

CHAPTER 7

PRECURSORS AND INDIRECT EMISSIONS

[Parts shaded in grey – the unchanged text from the 2006 IPCC Guidelines]

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7 PRECURSORS AND INDIRECT EMISSIONS

7.1 INTRODUCTION

[Elaboration of the section 7.1 of the 2006 IPCC Guidelines].

Global warming potential-weighted greenhouse gas emission totals are based upon greenhouse gas emissions calculated following the guidance described in volumes 2-5 of the 2006 IPCC Guidelines. This chapter addresses the calculation of emissions of precursors of greenhouse gases and of indirect emissions that have not been addressed in Volumes 2-5 and that may be reported in greenhouse gas inventories. The guidance of this chapter supports the use of any radiative forcing metric (e.g., global warming potential or global temperature potential) included in assessment reports of the IPCC so far and follows the principle to avoid double counting. This chapter is based on the underlying assumptions used in the derivation of the GWP and GTP metrics and on the current understanding of the relevant atmospheric processes. However, it does not provide guidance to estimate the overall radiative forcing resulting from emissions of greenhouse gases, precursors and indirect emissions.

Although they are not included in global warming potential-weighted greenhouse gas emission totals, emissions of carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO₂) are also reported in greenhouse gas inventories. Carbon monoxide (CO), Nitrogen oxides (NO_x) and NMVOC as well as CH₄ in the presence of sunlight contribute to the formation of the greenhouse gas ozone (O₃) in the troposphere and are therefore often called 'ozone precursors'. Furthermore, NO_x emission plays an important role in the Earth's nitrogen cycle. Sulphur dioxide emissions lead to formation of sulphate particles, which also play a role in climate change. Ammonia (NH₃) is an aerosol precursor, but is currently less important for aerosol formation than SO₂.

Section 7.2 addresses the estimation and reporting of the precursors for national inventories. The methodologies for ambient air quality emission inventories have been elaborated in detail in the EMEP¹/EEA² Emission Inventory Guidebook (Guidebook), and these methodologies for CO, NO_x, NMVOCs, and SO₂ emissions are referenced in this chapter rather than to be included in the 2006 IPCC Guidelines. Exceptions are for sources not well covered by the Guidebook.

Section 7.3 addresses nitrous oxide (N₂O) emissions that result from the deposition of the nitrogen emitted as NO_x and NH₃. Nitrous oxide is produced in soils through the biological processes of nitrification and denitrification. Simply defined, nitrification is the aerobic microbial oxidation of ammonium to nitrate and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N₂). Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification that leaks from microbial cells into the soil atmosphere. One of the main controlling factors in this reaction is the availability of inorganic nitrogen in the soil and therefore deposition of nitrogen resulting from NO_x and ammonia (NH₃) will enhance emissions. N₂O emissions will also be enhanced if nitrogen is deposited in the ocean or in lakes. For this reason, the 2006 Guidelines include guidance for estimating N₂O emissions resulting from nitrogen deposition of all anthropogenic sources of NO_x and NH₃. Only agricultural sources of nitrogen were considered in the Revised 1996 Guidelines (IPCC, 1997).

Guidance is provided in Section 7.3 on estimating N₂O emissions from atmospheric deposition resulting from all categories except agricultural soil management and manure management. Section 7.3 provides information on NO_x emissions. Countries may use national methodologies to estimate emissions of NH₃ not originating from agriculture. NH₃ emissions are also covered in the EMEP/EEA Emission Inventory Guidebook.

7.2 PRECURSOR EMISSIONS

No refinement.

¹ Cooperative programme for the monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP).

² Up until 2007 this EMEP/EEA Guidebook was formally called the EMEP/CORINAIR emission inventory guidebook

7.2.1 Inventory of precursors

[Elaboration of the section 7.2.1 of the 2006 IPCC Guidelines].

7.2.1.1 ENERGY

For most countries, road transportation will be a major source of NO_x, CO, and NMVOC emissions. Public electricity and heat production will likely be the major source of SO₂ emissions in countries where coal is used extensively, and also an important source of NO_x emissions. Industrial combustion will also be a source of SO₂, NO_x and CO emissions and residential combustion a source of CO emissions. Oil production will likely be a source of NMVOC, NO_x, and, CO emissions in countries that produce oil and gas.

Most NO_x emissions resulting from fuel combustion are typically 'fuel-NO' that is formed from the conversion of chemically bound nitrogen in the fuel. The content of nitrogen in different fuel varies. Depending on the combustion temperature, thermal-NO_x can also be formed from nitrogen contained in the combustion intake air.

Carbon monoxide and NMVOCs are generated during under-stoichiometric combustion conditions and are dependent on a variety of factors, including fuel type and combustion conditions.

Emissions of sulphur oxides (SO_x) are primarily related to the sulphur content of the fuel, although some sulphur can be retained in the ash. Abatement in stationary combustion can reduce the amount emitted; desulphurization of fuels can reduce SO₂ emissions in transport related emissions.

7.2.1.2 INDUSTRIAL PROCESSES AND PRODUCT USE

No refinement.

7.2.1.3 AGRICULTURE, FORESTRY AND OTHER LAND USE

The burning of crop residues emits NO_x, as does the addition of nitrogen to the soils from nitrogen fertilizers and other nutrients. Carbon Monoxide and SO₂ are emitted when biomass is burned. The primary sources of the NMVOC emissions are burning of crop residues and other plant wastes, and the anaerobic degradation of livestock feed and animal excreta. Plants, mainly trees (e.g. oil palm trees) and cereals, also contribute to NMVOC concentrations in the atmosphere.

The EMEP/EEA Guidebook does not fully cover emissions from burning of biomass, therefore additional guidance is given in AFOLU Volume, Chapter 4.2.4 for Non-CO₂ emissions from biomass burning from forest, Chapter 5.2.4 and 5.3.4 for Non-CO₂ emissions from biomass burning in Cropland, and Chapter 6.2.4 and 6.3.4 for Non-CO₂ emissions from biomass burning in Grassland (CO, CH₄, N₂O, NO_x). Biomass burning when forest and grasslands are converted to other uses, forest fires, and biomass burning due to forest management practices are discussed in these chapters of Volume 4 for AFOLU sector.

7.2.1.4 WASTE

Domestic and municipal waste incineration processes as well as the incineration of sludge from wastewater treatment produce emissions of NO_x, CO, and SO₂. NMVOC emissions can originate from wastewater treatment plants and solid waste disposal on land.

7.2.1.5 CO₂ INPUTS TO THE ATMOSPHERE FROM EMISSIONS OF CARBON-CONTAINING COMPOUNDS

[Elaboration of the section 7.2.1.5 of the 2006 IPCC Guidelines].

The 2006 Guidelines estimate carbon emissions in terms of the species that are emitted. The majority of the carbon emitted in the form of non-CO₂ species (i.e., CH₄, CO, and NMVOCs) eventually oxidizes to CO₂ in the atmosphere and this amount can be estimated from the emissions estimates of the non-CO₂ gases (Seinfeld and

Pandis, 1998; Boucher *et al.* 2009). This section provides guidance on calculating CO₂ inputs to the atmosphere from emissions of carbon-containing compounds that are not included under other emission categories.³

In national GHG inventories, inputs of CO₂ from the atmospheric oxidation of CH₄, CO, and NMVOCs are typically included in inventories for some source categories, correctly excluded for some other categories, and likely require estimating separately for yet other categories. The source categories falling into these first two groups are as follows (Gillenwater 2008):

- Fossil fuel combustion and fueling activities including the atmospheric oxidation of CH₄, CO, and NMVOCs to CO₂ is accounted for by the methodology used by most countries to calculate CO₂ emissions from fossil fuel combustion.⁴ This methodology is based on fuel consumption statistics, data on the carbon content of each fuel, and oxidation factors; IPCC default carbon content or CO₂ emission factors assume that except the small fraction of carbon remaining as un-oxidized solids, for example soot or ash (IPCC, 2000, 2006; IPCC/UNEP/OECD/IEA, 1997), all carbon in the fuel is oxidized to CO₂ in the combustion process or atmosphere.⁵ For most countries that use common CO₂ factors, these inputs to the atmosphere of CO₂ from fossil fuel combustion related emissions of CH₄, CO, and NMVOCs are already accounted for under the Energy sector category 1A.⁶
- Several managed sources of biogenic carbon (e.g., livestock) also emit CH₄, CO, and NMVOCs. The carbon in these gases is derived from rapidly cycling (non-fossil) sources. For example, the carbon content of CH₄ from enteric fermentation is derived from plant matter, which has converted atmospheric CO₂ to organic compounds. The atmospheric oxidation of CH₄ merely completes a natural cycle and is not treated as a net anthropogenic contribution to the atmosphere's CO₂ burden. Any net changes in the biogenic carbon stocks found in plant matter are assumed to be captured under the AFOLU sector through estimates of CO₂ emissions and removals from land-use and land-use changes and forestry (i.e., biogenic carbon stock changes).

Methane, CO, or NMVOCs are also emitted as fugitives from fossil fuel production activities such as coal mining as well as petroleum and natural gas exploration, processing and storage. The carbon emitted in the form of CH₄, CO, or NMVOCs from these fugitive emission source categories is not typically captured in fuel combustion activity data because these emissions occur prior to the collection of data on fossil fuel consumption. Therefore, CO₂ inputs to the atmosphere from the oxidation of these fugitive emissions are typically not accounted for elsewhere in national GHG inventories.

Some industrial processes in which carbon from fossil fuel sources is used as a production feedstock (e.g., petrochemical production) may also lead to indirect CO₂ inputs to the atmosphere. The carbon emitted in the form of CH₄, CO, or NMVOCs from these industrial processes may be included in a country's non-energy use of fossil fuel statistics or they may be estimated separately.⁷ Carbon dioxide emissions from industrial processes that use carbon feedstock as reducing agents (e.g., iron and steel production) are typically included in GHG inventories based on the assumption that the carbon in the reducing agent is fully oxidized. Depending on the assumptions and methods used to estimate storage and emissions from those non-energy use and feedstock categories (e.g., solvent use), CO₂ resulting from emissions of CH₄, CO, and NMVOCs may or may not be accounted for in GHG inventories.

Two options are possible to account for inputs of CO₂ from CH₄ of fossil origin. Countries may apply the methods described below to calculate the mass of CO₂ oxidised. Or countries may choose to apply separate global warming potentials or other metrics for CH₄ emissions of fossil and biogenic origin (see Appendix 8.A in IPCC 2013). Countries should transparently document which option used.

The methodologies for calculating CO₂ from the atmospheric oxidation of CH₄, CO, and NMVOCs are simple and for countries that already have detailed inventories of CH₄, CO, and NMVOC emissions, no additional activity

³ The contents of Box 7.1 from the 2006 IPCC Guidelines have been elaborated and included in the text of this section.

⁴ This includes evaporative emissions of NMVOCs associated with immediate fueling activities for mobile or stationary sources where the mass of carbon associated with these emissions is accounted for in the fuel consumption activity data used in the combustion-related emission estimates for CO₂.

⁵ If a direct measurement method is used to estimate CO₂ emissions from fuel combustion then CO₂ emissions from the atmospheric oxidation of CH₄, CO, and NMVOCs will not be included and must be estimated separately.

⁶ If a country uses a country-specific CO₂ emission factor based on direct measurement data to estimate emissions then CO₂ from the atmospheric oxidation of CH₄, CO, and NMVOCs would not be included in emission estimates for fossil fuel combustion, as the direct measurement occurs prior to the atmospheric oxidation process.

⁷ Non-energy products from fossil fuels include industrial applications of fossil carbon material such as in the manufacture of ammonia from natural gas.

data collection should be necessary. Input of CO₂ to the atmosphere are calculated by converting previously estimated mass emissions of CH₄, CO, or NMVOCs to CO₂ based on the carbon content of each gas. For example, the activity data used to estimate CO₂ inputs from the oxidation of emissions coal mining is already collected to estimate CH₄ for that category (1.B.1).

Methane, CO, or NMVOC emissions will eventually be oxidised to CO₂ in the atmosphere. These CO₂ inputs could be included in national inventories. They can be calculated from emissions of methane, CO and NMVOCs. The basic calculation principles are:

From CH₄: $Inputs_{CO_2} = Emissions_{CH_4} \bullet 44/16$

From CO: $Inputs_{CO_2} = Emissions_{CO} \bullet 44/28$

From NMVOC: $Inputs_{CO_2} = Emissions_{NMVOC} \bullet C \bullet 44/12$

Where,

$Inputs_{CO_2}$ are the added CO₂ to the atmosphere from the oxidation of CH₄, CO, and NMVOCs that are not accounted for already under other categories.

$Emissions_{CH_4}$, $Emissions_{CO}$, and $Emissions_{NMVOC}$ are the emission estimates taken from other relevant emission categories (e.g., CH₄ from oil and gas systems, 1.B.2).

C is the fraction carbon in NMVOC by mass (default = 0.6 for solvent use and 0.85 for other source categories)

The carbon content in NMVOCs will vary depending on the source. Therefore, an inventory based on the speciation of the NMVOC compounds gives more accurate results.

In making these estimates inventory compilers should assess each category to ensure that this carbon is not already covered by the assumptions and approximations made in estimating CO₂ emissions.

See Table A7.1 for a list of the source categories relevant to the accounting of CO₂ from atmospheric oxidation. When identifying categories for which these CO₂ inputs are to be estimated, it is good practice to prevent double counting or omitting of carbon added to the atmosphere as CO₂.

NMVOCs do not represent a single molecular species, but instead a broad range of volatile hydrocarbon species with varying molecular weights and carbon contents. Therefore, an accurate estimate of emissions of CO₂ from the atmospheric oxidation of NMVOCs requires a chemical speciation profile of the constituent NMVOCs (Gillenwater 2008).

To estimate indirect CO₂ from NMVOC emissions the following steps may be used:

Separate the portion of national NMVOCs emissions resulting from biogenic materials from the portion of NMVOC emissions resulting from petroleum or other fossil fuel products.

Identify the portion of the fossil-based NMVOC emissions resulting from relevant energy and industrial process source categories (as determined using Table A7.2).

For the portion of these NMVOC emissions resulting from solvent use, determine the average carbon content (on a mass basis) based on a chemical speciation profile (see Table A7.3 for example). If information on the speciation profile is not available, assume a default average carbon content of 60 percent by mass (default).

For the remaining portion of relevant NMVOC emissions from other source categories, determine carbon content values using a chemical speciation profile. If information on the speciation profile is not available, assume an average default carbon content of 85 percent by mass (Gillenwater 2008).

There is scientific uncertainty regarding the degree to which all CH₄ and NMVOCs are completely oxidised to CO₂ in the atmosphere. There is very low uncertainty in this assumption for CO emissions. Boucher et al. (2009) assumes 95 percent of emitted CH₄ is oxidised, with a range of 51 to 100 percent. NMVOCs include a wide range of chemical species with atmospheric lifetimes that range from minutes to months. Although, the fate of NMVOCs emitted to the atmosphere is generally oxidation to CO₂ through complex chemical and photochemical reactions, the fate of a fraction of some NMVOC species can be dry or wet deposition to the Earth's surface, where the carbon they contain may escape complete oxidation to CO₂.

7.2.2 Link to relevant methodology chapters in the EMEP/CORINAIR Emission Inventory Guidebook

No refinement.

7.3 INDIRECT N₂O EMISSIONS FROM THE ATMOSPHERIC DEPOSITION OF NITROGEN IN NO_x AND NH₃

No refinement.

7.3.1 Methodology

All anthropogenic NH₃ or NO_x emissions are potential sources of N₂O emissions⁸. Specific guidance on estimating N₂O emissions from that portion of nitrogen compounds associated with the volatilisation of NO_x and NH₃ from (1) manure management systems and applied sewage sludge and (2) synthetic and organic nitrogen input to managed soils, and urine and dung nitrogen deposited by grazing animals, are provided in Section 10.5 of Chapter 10, emissions from livestock and manure management, and Section 11.2.2 of Chapter 11, N₂O emissions from managed soils and CO₂ emissions from lime and urea application, of Volume 4 of AFOLU.

This section provides guidance on estimating N₂O emissions from the atmospheric deposition of nitrogen compounds from all other sources of NO_x and NH₃ emissions, such as fuel combustion, industrial processes, and burning of crop residues and agricultural wastes. The method needs only to be applied where data on NO_x and NH₃ emissions from these sources are available, e.g., from the inventories identified Section 7.2.

Equation 7.1 and EF₄ from Table 11.4 chapter 11 of Volume 4 can be used to estimate N₂O emissions from the atmospheric deposition of nitrogen resulting from NO_x and NH₃.

$$\text{EQUATION 7.1}$$

$$\text{N}_2\text{O EMISSIONS FROM ATMOSPHERIC DEPOSITION OF NO}_x \text{ AND NH}_3$$

$$N_2O_{(i)} = \left[(NO_x - N_{(i)}) + (NH_3 - N_{(i)}) \right] \cdot EF_4 \cdot 44 / 28$$

Where:

$N_2O_{(i)}$ = N₂O produced from atmospheric deposition of N from NO_x and NH₃ emissions from source i , in Gg;

$NO_x - N_{(i)}$ = Nitrogen content of NO_x emissions from source i assuming that NO_x is reported in NO₂ equivalents (Gg NO_x-N or Gg NO₂ • 14/46);

$NH_3 - N_{(i)}$ = Nitrogen content of NH₃ emissions from source i (Gg NH₃-N or Gg NH₃ • 14/17);

EF_4 = Emission factor for N₂O emissions from atmospheric deposition of N on soils and water surfaces (kg N₂O-N/kg NH₃-N or NO_x-N emitted).

The activity data $NO_x - N_{(i)}$ and $NH_3 - N_{(i)}$ are taken from the inventories as identified in Section 7.2, if available.

This method assumes that N₂O emissions from atmospheric deposition are reported by the country that produced the original NO_x and NH₃ emissions. In reality, the ultimate formation of N₂O may occur in another country due

⁸ In addition to being redeposited on soils and surface waters, NH₃ can also lead to the formation of N₂O from atmospheric chemical reactions. However, there is currently no method available for estimating conversion of NH₃ to N₂O in the atmosphere.

252 to atmospheric transport of emissions. The method also does not account for the probable lag time between NO_x
253 and NH₃ emissions and subsequent production of N₂O in soils and surface waters. This time lag is expected to be
254 small relative to an annual reporting cycle.

255 **7.3.2 Quality Assurance/Quality Control, Reporting and** 256 **Documentation**

257 It is *good practice* to estimate and report N₂O emissions from atmospheric deposition of NO_x and NH₃ where a
258 country already has an inventory of these gases. For the purposes of calculation, it is assumed that N₂O is emitted
259 in the same year that the original NO_x and NH₃ were emitted.

260 It is *good practice* to estimate emissions ensuring consistency with the emissions estimated for agriculture sources
261 and avoiding double counting. Because N₂O emissions may occur outside the country emitting NH₃ or NO_x, use
262 of country- or region-specific emission factors should be thoroughly documented.

263 N₂O emissions from atmospheric deposition of NH₃ and NO_x are reported in Table 5A of reporting tables in Annex
264 8A.2 for all sectors, and the AFOLU Sector is also reported in Table 3.8 in Annex 8A.2.

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⁹ <http://iopscience.iop.org/article/10.1088/1748-9326/4/4/044007/meta;jsessionid=16250453EF1AED50C07C22C04281B307.c2.iopscience.cld.iop.org>.

Table A7.1: Non-Biogenic sources of CO₂ from the atmospheric oxidation of CH₄, CO, and NMVOCs

Source Category (IPCC reporting format)	Gases Emitted ^(a)			Fossil Origin	CO ₂ included in existing category emission estimates?	Explanation
	CH ₄	CO	NM VOC			
1. Energy						
A. Fuel Combustion Activities ^(b)	x	x	x	Yes ^(e)	Yes	Fossil fuel combustion emission estimates calculated with use of carbon content and oxidation factors will typically include emissions of CO ₂ from atmospheric oxidation of CH ₄ , CO and NMVOC (i.e., if they assume complete oxidation of carbon except for that remaining as soot or ash solids).
B. Fugitive Emissions from Fuels						The carbon in fugitive emissions of CH ₄ and NMVOCs is fossil in origin, but the CO ₂ from the atmospheric oxidation of this carbon is not typically included in emissions estimates from any other source category. However, the carbon in NMVOC emissions from fueling stations would typically be captured in fossil fuel consumption activity data and therefore in emissions from 1.A.
1. Solid Fuels						
a. Coal Mining	x		x	Yes	No	
2. Oil and Natural Gas						
a. Oil	x	x	x	Yes	No	
b. Natural Gas	x		x	Yes	No	
c. Venting	x		x	Yes	No	Combustion emission estimates with use of carbon content factors typically include emissions of CO ₂ from atmospheric oxidation of CH ₄ , CO and NMVOC.
d. Flaring	x	x	x	Yes	Yes	
2. Industrial Processes and Product Use						
B. Chemical Industry	x	x	x	Yes	(d)	The carbon in emissions of CH ₄ and NMVOCs from chemical and metallurgical processes is likely to be of fossil in origin. The CO ₂ from the atmospheric oxidation of this carbon may or may not be included in emissions estimates from these source categories or from non-energy uses of fossil fuels as feedstock.
C. Metal Industry		x	x	Yes	(d)	
D. Non-Energy Use of Fuels						The carbon in emissions of CH ₄ and NMVOCs occurring from the use of non-energy products is of fossil origin and does lead to CO ₂ emissions. The Oxidized During Use (ODU) factors applied for estimating emissions from these source categories in most cases will include CO ₂ emissions.
1. Lubricant Use			x	Yes	(d)	
2. Asphalt Paving of Roads and Roofs	x		x	Yes	(d)	
3. Paraffin Waxes Use			x	Yes	(d)	
4. Solvents and other Petroleum Product Use			x	Yes	(d)	

5. Waste ^(c)						
A. Solid Waste Treatment and disposal	x	x	x	No	-	The vast majority of the carbon in CH ₄ , CO, and NMVOC emissions is likely to be of biogenic origin.
B. Wastewater Treatment and discharge	x	x	x	No	-	
C. Incineration and open burning of waste ^(b)	x	x	x	Yes	Yes	The carbon in CH ₄ , CO, and NMVOC emissions is of both biogenic and fossil origin. Estimates of CO ₂ emissions from the fossil carbon portion of waste materials include the emissions of CO ₂ from atmospheric oxidation of CH ₄ , CO and NMVOCs when carbon content factors are used.
<p>^(a) Only gases listed are those relevant to the estimation of CO₂ emissions from atmospheric oxidation of CH₄, CO and NMVOCs.</p> <p>^(b) Assumes that CO₂ emissions are estimated using data on the carbon content of fuels or waste materials, not direct measurement.</p> <p>^(c) Emissions assumed to be biogenic in origin.</p> <p>^(d) CO₂ emissions from atmospheric oxidation of CH₄, CO and NMVOCs may or may not be accounted for depending on the Oxidized During Use factor assumptions under non-energy use of fuels (2.D).</p> <p>^(e) Assumes biofuels are reported separately.</p> <p>Source: Gillenwater (2008).</p>						

288 **Table A7.2: Examples of NMVOCs from the different source categories**

CAS number	NMVOC Species	Carbon content	ENERGY									IPPU		AFOLU	WASTE	Total
			Stationary Combustion			Transport					Extraction & Distribution of Fossil Fuels	Industrial Processes	Solvent Use	Nature (Forests)	Waste Treatment and Disposal	
			Commercial and Residential	Energy Production	Combustion in Industry	Road Transport (DERV)	Road Transport (Evaporation)	Road Transport (PETROL)	Other Transportation and Machinery, Off Road	Other Transp & Mach (Other Transport) (5)						
107-98-2	2-propanol	0.533										✓	✓		✓	✓
67-64-1	Acetone	0.620	✓	✓	✓	✓		✓	✓	✓		✓	✓		✓	✓
74-86-2	Acetylene	0.923	✓	✓	✓	✓		✓	✓	✓		✓				✓
71-43-2	Benzene	0.923	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
106-97-8	Butane	0.827	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
74-84-0	Ethane	0.799	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓
64-17-5	Ethanol	0.521	✓		✓							✓	✓		✓	✓
74-85-1	Ethylene	0.856	✓	✓	✓	✓		✓	✓	✓	✓	✓				✓
110-54-3	Hexane	0.835	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
75-28-5	Isobutane	0.827	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
78-78-4	Isopentane	0.832	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
108-38-3	m-xylene	0.905	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
95-47-6	o-xylene	0.905	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
109-66-0	Pentane	0.832	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
74-98-6	Propane	0.817	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓
115-07-01	Propylen	0.621	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓
106-42-3	p-xylene	0.905	✓			✓	✓	✓	✓	✓	✓	✓	✓			✓
108-88-3	Toluene	0.913	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Unspeciated mixtures of m-, o- and p-xylene		0.905	✓		✓					✓		✓	✓		✓	
Total			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓

289 Source: Data in table compiled from various references by Kristina Saarinen, Finnish Environment Institute.

Table A7.3: Carbon content of various materials (percent carbon by mass, PC) and percent of total solvent NMVOC emissions (by mass, PU)

Material	P _C	P _U		P _C	P _U		P _C	P _U
Methane	75.0	-						
Carbon monoxide	42.9	-						
United States			Austria			Hungary ¹⁹		
Solvent NMVOCs ¹			Solvent NMVOCs			Solvent NMVOCs		
Methylene chloride	14	2						
Perchloroethylene	14	1						
Trichloroethane	18	1						
Trichloroethylene	18	1	Residuals	25				
Methyl alcohol	38	1	Methanol	38				
Ethylene glycol	39	1						
Propylene glycol solvents ²	47	1	Glycols	50				
Ester solvents ³	49	1						
Ethyl alcohol	52	24	Alcohols	52				
Butanediol derivatives ⁴	53	7						
Ester acetate ⁵	55	19	Ester	59				
Other ethylene oxide solvents ⁶	55	<1				Glue, etc.	57	-
Propyl acetate	59	2				Waste base paint	57	-
Isopropyl alcohol	60	10						
Propyl alcohol	60	2	Alcohols / propanols	60				
E-series ether solvents ⁷	61	<1						
Acetone	62	2	Acetone	62				
Butyl acetate	62	<1						

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Other propylene oxide-derived solvents ⁸	62	<1						
Furfural solvents ⁹	63	2						
Other chlorinated solvents ¹⁰	64	<1						
Ether solvents ¹¹	65	1	Ether	65				
Other alcohol solvents ¹²	65	2						
Methyl ethyl ketone	67	1	Ketones	67				
Tetrahydrofuran solvents ¹³	67	1	Aldehydes	67				
Methyl isobutyl ketone	72	1						
Other ketone solvents ¹⁴	72	2				Other paint, lack, etc.	80	-
Special naphthas ¹⁵	84	12	Solvent naphta	86		Solvent based paint	81.4	-
D-Limonene solvents ¹⁶	88	<1	Cyclic hydrocarbons	86		Solvent	81.6	-
Pinene solvents ¹⁷	88	1	Paraffins	86				
Toluene	91	<1	Aromates	91				
Xylene	91	<1						
Benzene	92	<1						
Solvent weighted average¹⁸	56.3			60 to 66			76 to 80	

- 292 *Source:* P_a values taken from national inventory reports submitted in 2004. <http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3473.php>.
- 293 P_c values as noted below.
- 294 1) Except where noted, values from CRC Handbook of Chemistry and Physics. CRC Press, 1995.
- 295 2) Assumed to be "propylene glycol".
- 296 3) Assumed to be DuPont "Dibasic Ester Solvent" <http://pubs.acs.org/pin/dupont/dup222p6.html>.
- 297 4) "The Physical and Theoretical Chemistry Laboratory Oxford University Chemical and Other Safety Information," assumed to be 1,3-butanediol, <http://physchem.ox.ac.uk/MSDS/BU/1,3-butanediol.html>.
- 298 5) Assumed to be "ethyl acetate".
- 299 6) Assumed to be "ethylene oxide".
- 300 7) Assumed to be "ethylene glycol n-butyl ether" (trade name "Dowanol EB), www.dow.com/dowanol/nam/products/eb.htm.
- 301 8) Assumed to be "propylene oxide".
- 302 9) "The Physical and Theoretical Chemistry Laboratory Oxford University Chemical and Other Safety Information," assumed to be "furfural" (2-furaldehyde), <http://physchem.ox.ac.uk/MSDS/FU/furfural.html>.
- 303 10) Assumed to be "chlorobenzene".
- 304 11) "The Physical and Theoretical Chemistry Laboratory Oxford University Chemical and Other Safety Information," assumed to be "diethyl ether, http://ptcl.chem.ox.ac.uk/MSDS/DI/diethyl_ether.html.
- 305 12) Assumed to be "butyl alcohol".
- 306 13) "The Physical and Theoretical Chemistry Laboratory Oxford University Chemical and Other Safety Information," assumed to be "tetrahydrofuran" (THF) (1,4-Epoxybutane).
307 <http://ptcl.chem.ox.ac.uk/MSDS/TE/tetrahydrofuran.html>.
- 308 14) "The Physical and Theoretical Chemistry Laboratory Oxford University Chemical and Other Safety Information," assumed to be methyl isobutyl ketone (MIBK).
309 http://physchem.ox.ac.uk/MSDS/ME/methyl_isobutyl_ketone.html.
- 310 15) Assumed to be "hexane".
- 311 16) "The Physical and Theoretical Chemistry Laboratory Oxford University Chemical and Other Safety Information," Assumed to be "limonene" (1-methyl-4-(1-methylethyl)cyclohexene),
312 <http://physchem.ox.ac.uk/MSDS/LI/limonene.html>.
- 313 17) Assumed to be "alpha pinene" (bicylc(3.1.1)hept-2-ene,2,6,6-trimethyl), <http://www.iff.com/Ingredients.nsf/0/D8DADD753B3B483780256990005DC01F>.
- 314 18) USA value is for 1998, Austria and Hungary values vary from year to year based on mix of solvent chemicals used.
- 315 19) Values apply only to the solvent portion of each material. The solvent content of each material assumed was: solvent based paint 50%, water based paint 5-6%, other paint 25%, glue 8%, and solvent 100%.