuss the use of average fuel consumption factors. It should be noted that the accuracy of the average fuel consumption factors is low due to the small number of engine size categories available and the large variation that can occur between different users.



Industrial processes

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2 Industrial processes including refrigerants and solvents

If your organisation undertakes, through the course of its operation, industrial processes such as those listed in Table 12, you will need to calculate the associated GHG emissions using the appropriate formula. The formulae contained in Table 12 are relatively simple but can only be applied if you have the data for the variables listed. The industrial processes your organisation undertakes will determine your choice of formula. The formulae are primarily sourced from the National Greenhouse Gas Inventory (NGGI) Workbook, Industrial Emissions, Workbook 7.1 Reprinted Revision 1, with Supplements 1998.

Table 12 Industrial Processes-Formulae					
Source	Formula	Data	Variables Required Da	ata Source	
Refrigerants & Solvents					
 HFCs in refrigerators/ air conditioning 	 HFCs (kg): house hold refrigeration = Q x 0.01 domestic window/wall air conditioning = Q x 0 domestic split system air conditioning = Q x 0 assuming residual charge vented on retirement Commercial chillers = Q x 0.15 Commercial non-chillers = Q x 0.15 transport refrigeration = Q x 0.15 mobile = Q x 0.13 to 0.29 dependent on whet there is recovery and recycling when serviced a on retirement 	0.02 0.20 It ther and	Q is the HFC contained in equipment. Both the type of HFC contained in equipment and the quantity of HFC will b shown on the equipment compliance plate.	Equipment specifications e	
Industrial processes					
Aluminium production – carbon anode consumption – PFC process emissions	$ \begin{array}{l} \cdot \ CO_{_2} \ (t) = Q \ x \ 1513/1000 \\ \cdot \ CF_{_4} \ (t) = Q \ x \ EF \ derived \ in \ accordance \ with \ IPG \\ Good \ Practice \ Guidance \\ \cdot \ C_{_2}F_{_6} \ (t) = Q \ x \ EF \ derived \ in \ accordance \ with \ IFG \\ Good \ Practice \ Guidance \end{array} $	00 209	Q= aluminium produced (t)	Records: Production	
Aluminium production	$CO_{2}(t) = -Q \times 94.2/1000$		Q= lime by-product produced (t)	Records: Production	
Iron & Steel – crude steel production	$CH_4(t) = Q \ge 0.44/1000$		Q= crude steel (t)	Records: Production	
Cement – calcination and clinkering of limestone rich raw meal in clinker production	Clinker: CO_2 (t) = Q x 0.518		Q= clinker produced (t)	Records: Production	
Quicklime production	CO_2 (t) = Q x 0.675		Q= quicklime produced (t)		
Dolomitic lime production	CO_2 (t) = Q x 0.867		Q= dolomitic lime produced (t) Records: Production	



Industrial processes

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Table 12 Industrial Processes-Formulae (continued)				
Magnesium – use of SF_6 as cover gas	$SF_{6}(t) = Q \times 23,900$	$Q = SF_6$ used (t)	Records: Production	
Soda Ash use	CO_2 (t) = Q x 0.415	Q= soda ash (t)	Records: Production	
Nitric acid production Records:Production	$N_2 0 (t) = Q \times 5.5/1000$	Q= nitric acid produced (t)		
SF ₆ (sulfur hexafluoride)	If you have SF_6 in gas-insulated switchgear or circuit breakers, please <i>CLICK HERE</i>			
SF ₆ 1 Gas Insulated Switchgear and Circuit Breaker Applications	Total SF ₆ emissions emitted assumes 0.01 (1%) loss per annum from original quantity (To convert to CO_2 -e use GWP 23900)			
2 Magnesium and aluminium production – SF ₆ used as cover gas	${\rm SF_6}$ annually emitted: kg ${\rm SF_6}/{\rm kg}~{\rm SF_6}$ – all cover gas	emitted		

In two other classes of activities: from the use of explosives in coal mining, where the activity level is the mass of explosive used (in tonnes), and from the distribution of petroleum products, where the activity level is the quantity of product distributed (in kilolitres), emissions are calculated as follows using the EFs from Table 13.

Table 13 Emission factors for explosive use			
Explosive type	Tonne CO ₂ /tonne product		
ANFO	0.1637		
Heavy ANFO	0.1778		
Emulsion	0.1659		

The formulae are primarily sourced from the Australian Methodology for the Estimation of Greenhouse Gases and Sinks, Workbook for Workbook Industrial Emissions and Solvents, 7.1 Reprinted Revision 1 With Supplements 1998.



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3 Waste to landfill and wastewater treatment

3.1 Introduction

As a majority of organisations produce waste, you will need to calculate the GHG emissions associated with the quantity that you produce. To determine these emissions, you have a choice of formulae that could be used in conjunction with the data variables provided and EFs contained in Table 14. Your choice of formula will be determined by the type of waste you produce or the waste treatment process you employ. Separate calculations should be carried out for each waste type.

It is important that Challenge members undertake activities (analyse samples) to derive at a site level, data to feed into estimating emissions from their undertakings. This is because default factors, for example, for biochemical oxygen demand (BOD), chemical oxygen demand (COD), and degradable organic carbon (DOC) are national averages that could by their use result in considerably over or underestimating emissions.

Conditions relating to emissions and abatement of greenhouse gases from waste to landfill

Where waste material is diverted from landfill to recycle or for energy use, no credit for emissions saved can be obtained from the material diverted. The advantage to the organisation is in having less emissions attributed to its activities because less waste is going to land fill. With paper recycling, for example, less energy will be used in processing (recycled paper would be partly processed) and less wood bought, as presumably raw wood would be more expensive than recycled (partly processed) paper.

Where methane is recovered from waste (solid waste or wastewater) the amount recovered is regarded as a saving (not an emission) only if it is flared or combusted for energy. The CO_2 emitted as a by-product of the flaring or subsequent combustion process is not counted as an emission but as part of the natural carbon cycle and not an addition to atmospheric CO_2 . The total amount of CH_4 recovered is therefore regarded as saved (not emitted) so long as it does not enter the atmosphere as CH_4 (ie it must be subsequently combusted or flared).

Should the recovered methane or part of it be vented to atmosphere that quantity vented would be considered an emission (multiplied by 21 to obtain the CO_2 equivalent emission) as this action would be adding to atmospheric CH_4 .

3.2 Municipal Solid Waste

If your organisation produces municipal solid waste that is ultimately disposed of in a landfill then this formula should be used to estimate the associated greenhouse gas emissions.

Formula: GHG Emissions (t CO_2 -e)=[((Q x DOC x DOC_F x F_1 x 16/12) - R) - (1-OX)] x 21

Where: (see Table 14)



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	Table 14 Waste variables and default values			
Variable	Default values			
Q (Activity)	Quantity of municipal solid waste expressed in tonnes and sourced from waste records or contractor invoices			
DOC	Degradable organic carbon expressed as a proportion of the particular waste type and contained in Table 15.			
DOC _F	Fraction of degradable organic carbon dissimilated for the waste type produced with a default value of 0.55 (see Intergovernmental Panel on Climate Change (IPCC) Good Practice Report - p 5.9) for Paper and paper board, Wood and straw and Garden and park waste, and 0.77 for other (non-lignin containing) materials; 0.66 (average of 0.77 and 0.55) for co-mingled waste.			
F,	Carbon fraction of landfill gas which has a default value of 0.50			
16/12	Conversion rate of carbon to methane			
R	Recovered CH ₄ in an inventory year and expressed in tonnes			
0.1	Oxidation factor (OX) ie $(1-OX=0.9) - 0.9$ is the default			
21	CH_4 global warming potential used to convert the quantity of methane emitted to CO_2 -e from the quantity of waste produced			

Note: The CH₄ recovered must be subtracted from the amount generated before applying he oxidation factor because only the landfill gas that is not captured is subject to oxidation.

Example: Calculation of Emissions Generated from Solid Waste

A higher education facility produced on average per annum a total solid waste stream of 240,000 kg. This waste comprises of 140,000 kilograms of food waste, 50,000 kilograms of paper/paper board, 10,000 kilograms of garden and park waste and 40,000 kilograms of concrete/metal/plastic/glass waste. No methane (R) was recovered during the inventory year. As each waste stream needs to be treated separately, their greenhouse gas emissions (GHG) are calculated as follows:

GHG emissions (t CO₂-e)= ([(Q x DOC x DOC_F x F₁ x 16/12)]- R) x 0.9] x 21

Food $= 140 \times 1.5 = 210 \text{ tonnes } \text{CO}_2\text{-e}$

Paper = 50×2.8 = 140 tonnes CO_2 -e

Garden = 10×1.2 = $12 \text{ tonnes } \text{CO}_2\text{-e}$

Plastic/Glass = 40×0.0 = 0 tonnes CO_2 -e

Total Waste GHG emissions = $362 \text{ t } \text{CO}_2\text{-e}$



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Table 15 Waste default DOC values ¹³					
Waste types	Default DOC percentage/fraction	Conversion to CO_2 -e with no CH_4 recovered (t=tonnes of waste type)	Conversion to CO ₂ -e with CH ₄ recovered (R) (t=tonnes of waste type)		
Paper and paper board	40% (0.4)	t x 2.8 (DOC _f =0.55)	18.9[(0.15t)-R]		
Textiles	40% (0.4)	t x 3.9 (DOC _f =0.77)	18.9[(0.205t)-R]		
Textiles synthetics	0%	t x 0	0		
Wood and straw	30% (0.3)	t x 2.1 (DOC _f =0.55)	18.9[(0.11t)-R]		
Garden and park	17% (0.17)	t x 1.2 (DOC _f =0.55)	18.9[(0.06t)-R]		
Food	15% (0.15)	t x 1.5 (DOC _f =0.77)	18.9[(0.08t)-R]		
Co-mingled	15% (0.15)	t x 1.2 (DOC _f =0.66) ¹⁴	18.9[(0.07t)-R]		
Medical waste (tissue, fluids, pharmaceuticals)	5% (0.05)	t x 0.5 (DOC _f =0.77)	18.9[(0.03t)-R]		
Concrete/metal/plastics/glass	0% (0.00)	t x 0 (DOC _f =0.0)	0		

Note: The percentage/fractions represent the quantity of DOC of the various waste types in the mix that may be available for conversion to CO,

 13 Degradable organic carbon (DOC) is the amount of carbon available for conversion to CO $_2$ -e

¹⁴ DOC_r=0.66: derived from average of 0.77 and 0.55 for DOC_r with and without lignin respectively (see IPCC Good Practice Workbook p 5.10)

Biochemical oxygen demand (BOD): BOD is an indicator of the concentration of organic material in water.

Oxygen is required in the biological decomposition of organic material. BOD measures the demand for oxygen by organisms (bacteria and protozoa) involved/undertaking the decomposition process. The BOD5 test measures the oxygen consumed by organisms in one litre of water as they decompose organics over a five-day period.

Chemical oxygen demand (COD): COD is an indicator of the concentration of organic (biological and inert) material in water.

Chemical oxygen demand (COD) may be defined as the amount of oxygen required to breakdown all the organic compounds present in the wastewater to be treated. COD is an indicator of the concentration of organics in water and measures the chemical oxidant required to break down organics. COD does not distinguish between biologically available and inert organic matter. The bigger the COD value the more oxygen required to treat the wastewater. COD levels are usually greater than BOD for a given wastewater.

3.3 Municipal Wastewater Treatment

Total emissions from municipal wastewater are the sum of emissions from wastewater treatment and sludge treatment. The total quantity of wastewater treated depends on the population that is generating wastewater.



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The following formula should be used to measure the CO_2 -e greenhouse gas emissions from treating municipal wastewater. This formula is most relevant to local government authorities.

Formula: GHG Emissions (t CO2-e) = $[(((P \times DC_w) \times (1 - F_s) \times EF_w)) + (P \times DC_w \times F_{sl} \times)) - R] \times 21$

Where: (see Table 16)

	Table 16 Municipal Waste variables and default values
Variable	Default values
P (Population)	The population served and measured in 1000 persons and sourced from waste treatment records
DC	The quantity in kilograms of BOD per 1000 persons per year of wastewater. In the event that no waste analysis data is available, a default value of 18,250 kg per 1000 persons per year can be used
F _{sl}	Default fraction of degradable organic component removed as sludge. Should be readily available from internal records of wastewater treatment plants (default 0.29)
EFw	Default methane emission factor for wastewater with value of 0.22kg CH_4/kg BOD
EF _s	Default methane emission factor for sludge with value of 0.22 kg CH_4 /kg DOC (where DOC can be either BOD or COD (kg/cap=18.25))
CH ₄ - GWP	21 – the Global Warming Potential of CH_4 used to convert the CH_4 emitted from wastewater to CO_2 -e
Energy potential CH ₄ /m ³	33810 kJ
Energy potential CH ₄ /kg	50312.5 kJ (0.672 kg CH_4 per m ³ (Waste Management Workbook p33)
R	Recovered CH_4 from wastewater in an inventory year and measured/expressed in tonnes
21	Global warming potential used to convert the quantity of methane emitted from the wastewater produced to $\rm CO_2$ -e

Example: Calculation of Emissions Generated from Municipal Wastewater

A local government wastewater treatment plant services a population of 20,000. Based on internal records, the average amount of BOD that is removed as sludge is 0.54. The treatment plant does not recover any methane. Their CO_2 -e GHG emissions are calculated as follows:

 $\begin{array}{ll} \text{GHG Emissions (t CO}_2\text{-}e) &= \{ [(\text{Population x DC}_w \text{ x } (1 - F_{sl}) \text{ x } \text{EF}_w) + (\text{P x DC}_w \text{ x } F_{sl} \text{ x } \text{EF}_{sl})] - \text{R} \} \text{ x } 21 \\ \text{GHG emissions (t CO}_2\text{-}e) &= \{ [(\text{P x DC}_w (1 - F_{sl}) \text{ x } \text{EF}_w) + (\text{P x DC}_w \text{ x } F_{sl} \text{ x } \text{EF}_{sl})] - \text{R} \} \text{ x } 21 \\ &= \{ [\text{P x DC}_w ((1 - F_{sl}) \text{ x } \text{EF}_w + F_{sl} \text{ x } \text{EF}_{sl})] - \text{R} \} \text{ x } 21 \\ &= \{ [\text{P x DC}_w \text{ x } \text{EF}_w (1 - \text{EF}_{sl} + \text{EF}_{sl})] - \text{R} \} \text{ x } 21 \\ &= \{ [\text{P x DC}_w \text{ x } \text{EF}_w (1 - \text{EF}_{sl} + \text{EF}_{sl})] - \text{R} \} \text{ x } 21 \\ &= \{ (20 \text{ x } 18250 \text{ x } 0.22 \text{ x } 1) \} - 0 \} \text{ x } 21 \\ &= 80,300 \text{ kg } \text{CH}_4 \text{ x } 21 \\ &= 1686 \text{ t } \text{CO}_2\text{-}e \end{array}$



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3.4 Industrial Wastewater Treatment

Total emissions from industrial wastewater are the sum of emissions from wastewater treatment and sludge treatment and depends on the quantity of output produced.

If your organisation operates an industrial wastewater treatment plant then this formula should be used to estimate the CO_2 -e GHG emissions. It should be noted that industrial wastewater is expressed in terms of COD. This enables the quantity of degradable carbon to be derived, which is the determinant of CH_4 emitted.

Formula: GHG emissions (t CO_2 -e) =[((W x O x DC_w x (1-F_{sl}) x EF_w)+(W x O x DC_{sl} x F_{sl} x EF_{sl}))-R] x 21

 $_{=}$ W x 0 x [((DC_w x (1-F_s) x EF_w) +(DC_s x F_s x EF_s))-R] x 21

Where: (see Table 17)

	Table 17 Industrial Waste variables and default values
Variable	Default values
W (Wastewater)	Wastewater in m ³ per tonne or ML (mega litres) of wastewater per tonne of product. Sourced from company discharge and production data [m ³ water=1kL=1 tonne]
0 (Output)	Company output/treatment production sourced from plant data
DC _w	Quantity in kilograms of COD per cubic metre (or kL) of wastewater sourced from company discharge and production data
F _{sl}	Default fraction of degradable organic component removed as sludge. Should be readily available from internal records of wastewater treatment plants (default 0.29)
EF_w	Methane emission factor for industrial wastewater and has default value of 0.22 kg $\rm CH_4/kg~BOD$ or COD
EF _{sl}	The default methane emission factor for industrial wastewater sludge with value of 0.22 kg $\rm CH_4/kg$ DOC (where DOC can be either BOD or COD
DC _{sl}	Quantity in kilograms of COD per cubic metre of sludge sourced from company discharge and production data
R	is the recovered CH_4 from wastewater year and measured in tonnes
21	Global Warming Potential of CH_4 used to convert the CH_4 emitted from wastewater to CO_2 -e

Example 1: Calculation of Emissions Generated from Industrial Wastewater

An industrial wastewater treatment plant produces 26m3 of wastewater per one tonne of product. Internal records show that the COD (DC_w) has a value of 3.0 kg per m³ of wastewater. Approximately 5% of the COD is removed as sludge. Consequently, for each tonne of output, methane emissions (with no recovery) is converted to CO₂-e in tonnes from:



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 $\begin{array}{l} \text{GHG Emissions (t CO2-e)} &= \text{W x O x}[((\text{DC}_{\text{w}} \text{ x } (1\text{-}\text{F}_{\text{s}}) \text{ x EF}_{\text{w}}) + (\text{DC}_{\text{sl}} \text{ x F}_{\text{sl}} \text{ x EF}_{\text{s}}))\text{-R] x 21} \\ &= 26 \text{ x 1 x } [((3 \text{ x } (1\text{-} 0.05) \text{ x } 0.22)\text{+} (3 \text{ x } 0.05 \text{ x } 0.22)) \text{-R] x 21/1000} \\ &= 0.22 \text{ x } 26 \text{ x 1 x } \{[3 \text{ x } (1\text{-} 0.05) \text{ + } 3 \text{ x } 0.05] \text{--0}\} \text{ x } 21/1000} \\ &= 17.16 \text{ kg of CH}_{4} \text{ per tonne of product} \\ &= 0.36 \text{ t of CO}_{2}\text{-e per tonne of product} \end{array}$

Example 2: Calculation of Emissions Generated from Industrial Wastewater

Company XX treats 312ML wastewater in-house yearly. The wastewater passes through a series of treatment tanks.

The COD and BOD levels vary through the system and average the following.

Tank		COD mg/LW(10 ⁻³ t/ML)	BOD mg/LW(10 ⁻³ t/ML)
1	Tank1	11026	6157
2	Anaerobic	3125	1248
3	Anaerobic	1198	351
4	Aerated (aerobic)	1000	438
5	Settling Pond	867	245
6	Storage 1	441	85
7	Storage 2	367	80

The wastewater leaves the tank 1 at 11,026mg/L. The anaerobic process reduces the COD from 11,026 to 3125mg/L. The sludge remains in each different treatment pond and is settled in a settling pond. The ponds have not been cleaned out since the plant commenced 10 years ago.

- 1. The wastewater leaves Tank1 and enters the anaerobic stage at a concentration of 11026mg COD/L.
- The wastewater leaves the anaerobic stage and enters the next anaerobic stage at a concentration of 3125mg COD/L. This means that 11026-3125 = 7901mg COD/L degrades anaerobically.
- 3. The wastewater leaves the anaerobic stage and enters the aerobic stage at a concentration of 1198 giving 3125-1198 = 1927 that degrades anaerobically. It then decomposes aerobically leaving the pond at a concentration of 1000mg COD/L. It may be assumed that from this point onwards all COD ultimately degrades anaerobically.
- 4. This interpretation means that 7901+1927 + 867 = 10695mg COD/L degrades anaerobically (10.695 t COD/ML).

Therefore, CH_4 produced is: 10.695 x 0.22 x 312 = 734.1t CH_4 =15416 t CO_2 -e.



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4 Agriculture

See Australian Methodology for the Estimation of Greenhouse Gas Emission and Sinks, Workbooks, Reprinted Revisions 1998, 1.5 and 1.6

5 Land-Use Change & Forestry (Vegetation sinks)

5.1 Introduction

If you have planted trees or are planning to plant trees as an option to abate greenhouse gas emissions the amount of carbon taken up (sequestered) in the vegetation will need to be estimated. Predicting and measuring carbon stocks in vegetation is complex. Methods of carbon accounting at the project level vary depending on the size and management of the planting.

Greenhouse Challenge Program members are particularly encouraged to focus on actions that are likely to be consistent with relevant international agreements.

5.2 Estimating carbon sequestration

Carbon accounting for sinks is based on the stock change approach. To determine carbon sequestration the change in carbon stocks over a period of time is calculated using the formula:

 $\Delta \mathbf{C}_{\mathrm{i}} = \boldsymbol{C}_{i} - \boldsymbol{C}_{i-1}$

Where: ΔC_i = change in carbon stocks in year i

 $C_i = carbon stocks in year i$

 C_i -1 = carbon stocks in the year before year i

Three methods of estimating carbon to different levels of accuracy and cost are described in Table 18 Methods for carbon accounting.

The method used should be specified in all reporting.



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Table 18 Methods for carbon accounting				
Carbon Estimation Method	Type of Planting	Methods (see references section below for details of methods discussed here)		
1 – Graphs in "Growing Trees as Greenhouse Sinks" booklet Very broad estimate	Small plantings that will not be harvested (eg shelterbelts and environmental plantings occupying less than about 20 hectares of the property) <u>Sinks</u> booklet.	Area and age of plantings estimated by the landholder; and Carbon sequestration estimated using the maps and graphs in the <u>Growing Trees as Greenhouse</u>		
2 – Basic CAMFor model Site specific prediction providing an estimate at low cost	Small or medium-sized commercial plantings that will be harvested (eg farm forestry); or Medium-sized environmental plantings on farms comprising a significant area of the property (eg over 20 hectares). AGO, Third Party Recruiter or member based on information provided by the landholder using standard Field Sheets (see below).	Area measured using the methods described in the <u>Bush for Greenhouse Field Measurement</u> <u>Procedures;</u> Age of plantings estimated by the landholder; and site specific <u>CAMFor</u> prediction undertaken by the		
3 – Full Carbon Accounting A higher level of accuracy at medium cost	Plantation estates (eg over 1,000 ha); Large scale environmental planting programs or groups of plantings; or Any planting where sale of carbon credits is being considered	Level 2 method as described above; and Initial site condition assessment, survival checks and monitoring measurements undertaken as described in the <u>Bush for Greenhouse Field</u> <u>Procedures</u> Where a forest inventory has been undertaken the results can be converted to carbon stocks		

5.3 Calculation Factors

There are many more calculation factors for carbon sinks than can be addressed in this publication. The following method and factors may be used in the relatively common situation where timber inventory results (stem volume) are converted to carbon stocks.

Convert stem volume to stem biomass using a known basic density. Basic density values for a wide range of species are available in <u>NCAS Technical Report No 18</u> (see references section below). For example, the basic density of Pinus radiata is 440 kg/m³

Calculate total above ground biomass from stem volume using an expansion factor. <u>NCAS Technical Report No 17</u> contains some detailed information on expansion factors. Table 19 below contains some default expansion factors for use if no better information is available.



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Table 19 Expansion factors		
Forest Type	Expansion factor	
Native forests	1.4	
Native Plantations	1.25	
Native Plantations (equation)	$= 1 / [0.9(age/35)^{0.23}]$ (maximum value of 'age' = 20)	
Other species	1.3	

Calculate root biomass from above ground biomass using a root to shoot ratio. NCAS Technical Report No 17 contains some of these ratios. The IPCC default root to shoot ratios shown in Table 20 can be used if no better information is available.

Table 20 Root to shoot ratios		
Forest type	Root to shoot ratio	
Conifers (Pines)	0.2	
Hardwoods (Eucalypts)	0.25	

1. Convert total biomass to carbon stocks by multiplying by 0.5.

2. Convert to $\rm CO_2$ -e equivalent by multiplying by 3.67.

5.4 Contact

For more information on carbon accounting for vegetation sinks contact:

Mark Gardener Greenhouse and Land Management Team Australian Greenhouse Office GPO Box 621 Canberra ACT 2601

Tel: 02 6274 1358 Fax: 02 6274 1381 Email: <u>mark.gardener@greenhouse.gov.au</u>



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Table 21 References		
Reference and Link	Description	Location on the AGO website www.greenhouse.gov.au
Carbon Accounting Model for Forests (CAMFor) and NCAS Technical Reports	CAMFor is used to predict carbon sequestration.	Follow the links to the National Carbon Accounting System, then 'publications' on the left hand side. CAMFor is listed as report number 26.
NCAS Technical Reports	The NCAS technical reports contain scientific information for carbon accounting including some CAMFor inputs	Follow the links to the National Carbon Accounting System, then 'publications' on the left hand side.
<u>Growing Trees as Greenhouse Sinks</u> Booklet	Provides background information on greenhouse sinks and a ready reckoner to estimate carbon sequestration potential	Follow links to 'Natural Resources Forests and Agriculture' then 'Establishing and Maintaining Greenhouse Sinks'.
Bush for Greenhouse Field Procedures for Carbon Accounting	Detailed inventory procedures for quantifying carbon in forests. Also includes factors and methods to calculate carbon stocks.	Follow the links to 'Natural Resources, Forests and Agriculture' then 'Bush for Greenhouse'.
Field Sheets	The sheets provide a means to record field information used to develop carbon sequestration predictions using the CAMFor model.	See the next four pages of this document
Bush for Greenhouse Background Report – <u>Setting up a Greenhouse Sink</u> and Carbon Accounting System	Provides background information on carbon accounting.	Follow the links to 'Natural Resources, Forests and Agriculture' then 'Bush for Greenhouse'.



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- **5.5 Carbon Accounting Model for Forests**
- **Field sheets**
- **Form A Property description**

General Property Description

Date: / / 20
Project No:
Property Name:
Address:
Reference location: Farm Gate Planting Entry Point Other
EastingN
Datum used on map: AMG GDA Map Zone:
(refer to relevant topographic maps)
Assessing Organisation:
Project Officer:
Site Description and Land Use History (for establishing sink eligibility)
All data in this section applies to the areas that have been (or will be) established.
Average annual rainfall: (mm)
Was the land clear of forest at 1990: Yes No
Current land use:
Note significant land use changes (eg clearing) and when they occurred:
Event Description Date



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- 1. If possible attach photographs of the project area prior to any work being undertaken (eg: removal of trees). Use aerial photographs if project area greater than 20 ha. These maps or photographs should show:
 - the site immediately prior to establishment; and
 - trees to be killed or removed from the site.
- 2. Other comments on the site:

Sketch Map

Draw a sketch map of the project area showing: property and project boundaries; area to be planted with different types of vegetation (stand types), year of planting and points where photographs and GPS readings have been taken.

Draw a side view of the project area showing landforms and stand type locations. Draw a line on the main sketch map above to show where the profile was drawn from.



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Field Sheets

Form B – Stand Type Description

General Stand Type Description

A separate form is required for each stand-type (eg for each broad species mix or soil type)

Date:		/	/ 20
1.	Project	Name	or Number:
2.	Stand T	Type D	escription:
3.	Stand T	ype N	umber:ofof
4.	Tr	ee Pla	nting Direct Seeding
Plantin	ig seque	nce:	
Plantin	ng year		
Area (l	ha)		
5.	How wa	as the	area determined?
Specie	es mix ((tree :	species only):
Tree S	pecies		Proportion
			•



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Stand Type Information (for predicting carbon sequestration)

1. Predominant Slope (estimate in degrees):

2. flat (0-10 degrees) sloping (10-20 degrees) steep (over 20 degrees)
3. What direction does the slope face: North East South West
4. Position on slope: Upper Mid Lower Gully
Soil:
Parent rock type:
Depth to bedrock (estimate): 0-30cm 30cm-1m 1-2m over 2m
Texture if known :
5. Average annual rainfall for stand type: (mm)
6. Irrigation: Yes No Method :
7. Potential influence of other water sources (groundwater, rivers etc): Yes
Site Establishment
8. Were there any trees on the site before establishment Yes No:
What type were they :
Approximate age :
Estimate cover using the scale below:
0=nil, 1=edges only; 2=isolated individuals; 3=in patches, 4=scattered throughout, 5=abundant throughout.
Will these trees be killed and/or removed?



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Yes N arvesting event Proportion of Sten volume expected t al harvest? Yes	lo n to be removed	Expected Product Pulpwood %	Proportions Sawlog %
Yes N arvesting event Proportion of Sten volume expected t	lo n to be removed	Expected Product Pulpwood %	: Proportions Sawlog %
Yes N arvesting event Proportion of Sten volume expected t	lo n to be removed	Expected Product Pulpwood %	: Proportions Sawlog %
Yes N arvesting event Proportion of Sten volume expected t	lo n to be removed	Expected Product Pulpwood %	: Proportions Sawlog %
Yes N arvesting event Proportion of Sten	lo n	Expected Product	Proportions
Yes N	lo		
Yes	lo		
Wothod			
Nethod	THICKHESS		
Туре	Kate		
on			
Depth	(m)		
Туре	(m)		
Depth	(m)		
	Rate Depth Type	Rate Depth (m) Type (m)	Rate Depth (m) Type (m)



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Appendix 1 Transmission and distribution emission factors

Distribution and Transmission

The ratio between the (higher) coefficient for delivered electricity and the (lower) coefficient for energy sent to the distribution system corresponds to the percentage distribution loss, and the ratio between the coefficient for energy sent to the transmission system and the (lower still) coefficient for energy sent out corresponds to the percentage transmission loss.

Most users will take supply from the distribution system, and so should use the delivered electricity coefficients. Large users taking supply direct from the transmission system will have their own loss factors from NEMMCO and should probably apply those to their delivered electricity coefficient.

Electricity distribution

If your organisation is an electricity distribution organisation, the following formula should be used to estimate greenhouse gas emissions associated with electricity lost or used in the distribution system. The formula takes into account combustion and other emissions from State electricity systems (based on actual 1999 data).

Formula: GHG Emissions from electricity distribution $(tCO_2 - e) = Q \times EF / 1000$

Where: Q (Activity) is the quantity of electricity lost or used in kWh, as documented in the organisation's records.

EF (Emission Factor) is the full fuel cycle EF in kg CO₂-e/kWh for the bulk supply of electricity, in Table 22, classified according to State or Territory.

Table 22 Emission factor for bulk supply electricity (Full fuel cycle)	
Locality	kg CO ₂ -e/kWh (a)
NSW, ACT	0.918
VIC	1.363
QLD	0.975
SA	1.039
WA	0.976
TAS	0.000
NT	0.718

Source: George Wilkenfeld and Associates 2000; Greenhouse Gas Coefficients for Electricity, Australia 1998/99.

(a)

Bulk supply - includes transmission losses.



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Example: Calculation of emissions from electricity lost/used in a distribution system

A regional New South Wales electricity distribution organisation estimates a 900 MWh difference between bulk supply purchases and sales to customers in a give year. The greenhouse gas emissions (GHG) associated with this loss are calculated as follows:

GHG Emissions (t CO_2 -e) = (900 x 1000) x 0.918 /1000 = 826

Electricity transmission

The following EFs should be used to estimate the greenhouse gas emissions associated with electricity lost or used in the transmission system. The formula takes into account combustion and fugitive emissions from the State electricity systems (based on actual 1999 data). (These are not transmission coefficients but 'sent out' coefficients to be used to estimate the effect of reduction strategies.)

Formula: GHG emissions (t CO_2 -e) = Q x EF/1000

Where **Q** (Activity) is the quantity of electricity lost or used in kWh (sources from documented in the organisation's records).

EF (Emission Factor) is the full fuel cycle EF in kg CO_2 -e/kWh for the production of electricity in Table 23, classified according to State or Territory. Division by 1000 is to express the result in tonnes.

	Table 23 Emission factor for Electricity Sent Out
Locality	kg CO ₂ -e/kWh (a) FFC
NSW, ACT	0.904
VIC	1.308
QLD	0.930
SA	1.010
WA	0.888
TAS	0.000
NT	0.709

Source: George Wilkenfeld and Associates 2000. Greenhouse Gas Coefficients for Electricity, Australia 1998/99.

(a) Adjusted for interstate net energy transfers - electricity coefficients as sent out from power stations – excludes effects of transmission and distribution losses.

Note: The EFs take into account the combustion and indirect emissions from the State electricity systems (based on actual 1999 data).



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Appendix 2 Changes and additions from previous Workbook

Table 24 Fuel combustion emission factors (kg CO ₂ -e/GJ)				
Fuel combusted Point-source emission factors Full kg CO ₂ /GJ		Full fuel cycle emission fac kg CO ₂ -e/GJ	Full fuel cycle emission factors kg CO ₂ -e/GJ	
Black coal		NSW generation NSW other uses Queensland gen Queensland other	98.1 96.0 96.9 91.6 92.7 94.8	
Brown coal	<mark>93_</mark> 88.3			
Coal used in steel industry	93.0 91.8	100.7 112.8		
Coal by-products (gaseous)		50.8 48.5		
Coal by-products (coal tar and BT	ΓΧ)	81.0 92.5		
Brown Coal Briquettes		109.4 115.7		
Coke		133.3 131.0		
Naphtha		75.2 73.7		
Lighting kerosene		78.9 77.4		
Power kerosene		78.9 77.4		
Heating Oil		78.4 77.4		
Refinery Fuel		77.3 75.8		
Automotive diesel (ADO) 78.9 77.6				
Industrial/marin diesel fuel		78.9 77.7		
Fuel oil		82.8 81.5		
Town Gas	59.0 59.4			

Numbers in strike out mode represent those from the previous workbook updated by new numbers as presented.

	Table 25 Emission factors for electricity purchased/used/delivered per kWh
+Locality	kg CO ₂ -e/kWh Full fuel cycle emission factor
NSW, ACT	0.968 1.012
VIC	1.467 1.444
QLD	1.040 1.079
SA	1.109 1.186
WA	1.032 1.114



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Table 26 Emission factors for electricity purchased/used/delivered per GJ				
Locality	kg CO ₂ -e/GJ (Gg CO ₂ -e/PJ) Full fuel cycle emission factors			
NSW, ACT	281			
VIC	401			
QLD	300			
SA	329			
WA	309			
TAS	0.6			
NT	182			

Table 27 Emissions from combustion of natural gas - smaller users			
Locality	Point-sources emission factors kg CO ₂ -e/GJ	Full fuel cycle emission factors kg CO ₂ -e/GJ	
NSW & ACT	51.7	71.8 71.9	
Victoria	51.7	63.9 64.2	
Queensland	53.1	74.4 74.8	
SA	51.7	74.2 74.4	
WA	53.2	60.2 62.7	
TAS	NA	NA	
NT	51.8	53.4	

Table 28 Emissions from combustion of natural gas - larger users			
Locality	Point-source emission factors Kg CO ₂ -e/GJ	Full fuel cycle emission factors Kg CO ₂ -e/GJ	
NSW & ACT	51.7	70.7 70.9	
Victoria	51.6 51.7	63.4 63.8	
Queensland	53.0 53.1	66.2 66.6	
SA	51.6 51.7	72.0 723	
WA	53.1 53.2	59.3 61.7	
TAS	NA	NA	
NT	51.7 51.8	53.2 53.4	



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Table 29 Emission Factors for Transport Fuels ¹					
	Point Source			Full fuel cycle	
	(1) Energy	(2) Point-source	(3) Point-source	(4) Full Fuel	(5) FFC emission
	content GJ/kl	emission factor	emission factor	Cycle Emission	factor
		CO ₂ , CH4,	kg CO ₂ -e/kL	factor	kg CO ₂ -e/kL (g/L)
		N ₂ Okg (CO ₂ -e) /GJ	(g/L)(1)*(2)	kg CO ₂ -e/GJ	(1)* (4)
Automotive Gasoline	34.2	72.6 73.9	2.5	<mark>84.6</mark> 80.3	2.7
ADO(current fuel)	38.6	70'.4	2.7	82.4 78.1	3.0
ADO low sulfur (<500ppm)	38.6	70.4	2.7	83.3 78.1	3.0
ADO ultra low sulfur (<50pp	m) 38.6	70.4	2.7	84.7 -78.1	3.0
Aviation Gasoline	33.1	69.5	2.3	81.5 77.2	2.6
Aviation Turbine	36.8	70.4	2.6	82.4 78.1	2.9
IDF	39.6	70.5	2.8	82.4 78.2	3.1
Fuel Oil	40.8	74.3	3.0	86.3 82.0	3.3
LPG	25.7	60.5	1.6	72.5 68.2	1.8
Natural Gas	39.5 MJ/m ³	55.6 60.2 (LDV)	2.4 kg CO ₂ -e/m ³	68.4 74.1	2.9 kg CO_2 -e/m ³
		56.8 (HDV)	2.2 kg CO ₂ -e/m ³	70.0	2.8 kg CO_2 -e/m ³
Electricity for traction				See Table 4	



Glossary

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Appendix 3 Glossary

11	change	kWh	kilowatt hour
ANFO	ammonium nitrate and fuel oil	L	litre
basic	dry weight to green weight ratio	I	litter
	basis density (wood	m ³	cubic metre
BOD		MJ	megajoule (10 ⁶ joules)
BOD		MSW	municipal solid waste
	carbon	MWh	megawatt hour
CAI	current annual increment of trunk timber	moisture%	% water content
	metnane	N/C	not considered
CO ₂ -e	carbon dioxide equivalent	NGGI	National Greenhouse Gas Inventory
COD	chemical oxygen demand	NMVOC	non-methane volatile organic compound
dbh	tree diameter at breast height	NO	Nitrogen oxide
DC	degradable organic component (BOD & COD used to measure DC	0	production in tonnes (output)
	kg of COD per m ³ /sludge	OD:AD	oven-dry to air-dry ratio
DC,	kg of BOD/1000 persons	OF	oxidation factor
DOC	degradable organic carbon	OX	MSW oxidation factor
DOC _F	dissimilated degradable organic component	Р	population served
EC	energy content of fuel	ра	per annum
EF	emission factor	PJ	petajoule (10 ¹⁵ joules)
EFs	sludge emission factor	Q	activity
EF	waste emission factor	R	recovered CH_4
F,	carbon fraction of landfill gas (default 0.50)	S	soil
FE	fuel efficiency	SF_6	Sulfur hexafluoride
F _{sl}	fraction removed as sludge	t	Tonne (1000 kg)
GC	Greenhouse Challenge Program	TR	trees and roots
ghg	greenhouse gas	V	other vegetation
GJ	gigajoule (10 ⁹ joules)	V	volume
GWP	global warming potential	W	m ³ of wastewater/tonne of product
ha	hectare (10,000 m ²)	wt	weight
IPCC	Intergovernmental Panel on Climate Change	WP	wood products
kg	kilogram		
kL	kilolitre		
km	kilometre		



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Appendix 4 Greenhouse gas global warming potentials

Global Warming Potential (GWP) is an index used to convert relevant non- CO_2 gases to a CO_2 equivalent (CO_2 -e) by multiplying the quantity of the gas by its GWP in the Table below.

Gas	Chemical Formula	IPCC 1996 Global Warming Potential
Carbon dioxide	CO ₂	1
Methane	CH	21
Nitrous oxide	N ₂ 0	310
Hydrofluorocarbons HFCs	L	
HFC-23	CHF ₃	11,700
HFC-32	CH ₂ F ₂	650
HFC-41	CH ₃ F	150
HFC-43-10mee	$C_{5}H_{2}F_{10}$	1,300
HFC-125	C ₂ HF ₅	2,800
HFC-134	C ₂ H ₂ F ₄ (CHF ₂ CHF ₂)	1,000
HFC-134a	$C_2H_2F_4$ (CH_FCF_3)	1,300
HFC-143	$C_2H_3F_3$ (CHF_2CH_2F)	300
HFC-143a	C ₂ H ₃ F ₃ (CF ₃ CH ₃)	3,800
HFC-152a	$C_2H_4F_2$ (CH ₃ CHF ₂)	140
HFC-227ea	C ₃ HF ₇	2,900
HFC-236fa	$C_3H_2F_6$	6,300
HFC-245ca	$C_3H_3F_5$	560
Hydrofluoroethers(HFEs)		
HFE-7100	C ₄ F ₉ OCH ₃	500
HFE-7200	$C_4F_9OC_2H_5$	100
Perfluorocarbons PFCs		
Perfluoromethane (tetrafluoromethane)	CF_4	6,500
Perfluoroethane (hexafluoroethane)	C_2F_6	9,200
Perfluoropropane	C ₃ F ₈	7,000
Perfluorobutane	C_4F_{10}	7,000
Perfluorocyclobutane	$c-C_4F_8$	8,700
Perfluoropentane	$C_{5}F_{12}$	7,500
Perfluorohexane	C_6F_{14}	7,400
Sulfer hexafluoride	SF ₆	23,900
Indirect gases		
Carbon monoxide	CO	n/a
Nitrogen oxide	NO _x	n/a
Non-methane volatile organic compounds (NMVO	Cs) various	n/a



Basic Information

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Appendix 5 Basic Information

Abbreviation	Prefix	Symbol	
10 ¹⁵ (10 ⁶ x10 ⁹)	Peta (million billion [thousand trillion])	Р	
10 ¹² (10 ³ x10 ⁹)	Tera (thousand billion [trillion])	Т	
10 ⁹	Giga (billion)	G	
106	Mega (million)	Μ	
10 ³	kilo (thousand)	k	
10 ²	hecto	h	
10 ¹	deca	da	
10 ⁰	- (eg gram)	g	
10-1	deci	d	
10-2	centi	C	
10 ⁻³	milli	m	
10-6	micro	Μ	
10-9	nano	n	
10-12	pico	р	

Equivalences

10 ¹⁵ grams (Petagram)	Gigatonne (Gt)
10 ¹² grams (Teragram)	Megatonne (Mt)
10º grams (Gigagram)	kilotonnes (kt) (10 ³ tonnes)
10 ⁶ grams (million grams)	1 tonne
kg/GJ (10 ³ g/10 ⁹ J)	Gg/PJ (10 ⁹ g/10 ¹⁵ J)
Mg/PJ (10 ⁶ g/10 ¹⁵ J)	g/GJ 10ºg/10ºJ)

eg 423 000 Gg, equivalent to 423 000 kt are equivalent to 423 Mt

Unit of energy Joule

Unit of power (rate of energy usage) Watt



Conversion factors

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Conversion factors

1 Watt=1 Joule/Sec

3600 watt-seconds=1 Watt-hour (3600 seconds in one hour)

1 Watt-hour=3600 Joules

1000 Watt-hours=1Kilowatt hour (kWh)

1 kWh=3.6x10⁶ Joules= 3.6MJ

 $1 \text{ kWh} = 3.6 \text{ x} 10^{-3} \text{GJ}$

1GJ =278 kWh

kWh to J	kWh x 3.6x106	Joules
J to kWh	J x 1/3.6 x 10⁻ ⁶	kWh
kWh to MJ	kWh x 3.6	MJ
MJ to kWh	MJ x 0.278	kWh
kWh to GJ	kWh x 3.6 x 10 ⁻³	GJ
GJ to kWh	GJ x 278	kWh
kWh to PJ	kWh x 3.6x 10⁻⁰	PJ