

CHAPTER 4

FUGITIVE EMISSIONS

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4 FUGITIVE EMISSIONS

4.1 FUGITIVE EMISSIONS FROM MINING, PROCESSING, STORAGE AND TRANSPORTATION OF COAL

This section is an elaboration of Section 4.1, Vol. 2 of the *2006 IPCC Guidelines*.

Intentional or unintentional release of greenhouse gases may occur during the extraction, processing and delivery of fossil fuels to the point of final use. These are known as fugitive emissions.

4.1.1 Overview and description of sources

ELABORATED TO INCLUDE DESCRIPTION OF NEW COAL EXPLORATION SOURCE

Fugitive emissions associated with coal can be considered in terms of the following broad categories.¹

4.1.1.1 COAL MINING AND HANDLING

The geological processes of coal formation also produce methane (CH₄), and carbon dioxide (CO₂) may also be present in some coal seams. These are known collectively as seam gas, and remain trapped in the coal seam until the coal is exposed and broken during mining. CH₄ is the major greenhouse gas emitted from coal mining and handling.

The major stages for the emission of greenhouse gases for both underground and surface coal mines are:

- **Mining emissions** – These emissions result from the liberation of stored gas during the breakage of coal, and the surrounding strata, during mining operations.
- **Post-mining emissions** – Not all gas is released from coal during the process of coal breakage during mining. Emissions, during subsequent handling, processing and transportation of coal are termed post-mining emissions. Therefore coal normally continues to emit gas *even after it has been mined*, although more slowly than during the coal breakage stage.
- **Low temperature oxidation** – These emissions arise because once coal is exposed to oxygen in air, the coal oxidizes to produce CO₂. However, the rate of formation of CO₂ by this process is low.
- **Uncontrolled combustion** – On occasions, when the heat produced by low temperature oxidation is trapped, the temperature rises and an active fire may result. This is commonly known as uncontrolled combustion and is the most extreme manifestation of oxidation. Uncontrolled combustion is characterised by rapid reactions, sometimes visible flames and rapid CO₂ formation, and may be natural or anthropogenic. It is noted that uncontrolled combustion only due to coal exploitation activities is considered here.
- **Exploration emissions** – These emissions result from boreholes drilled through carbonaceous strata for the purposes of coal exploration. This is distinct from gas drainage boreholes which form part of a degasification system, which are included for under Mining Emissions.

After mining has ceased, **abandoned coal mines** may also continue to emit methane.

A brief description of some of the major processes that need to be accounted for in estimating emissions for the different types of coal mines follows:

UNDERGROUND MINES

Active Underground Coal Mines

The following *potential* source categories for fugitive emissions for active underground coal mines are considered in this document:

- Seam gas emissions vented to the atmosphere from coal mine *ventilation air* and *degasification systems*
- Post-mining emissions

¹ Methods for determining emissions from *peat extraction* are described in Volume 4 AFOLU Chapter 7 'Wetlands'.

• Low temperature oxidation

• Uncontrolled combustion

Coal mine ventilation air and degasification systems arise as follows:

Coal Mine Ventilation Air

Underground coal mines are normally ventilated by flushing air from the surface, through the underground tunnels in order to maintain a safe atmosphere. Ventilation air picks up the CH₄ and CO₂ released from the coal formations and transports these to the surface where they are emitted to atmosphere. The concentration of CH₄ in the ventilation air is normally low, but the volume flow rate of ventilation air is normally large and therefore the methane emissions from this source can be very significant.

Coal Mine Degasification Systems

Degasification systems comprise wells drilled before, during, and after mining to drain gas (mainly CH₄) from the coal seams that release gas into the mine workings. During active mining the major purpose of degasification is to maintain a safe working atmosphere for the coal miners, although the recovered gas may also be utilised as an energy source. Degasification systems can also be used at abandoned underground coal mines to recover methane. The amount of methane recovered from coal mine degasification systems can be very significant and is accounted for, depending on its final use, as described in Section 4.1.3.2 of this chapter.

Abandoned Underground Mines

After closure, coal mines that were significant CH₄ emitters during mining operations continue to emit methane unless there is flooding that cuts off the emissions. Even if the mines have been sealed, methane may still be emitted to the atmosphere as a result of gas migrating through natural or manmade conduits such as old portals, vent pipes, or cracks and fissures in the overlying strata. Emissions quickly decline until they reach a near-steady rate that may persist for an extended period of time.

Abandoned mines may flood as a result of intrusion of groundwater or surface water into the mine void. These mines typically continue to emit gas for a few years before the mine becomes completely flooded and the water prevents further methane release to the atmosphere. Emissions from completely flooded abandoned mines can be treated as negligible. Mines that remain partially flooded can continue to produce methane emissions over a long period of time, as with mines that do not flood.

A further potential source of emissions occurs when some of the coal from abandoned mines ignites through the mechanism of uncontrolled combustion. However, there are currently no methodologies for estimating potential emissions from uncontrolled combustion at abandoned underground mines.

SURFACE COAL MINES

Active Surface Mines

The *potential* source categories for surface mining considered in this chapter are:

- Methane and CO₂ emitted during mining from breakage of coal and associated strata and leakage from the pit floor and highwall
- Post-mining emissions
- Low temperature oxidation
- Uncontrolled combustion in waste dumps

Emissions from surface coal mining occur because the mined and surrounding seams may also contain CH₄ and CO₂. Although the gas contents are generally less than for deeper underground coal seams, the emission of seam gas from surface mines needs to be taken into account, particularly for countries where this mining method is widely practised. In addition to seam gas emissions, the waste coal that is dumped into overburden or reject dumps may generate CO₂, either by low temperature oxidation or by uncontrolled combustion.

Abandoned Surface Mines

After closure, abandoned or decommissioned surface mines may continue to emit methane as the gas leaks from the coal seams that were broken or damaged during mining. There are at present no methods for estimating emissions from this source.

Second-order Draft

COAL EXPLORATION

This source category is concerned with emissions arising from boreholes drilled for coal mining exploration purposes. It does not include coal gas drainage wells used to collect gas prior or as a part of coal mining activities. Fugitive emissions from coal seam gas drainage wells are already counted in Underground and Surface Mining Activities. Gas drainage or production boreholes that may also include an exploration aspect are not to be counted as coal exploration boreholes.

The overall coal exploration process involves drilling of vertical boreholes from surface of the Earth to find out presence of coal seams, their depth of occurrence, thickness and other geological structures, resource and chemical characteristics such as ash, moisture, volatile matter (VM) and fixed carbon (FC). A small fraction of the methane gas retained by the coal seams may be released during borehole drilling and escape to the atmosphere. Emissions will occur only if the borehole drilling penetrates some gas bearing strata such as coal and carbonaceous shale.

Boreholes and wells associated with coal gas drainage and coal bed methane/natural exploration are concerned with gas flow, and gas bearing strata are often stimulated to increase gas flow. Coal exploration boreholes are focused on obtaining core samples or understanding strata geophysics, and therefore the coal fracture systems are not artificially stimulated. Thus, the gas flow from coal exploration boreholes and coal bed methane/natural gas boreholes are not comparable.

4.1.1.2 SUMMARY OF SOURCES

The major sources are summarised in Table 4.1.1 below.

TABLE 4.1.1 (ELABORATION)		
DETAILED SECTOR SPLIT FOR EMISSIONS FROM MINING, PROCESSING, STORAGE AND TRANSPORT OF COAL		
IPCC code	Category/subcategory	
1 B	<i>Fugitive emissions from fuels</i>	Includes all intentional and unintentional emissions from the extraction, processing, storage and transport of fuel to the point of final use.
1 B 1	<i>Solid Fuels</i>	Includes all intentional and unintentional emissions from the extraction, processing, storage and transport of solid fuel to the point of final use.
1 B 1 a	<i>Coal mining and handling</i>	Includes all fugitive emissions from coal
1 B 1 a i	<i>Underground mines</i>	Includes all emissions arising from mining, post-mining, abandoned mines and flaring of drained methane.
1 B 1 a i 1	<i>Mining</i>	Includes all seam gas emissions vented to atmosphere from coal mine ventilation air and degasification systems.
1 B 1 a i 2	<i>Post-mining seam gas emissions</i>	Includes methane and CO ₂ emitted after coal has been mined, brought to the surface and subsequently processed, stored and transported.
1 B 1 a i 3	<i>Abandoned underground mines</i>	Includes methane emissions from abandoned underground mines
1 B 1 a i 4	<i>Flaring of drained methane or conversion of methane to CO₂</i>	Methane drained and flared, or ventilation gas converted to CO ₂ by an oxidation process should be included here. Methane used for energy production should be included in Volume 2, Energy, Chapter 2 'Stationary Combustion'.
1 B 1 a ii	<i>Surface mines</i>	Includes all seam gas emissions arising from surface coal mining
1 B 1 a ii 1	<i>Mining</i>	Includes methane and CO ₂ emitted during mining from breakage of coal and associated strata and leakage from the pit floor and highwall
1 B 1 a ii 2	<i>Post-mining seam gas emissions</i>	Includes methane and CO ₂ emitted after coal has been mined, subsequently processed, stored and transported.

1 B 1 a ii 3	<i>Abandoned surface mines</i>	Includes methane emissions from abandoned surface mines.
1 B 1 a iii	<i>Coal exploration</i>	Includes methane emissions from boreholes drilled for the purposes of coal exploration.
1 B 1 b	<i>Uncontrolled combustion and burning coal dumps</i>	Includes emissions of CO ₂ from uncontrolled combustion due to coal exploitation activities.

4.1.2 Methodological issues

The following sections focus on methane emissions, as this gas is the most important fugitive emission for coal mining. Methods for estimating carbon dioxide emissions from underground and surface mining are also provided. Carbon dioxide emissions from other coal mining sources such as post-mining and abandoned mines should also be included in the inventory where data are available.

UNDERGROUND MINING

Fugitive emissions from underground mining arise from both ventilation and degasification systems. These emissions are normally emitted at a small number of centralised locations and can be considered as point sources. They are amenable to standard measurement methods.

SURFACE MINING

For surface mining the emissions of greenhouse gases are generally dispersed over sections of the mine and are best considered area sources. These emissions may be the result of seam gases emitted through the processes of breakage of the coal and overburden, low temperature oxidation of waste coal or low quality coal in dumps, and uncontrolled combustion. Measurement methods for low temperature oxidation and uncontrolled combustion are still being developed and therefore estimation methods are not included in this chapter.

ABANDONED MINES

Abandoned underground mines present difficulties in estimating emissions, although a methodology for abandoned underground mines is included in this chapter. Methodologies do not yet exist for abandoned or decommissioned surface mines, and therefore they are not included in this chapter.

EXPLORATION

Large fraction of the gas contained in the coal seams is adsorbed on the coal surface inside the micropores and a small fraction in the free state in the macro pores and cleats. The hydrostatic pressure that a coal seam is subjected to prevents desorption of the gas from coal matrix. Gas flow from exploration boreholes is not comparable to the flow of gas in coalbed methane wells where the coal seams are stimulated by hydro fracturing and depressurized by dewatering the coal seams. Emissions during exploratory borehole drilling may be largely associated with the amount of coal or lignite added to the national resource augmented during the reporting period. This addition of resource is termed as augmentation of resource during the period.

METHANE RECOVERY AND UTILISATION

Methane recovered from drainage, ventilation air, or abandoned mines may be mitigated in two ways: (1) direct utilization as a natural gas resource or (2) by flaring to produce CO₂, which has a lower greenhouse warming potential than methane.

TIERS

Use of appropriate tiers to develop emissions estimates for coal mining in accordance with *good practice* depends on the quality of data available. For instance, if limited data are available and the category is not key, then Tier 1 is *good practice*. The Tier 1 approach requires that countries choose from a global average range of emission factors and use country-specific activity data to calculate total emissions. Tier 1 is associated with the highest level of uncertainty. The Tier 2 approach uses country- or basin-specific emission factors that represent the average values for the coals being mined. These values are normally developed by each country, where appropriate. The Tier 3 approach uses direct measurements on a mine-specific basis and, properly applied, has the lowest level of uncertainty.

4.1.3 Underground coal mines

***ELABORATED TO ADD METHOD FOR ESTIMATING CARBON DIOXIDE EMISSIONS FROM UNDERGROUND MINES ***

Second-order Draft

The general form of the equation for estimating emissions for Tier 1 and 2 approaches, based on coal production activity data *from underground coal mining and post-mining emissions* is given by Equation 4.1.1 below. Methods to estimate emissions from *abandoned* underground mines, included in the guidelines for the first time, are described in detail in Section 4.1.5.

Equation 4.1.1 represents emissions before adjustment for any utilisation or flaring of recovered gas:

EQUATION 4.1.1
ESTIMATING EMISSIONS FROM UNDERGROUND COAL MINES FOR TIER 1 AND TIER 2 WITHOUT
ADJUSTMENT FOR METHANE UTILISATION OR FLARING
Greenhouse gas emissions = Raw coal production • Emission Factor • Units conversion factor

The definition of the Emission Factor used in this equation depends on the activity data used. For Tier 1 and Tier 2, the Emission Factor for underground, surface and post-mining emissions has units of m³tonne⁻¹, the same units as *in situ* gas content. This is because these Emission Factors are used with activity data on raw coal production which has mass units (i.e. tonnes). However, the Emission Factor and the *in situ* gas content are not the same and should not be confused. The Emission Factor is always larger than the *in situ* gas content, because the gas released during mining draws from a larger volume of coal and adjacent gas-bearing strata than simply the volume of coal produced. For abandoned underground mines, the Emission Factor has different units, because of the different methodologies employed, see Section 4.1.5 for greater detail.

The equation to be used along with Equation 4.1.1 in order to adjust for methane utilisation and flaring for Tier 1 and Tier 2 approaches is shown in Equation 4.1.2.

EQUATION 4.1.2 (ELABORATION)
ESTIMATING EMISSIONS FROM UNDERGROUND COAL MINES FOR TIER 1 AND TIER 2 WITH
ADJUSTMENT FOR METHANE UTILISATION OR FLARING
*CH₄ emissions from underground mining activities = Emissions from underground mining CH₄ +
Post-mining emission of CH₄ – CH₄ recovered and utilized for energy production or flared*
*CO₂ emissions from underground mining activities = Emissions from underground mining CO₂ -
the amount of CO₂ contained in the gas recovered and utilized for energy production*

Emissions from underground mines in equations 4.1.1 and 4.1.2 include abandoned mines (see Section 4.1.5) and both go into the total for 1.B.1.a.i (Underground mines).

Equation 4.1.2 is used for Tiers 1 and 2 because they use Emission Factors to account for emissions from coal mines on a national or coal-basin level. The emission factors already include all the methane likely to be released from mining activities. Thus, any methane recovery and utilization must be explicitly accounted for by the subtraction term in Equation 4.1.2.

Similarly, the amount of CO₂ contained in the gas that is recovered and utilized for energy production should also be accounted for by the subtraction term in Equation 4.1.2, because this amount of CO₂ is included in the recovered gas (rather than released from an underground mine). CO₂ emission should be reported under other relevant source categories depending on the final use of the recovered gas. When the gas is simply flared or catalytically oxidised with no useful energy, the amount of CO₂ contained in the flared or catalytically oxidised gas should be reported as fugitive emissions, and since it is already included via the emission factors, hence no subtraction or addition is needed. The corresponding CO₂ emissions from drained methane flared or ventilation gas converted to CO₂ by an oxidation process, including the unburnt CH₄ emissions, should be reported under subcategory 1 B 1 a i 4 (See Equation 4.1.5 below). Tier 3 methods involve mine-specific calculations which take into account the methane drained and recovered from individual mines rather than emission factors, and therefore Equation 4.1.2 is not appropriate for Tier 3 methods.

4.1.3.1 CHOICE OF METHOD

UNDERGROUND MINING

Figures 4.1.1 and 4.1.1a shows the methane and carbon dioxide decision trees for underground coal mining activities. For countries with underground mining, and where mine-specific measurement data are available it is *good practice* to use a Tier 3 method. Mine-specific CH₄ and CO₂ data, based on ventilation air measurements and degasification system measurements, reflect actual emissions on a mine-by-mine basis, and therefore produce a more accurate estimate than using Emission Factors.

Hybrid Tier 3 - Tier 2 approaches are appropriate in situations when mine-specific measurement data are available only for a subset of underground mines. For example, if only mines that are considered gassy report data, emissions from the remaining mines can be calculated with Tier 2 emission factors. The definition of what constitutes a gassy mine will be determined by each country. For instance, in the United States, gassy mines refers to coal mines with average annual ventilation emissions exceeding the range of 2 800 to 14 000 cubic meters per day. Emission factors can be based on specific emission rates derived from Tier 3 data if the mines are operating within the same basin as the Tier 3 mines, or on the basis of mine-specific properties, such as the average depth of the coal mines.

When no mine-by-mine data are available, but country- or basin-specific data are, it is *good practice* to employ the Tier 2 method.

Where no data (or very limited data) are available, it is *good practice* to use a Tier 1 approach, provided underground coal mining is not a key sub source category. If it is, then it is *good practice* to obtain emissions data to increase the accuracy of these emissions estimates (see Figures 4.1.1 and Figures 4.1.1a). A reliable relationship between CH₄ and CO₂ emissions levels from underground coal mining cannot be established for the purposes of emission estimation purposes. Therefore emission methods based on correlation between CH₄ and CO₂ are not provided.

POST-MINING

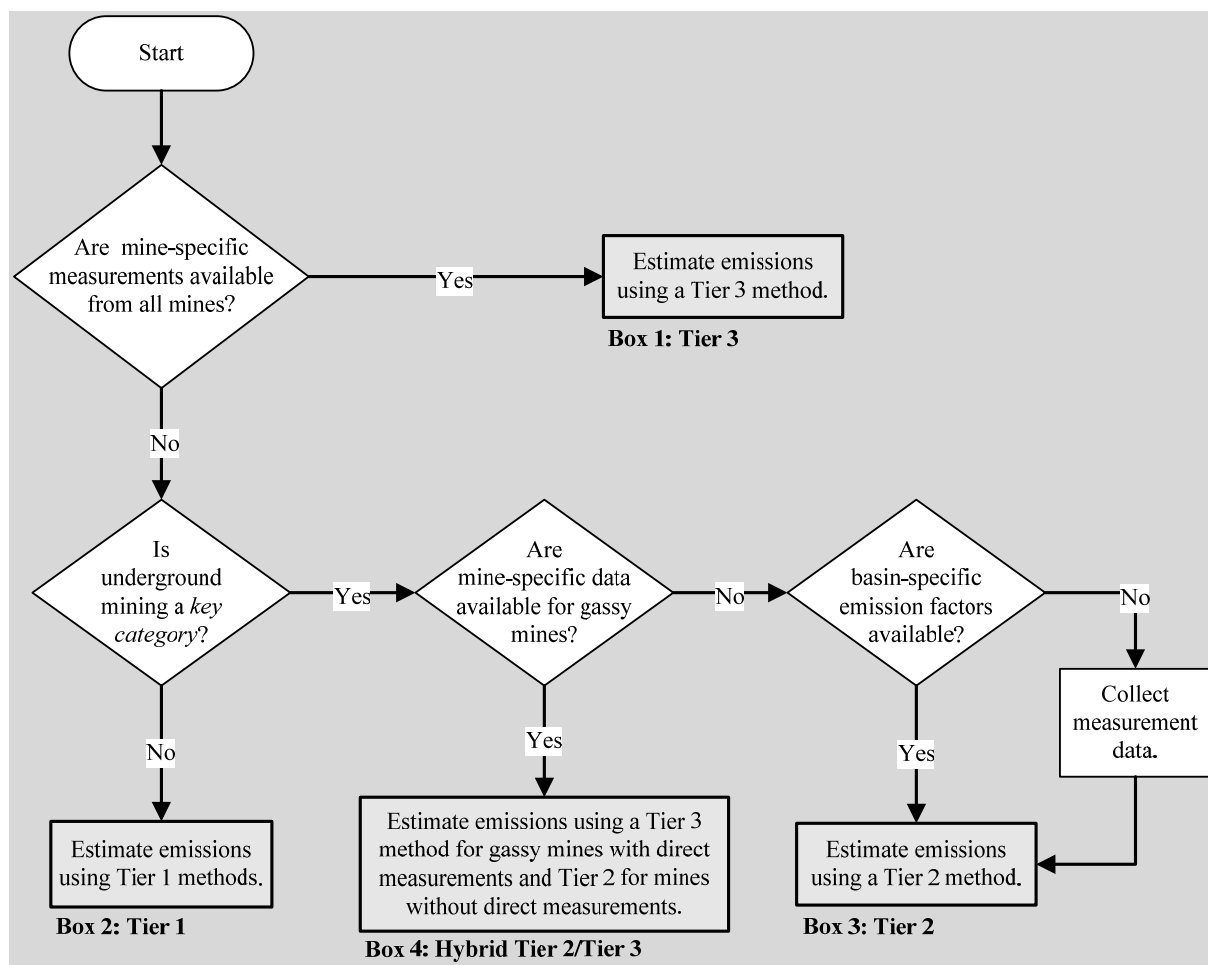
Direct measurement (Tier 3) of all post-mining emissions is not feasible, so an emission factor approach must be used. The Tier 2 and Tier 1 methods described below represent *good practice* for this source, given the difficulty of obtaining better data.

LOW TEMPERATURE OXIDATION

Oxidation of coal when it is exposed to the atmosphere by coal mining releases CO₂. Coal low temperature oxidation is one among other sources of CO₂ during mining activity. Tier 1 approach uses general emission factors that cover all fugitive sources of CO₂ including low temperature oxidation.

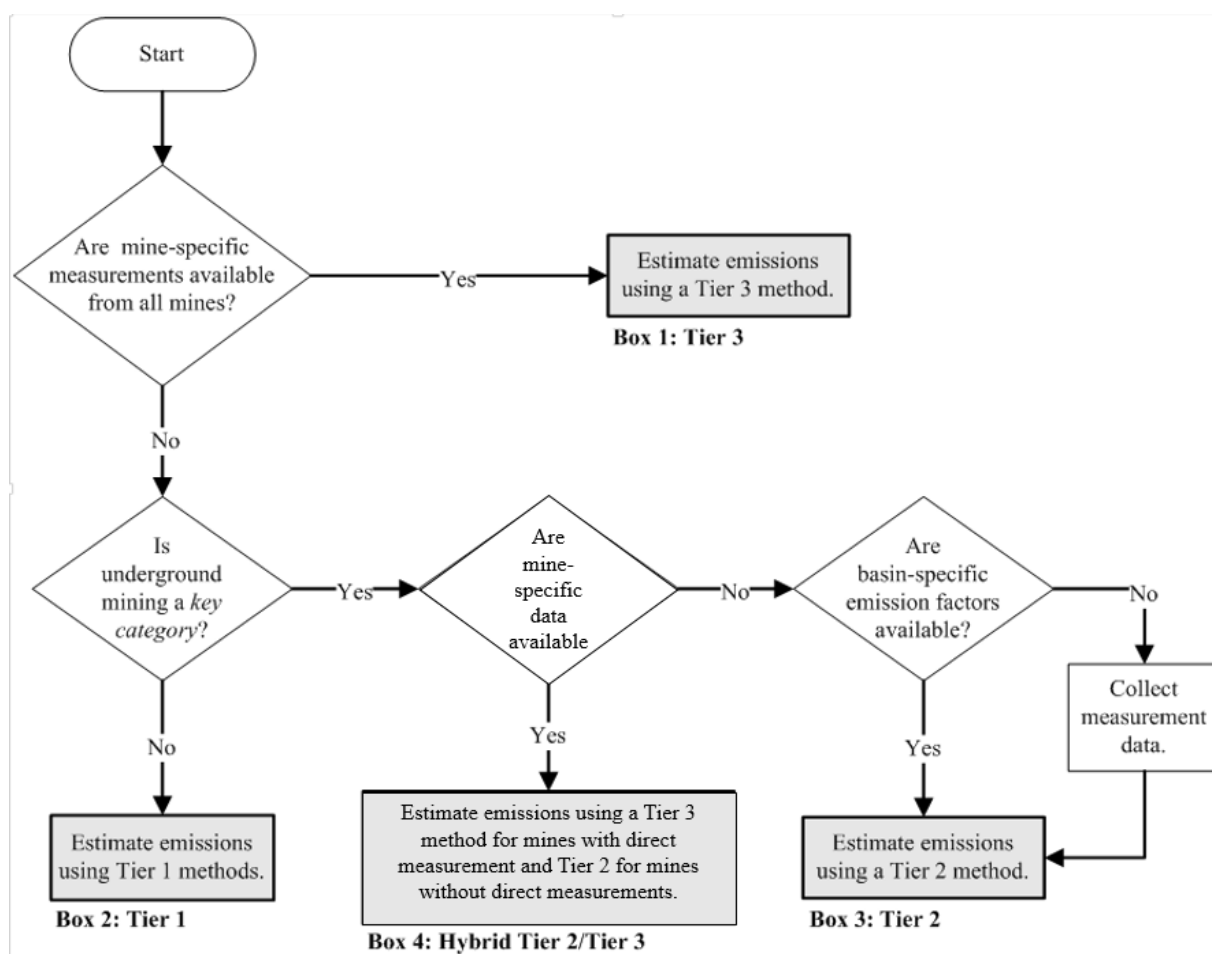
ABANDONED UNDERGROUND MINES

Fugitive methane emissions from abandoned underground mines should be reported in Underground Mines in IPCC Category 1.B.1.a.i.3, using the methodology presented in Section in 4.1.5.

Figure 4.1.1 Decision tree for methane from underground coal mines

Note: See Volume 1 Chapter 4, "Methodological Choice and Key Categories" (noting Section 4.1.2 on limited resources) for discussion of key categories and use of decision trees

443 **Figure 4.1.1a Decision tree for carbon dioxide from underground coal mines**



444 Note: See Volume 1 Chapter 4, “Methodological Choice and Key Categories” (noting Section 4.1.2 on limited resources) for discussion of *key*
 445 *categories* and use of decision trees
 446

447 4.1.3.2 CHOICE OF EMISSION FACTORS FOR UNDERGROUND MINES

448 MINING

449 Methane

450 Tier 1 Emission Factors for underground mining are shown below. The emission factors are the same as those
 451 described in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (BCTSR, 1992; Bibler
 452 et al, 1991; Lama, 1992; Pilcher et al, 1991; USEPA, 1993a,b and Zimmermeyer, 1989).

453 EQUATION 4.1.3

454 **TIER 1: GLOBAL AVERAGE METHOD – UNDERGROUND MINING – METHANE -BEFORE**
 455 **ADJUSTMENT FOR ANY METHANE UTILISATION OR FLARING**

$$456 \text{CH}_4 \text{ emissions} = \text{CH}_4 \text{ Emission Factor} \bullet \text{Underground Coal Production} \bullet \text{Conversion Factor}$$

457 Where units are:

458 Methane Emissions (Gg year⁻¹)

459 CH₄ Emission Factor (m³ tonne⁻¹)

460 Underground Coal Production (tonne year⁻¹)

461 **Emission Factor:**

462 Low CH₄ Emission Factor = 10 m³ tonne⁻¹

463 Average CH₄ Emission Factor = 18 m³ tonne⁻¹

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High CH₄ Emission Factor = 25 m³ tonne⁻¹

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67 • 10⁻⁶ Gg m⁻³.

Countries using the Tier 1 approach should consider country-specific variables such as the depth of major coal seams to determine the emission factor to be used. As gas content of coal usually increases with depth, the low end of the range should be chosen for average mining depths of <200 m, and for depths of > 400 m the high value is appropriate. For intermediate depths, average values can be used.

For countries using a Tier 2 approach, basin-specific emission factors may be obtained from sample ventilation air data or from a quantitative relationship that accounts for the gas content of the coal seam and the surrounding strata affected by the mining process, along with raw coal production. For a typical longwall operation, the amount of gas released comes from the coal being extracted and from any other gas-bearing strata that are located within 150 m above and 50 m below the mined seam (*Good Practice Guidance*, 2000).

Carbon dioxide

Tier 1 Emission Factors for underground mining are shown below. The emission factors have been derived from National Inventory Reports, scientific literature, and data reported to national reporting programs, of the following countries; Australia, China, Czech Republic, India, Japan, Slovakia, Slovenia, South Africa, Russia and Ukraine.

(Moscow Geological Prospecting Institute 1979; Moscow Geological Prospecting Institute 1980; China State Administration of Coal Mine Safety 2012; Central Institute of Mining and Fuel Research 2016; Commonwealth of Australia 2017; Czech Republic 2017; Lloyd 2008; Ministry of the Environment Japan 2017; Republic of Slovenia 2017; Slovak Republic 2017; Yu *et al.* 2018)

EQUATION 4.1.3A**TIER 1: GLOBAL AVERAGE METHOD – UNDERGROUND MINING – CARBON DIOXIDE**

$$CO_2 \text{ emissions} = CO_2 \text{ Emission Factor} \bullet \text{Underground Coal Production} \bullet \text{Conversion Factor}$$

Where units are:

Carbon dioxide Emissions (Gg year⁻¹)

CO₂ Emission Factor (m³ tonne⁻¹)

Underground Coal Production (tonne year⁻¹)

Emission Factor:

Low CO₂ Emission Factor = 0.05 m³ tonne⁻¹

Average CO₂ Emission Factor = 5.9 m³ tonne⁻¹

High CO₂ Emission Factor = 12.3 m³ tonne⁻¹

Conversion Factor:

This is the density of CO₂ and converts volume of CO₂ to mass of CO₂. The density is taken at 20°C and 1 atmosphere pressure and has a value of 1.839 • 10⁻⁶ Gg m⁻³ (GOST 2015).

Countries should use the average emission factor unless there is country-specific evidence to support use of an alternative factor within the low/high range. Countries may consider country-specific circumstances such as geological location/basis/depth to determine the emission factor to be used. Where CO₂ outbursts have been frequently observed as a safety concern in mining, then a country should consider the use of the high end CO₂ emission factor.

For countries using a Tier 2 approach, basin-specific emission factors may be obtained from analysis of ventilation air data. When assessing CO₂ gas volumes in mine ventilation systems, care needs to be taken to exclude CO₂ from non-fugitive sources such as;

- ambient carbon dioxide present in the air that was drawn into the mine ventilation intake - to take into account the atmospheric CO₂ constant of the air drawn into the intake of the ventilation system.
- fuel combustion CO₂ emissions arising from the use of machinery, while the machinery is in the underground mine.

A Tier 3 approach, is based on direct measurement of gas composition. So for countries using Tier 3 approach assessing CO₂ gas volumes in mine ventilation systems needs to be taken to exclude CO₂ of above mentioned non-

fugitive sources. Basin-specific emission factors may be obtained from analysis of ventilation air data. When assessing CO₂ gas volumes in mine ventilation systems, care needs to be taken to exclude CO₂ of above mentioned non-fugitive sources.

POST-MINING EMISSIONS

For a Tier 1 approach the post-mining emissions factors are shown below together with the estimation method:

EQUATION 4.1.4

TIER 1: GLOBAL AVERAGE METHOD – POST-MINING EMISSIONS – UNDERGROUND MINES

$$\text{Methane emissions} = \text{CH}_4 \text{ Emission Factor} \bullet \text{Underground Coal Production} \bullet \text{Conversion Factor}$$

Where units are:

Methane Emissions (Gg year⁻¹)

CH₄ Emission Factor (m³ tonne⁻¹)

Underground Coal Production (tonne year⁻¹)

Emission Factor:

Low CH₄ Emission Factor = 0.9 m³ tonne⁻¹

Average CH₄ Emission Factor = 2.5 m³ tonne⁻¹

High CH₄ Emission Factor = 4.0 m³ tonne⁻¹

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67•10⁻⁶ Gg m⁻³.

Tier 2 methods to estimate post-mining emissions take into account the *in situ* gas content of the coal. Measurements on coal as it emerges on a conveyor from an underground mine without degasification prior to mining indicate that 25-40 percent of the *in situ* gas remains in the coal (Williams and Saghafi, 1993). For mines that practice pre-drainage, the amount of gas in coal will be less than the *in situ* value by some unknown amount. For mines with no pre-drainage, but with knowledge of the *in situ* gas content, the post-mining emission factor can be set at 30 percent of the *in situ* gas content. For mines with pre-drainage, an emission factor of 10 percent of the *in situ* gas content is suggested.

Tier 3 methods are not regarded as feasible for post-mining operations.

EMISSIONS FROM DRAINED METHANE

Methane drained from working (or abandoned) underground (or surface) coal mines can be vented directly to the atmosphere, recovered and utilised, or converted to CO₂ through combustion (flaring or catalytic oxidation) without any utilisation. The manner of accounting for drained methane varies, depending on the final use of the methane.

In general:

- Tier 1 represents an aggregate emissions estimate using emission factors. In general, it is not expected that emissions associated with drained methane would be applicable for Tier 1. Presumably, if methane were being drained, there would be better data to enable use of Tier 2 or even Tier 3 methods to make emissions estimates. However, Tier 1 has been included in the discussion below, in case Tier 1 methods are being used to estimate national emissions where there are methane drainage operations.
- When methane is drained from coal seams as part of coal mining and subsequently flared or used as a fuel, it is *good practice* to subtract this amount from the total estimate of methane emissions for Tier 1 and Tier 2 (Equation 4.1.2). Data on the amount of methane that is flared or otherwise utilised should be obtained from mine operators with the same frequency of measurement as pertains to underground mine emissions generally.
- For Tiers 1 and 2, if methane is drained and vented to the atmosphere rather than utilized, it should not be re-counted as it already forms part of the emissions estimates for these approaches.
- For Tier 3, methane recovered from degasification systems and vented to the atmosphere prior to mining should be added to the amount of methane released through ventilation systems so that the total estimate is complete. In some cases, because degasification system data are considered confidential, it may be necessary to estimate degasification system collection efficiency, and then subtract known reductions to arrive at the net degasification system emissions.

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• All methane emissions associated with coal seam degasification related to coal mining activities should be accounted for in the inventory year in which the emissions and recovery operations occur. Thus, the total emissions from all ventilation shafts and from all degasification operations that emit methane to the atmosphere are reported for each year, regardless of when the coal seam is mined through, as long as the emissions are associated with mining activities. This represents a departure from the previous guidelines where the drained methane was accounted for in the year in which the coal seam was mined through.

• When coal bed methane is extracted from coal seams for the purpose of gas mining for delivery into a natural gas system, then the fugitive emissions associated with the exploration, production, processing, transmission and storage are dealt with in the oil and natural gas source category (Section 4.2). Tier 1 fugitive emission factors for coal bed methane production are provided under 1B 2 b iii 2 Production and Gathering in Table 4.2.10.

When recovered methane is utilized as an energy source:

• Any emissions resulting from use of recovered coal mine methane as an energy source should be accounted for based on its final end-use, for example in the Energy Volume, Chapter 2, 'Stationary Combustion' when used for stationary energy production.

• Where recovered methane from coal seams is fed into a natural gas system and used as natural gas, the fugitive emissions occurring as part of those natural gas systems are dealt with in the oil and natural gas source category (Section 4.2).

When recovered methane is flared:

• When the methane is simply combusted with no useful energy, as in flaring or catalytic oxidation to CO₂, the corresponding CO₂ production should be added to the total greenhouse gas emissions (expressed as CO₂ equivalents) from coal mining activities. Such emissions should be accounted for as shown by Equation 4.1.5, below. Amounts of nitrous oxide and non-methane volatile organic compounds emitted during flaring will be small relative to the overall fugitive emissions and need not be estimated.

EQUATION 4.1.5

EMISSIONS OF CO₂ AND CH₄ FROM DRAINED METHANE FLARED OR CATALYTICALLY OXIDISED

(a) Emissions of CO₂ from CH₄ combustion = 0.98 • Volume of methane flared • Conversion Factor
• Stoichiometric Mass Factor

(b) Emissions of unburnt methane = 0.02 • Volume of methane flared • Conversion Factor

Where units are:

Emissions of CO₂ from methane combustion (Gg year⁻¹)

Volume of methane oxidised (m³ year⁻¹)

Stoichiometric Mass Factor is the mass ratio of CO₂ produced from full combustion of unit mass of methane and is equal to 2.75

Note: 0.98 represents the combustion efficiency of natural gas that is flared (Compendium of Greenhouse Gas Emission Methodologies for the Oil and gas Industry, American Petroleum Institute, 2004)

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67 • 10⁻⁶ Gg m⁻³.

4.1.3.3 CHOICE OF ACTIVITY DATA

The activity data required for Tiers 1 and 2 are raw coal production. If the data on raw coal production are available these should be used directly. If coal is not sent to a coal preparation plant or washery for upgrading by removal of some of the mineral matter, then raw coal production equals the amount of saleable coal. Where coal is upgraded, some coal is rejected in the form of coarse discards containing high mineral matter and also in the form of unrecoverable fines. The amount of waste is typically around 20 percent of the weight of raw coal feed, but may vary considerably by country. Where activity data are in the form of saleable coal, an estimate should be made of the amount of production that is washed. Raw coal production is then estimated by increasing the amount of 'saleable coal' by the fraction lost through washing.

An alternative approach that may be more suitable for mines whose raw coal output contains rock from the roof or floor as a deliberate part of the extraction process, is to use saleable coal data in conjunction with emission factors referenced to the clean fraction of the coal, not raw coal. This should be noted in the inventory.

For the Tier 3 methods, coal production data are unnecessary because actual emissions measurements are available. However, it is *good practice* to collect and report these data to illustrate the relationship, if any, between underground coal production and actual emissions on an annual basis.

High quality measurements of methane drained by degasification systems should also be available from mine operators for mines where drainage is practised. If detailed data on drainage rates are absent, *good practice* is to obtain data on the efficiency of the systems (i.e. the fraction of gas drained) or to make an estimate using a range (e.g. 30-50 percent, typical of many degasification systems). If associated mines have data available these may also be used to provide guidance. Annual total gas production records for previous years should be maintained; these records may be available from appropriate agencies or from individual mines.

Where data on methane recovery from coal mines and utilisation are not directly available from mine operators, gas sales could be used as a proxy. If gas sales are unavailable, the alternative is to estimate the amount of utilised methane from the known efficiency specifications of the drainage system. Only methane that would have been emitted from coal mining activities should be considered as recovered and utilized. These emissions should be accounted for in Volume 2, Chapter 4, Section 4.2, 'Fugitive emissions from oil and natural gas', or if the emissions are combusted for energy, in Volume 2, Chapter 2 'Stationary Combustion'.

4.1.3.4 COMPLETENESS FOR UNDERGROUND COAL MINES

The estimate of emissions from underground mining should include:

- Drained gas produced from degasification systems
- Ventilation emissions
- Post-mining emissions
- Estimates of volume of methane recovered and utilized or flared
- Abandoned underground coal mines (see Section 4.1.5 for methodological guidance)

These sub sources categories are included in the current Guidelines.

4.1.3.5 DEVELOPING A CONSISTENT TIME SERIES

Comprehensive mine-by-mine (i.e. Tier 3) data may be available for some but not all years. If there have been no major changes in the number of active mines, emissions can be scaled to production for missing years, if any. If there were changes in the mine number, the mines involved can be removed from the scaling extrapolation and handled separately. However, care must be taken in scaling because the coal being mined, the virgin exposed coal and the disturbed mining zone each have different emission rates. Furthermore, mines may have a high background emission level that is independent of production.

The inventory guidelines recommend that methane emissions associated with coal seam degasification related to mining should be accounted for in the inventory year in which the emissions and recovery operations occur. This is a departure from previous guidelines which suggested that the methane emissions or reductions only be accounted for during the year in which the coal was produced (e.g. the degasification wells were "mined through.") Thus, if feasible, re-calculation of previous inventory years is desirable to make a consistent time series.

In cases where an inventory compiler moves from a Tier 1 or Tier 2 to a Tier 3 method, it may be necessary to calculate implied emissions factors for years with measurement data, and apply these emission factors to coal production for years in which these data do not exist. It is important to consider if the composition of the mine population has changed dramatically during the interim period, because this could introduce uncertainty. For mines that have been abandoned since 1990, data may not be archived if the company disappears. These mines should be treated separately when adjusting the time series for consistency.

For situations where the emissions of greenhouse gases from active underground mines have been well characterized and the mines have passed from being considered 'active' to 'abandoned', care should be taken so as not to introduce major discontinuities in the total emissions record from coal mining.

4.1.3.6 UNCERTAINTY ASSESSMENT

***ELABORATED TO ADD UNCERTAINTY ESTIMATES FOR UNDERGROUND MINING CARBON DIOXIDE EMISSION FACTORS ***

EMISSION FACTOR UNCERTAINTIES

Emission Factors for Tiers 1 and 2

The major sources of uncertainty for a Tier 1 approach arise from two sources. These are:

- The applicability of global emission factors to individual countries
- Inherent uncertainties in the emission factors themselves

The uncertainty due to the first point above is difficult to quantify, but could be significant. The inherent uncertainty in the emission factor is also difficult to quantify because of natural variability within the same coal region is known to occur.

For a Tier 2 approach, the same broad comments apply, although basin-specific data will reduce the inherent uncertainty in the Emission Factor compared with a Tier 1 approach. With regard to the inherent variability in the Emission Factor, 'Expert Judgement' in the *Good Practice Guidance (2000)* suggested that this was likely to be at least ± 50 percent.

Table 4.1.2 shows the Tier 1 and Tier 2 uncertainties associated with emissions from underground coal mining. The uncertainties for these Tiers are based on expert judgement.

TABLE 4.1.2 (ELABORATION) ESTIMATES OF UNCERTAINTY FOR UNDERGROUND MINING FOR TIER 1 AND TIER 2 APPROACHES		
Likely uncertainties of coal mine methane Emission factors (Expert judgment - GPG, 2000*)		
Method	Mining	Post-Mining
Tier 2	$\pm 50-75\%$	$\pm 50\%$
Tier 1	Factor of 2 greater or smaller	Factor of 3 greater or smaller
*GPG, 2000 <i>IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories</i> (2000)		
Likely uncertainties of coal mine carbon dioxide emission factors *		
Method	Mining	Post-Mining
Tier 2	$\pm 50-75\%$	Not applicable
Tier 1	Factor of 2 greater or smaller	Not applicable
*Uncertainties set to be consistent with methane emission factors given that measurement practices are likely to be similar		

Tier 3

Methane emissions from underground mines have a significant natural variability due to variations in the rate of mining and drainage of gas. For instance, the gas liberated by longwall mining can vary by a factor of up to two during the life of a longwall panel. Frequent measurements of underground mine emissions can account for such variability and also reduce the intrinsic errors in the measurement techniques. As emissions vary over the course of a year due to variations in coal production rate and associated drainage, *good practice* is to collect measurement data as frequently as practical, preferably biweekly or monthly to smooth out variations. Daily measurements would ensure a higher quality estimate. Continuous monitoring of emissions represents the highest stage of emission monitoring, and is implemented in some modern longwall mines.

Spot measurements of methane concentration in ventilation air are probably accurate to ± 20 percent depending on the equipment used. Time series data or repeat measurements will significantly reduce the uncertainty of annual emissions to ± 5 percent for continuous monitoring, and 10-15 percent for monitoring conducted every two weeks. Ventilation airflows are usually fairly accurately known (± 2 percent). When combining the inaccuracies in emissions concentration measurements with the imprecision due to measurement and calculation of instantaneous measurements, overall emissions for an individual mine may be under-represented by as much as 10 percent or over-represented by as much as 30 percent (Mutmanský and Wang, 2000).

Spot measurement of methane concentration in drained gas (from degasification systems) is likely to be accurate to ± 2 percent because of its higher concentration. Measurements should be made with a frequency comparable to

those for ventilation air to obtain representative sampling. Measured degasification flow rates are probably known to be ± 5 percent. Degasification flow rates that are estimated based on gas sales are also likely to have an uncertainty of at least ± 5 percent due to the tolerances in pipeline gas quality.

For a single longwall operation, with continuous or daily emission measurements, the accuracy of monthly or annual average emissions data is probably ± 5 percent. The accuracy of spot measurements performed every two weeks is ± 10 percent, at 3-monthly intervals: ± 30 percent. Aggregating emissions from mines based on the less frequent type of measurement procedures will reduce the uncertainty caused by fluctuations in gas production. However, as fugitive emissions are often dominated by contributions from only a small number of mines, it is difficult to estimate the extent of this improvement.

The uncertainty estimates for underground mines are shown in Table 4.1.3.

TABLE 4.1.3 ESTIMATES OF UNCERTAINTY FOR UNDERGROUND COAL MINING FOR A TIER 3 APPROACH			
Source	Details	Uncertainty	Reference
Drainage gas	Spot measurements of CH ₄ for drainage gas	$\pm 2\%$	Expert judgment (GPG, 2000*)
	Degasification flows	$\pm 5\%$	Expert judgment (GPG, 2000)
Ventilation gas	Continuous or daily measurements	$\pm 5\%$	Expert judgment (GPG, 2000)
	Spot measurements every 2 weeks	$\pm 10\%$	Mutmansky and Wang, 2000
	Spot measurements every 3 months	$\pm 30\%$	Mutmansky and Wang, 2000
*GPG, 2000 - IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000)			

ACTIVITY DATA UNCERTAINTIES

Coal production: Country-specific tonnages are likely to be known to 1-2 percent, but if raw coal data are not available, then the uncertainty will increase to about ± 5 percent, when converting from saleable coal production data. The data are also influenced by moisture content, which is usually present at levels between 5-10 percent, and may not be determined with great accuracy.

Apart from measurement uncertainty, there can be further uncertainties introduced by the nature of the statistical databases that are not considered here. In countries with a mix of regulated and unregulated mines, activity data may have an uncertainty of ± 10 percent

4.1.4 Surface coal mining

***ELABORATED TO ADD METHOD FOR ESTIMATING CARBON DIOXIDE EMISSIONS FROM SURFACE MINES ***

The fundamental equation to be used in estimating emissions from surface mining is as shown in Equation 4.1.6.

<p style="text-align: center;">EQUATION 4.1.6 (ELABORATION)</p> <p style="text-align: center;">GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM SURFACE COAL MINING</p> <p style="text-align: center;">$CH_4 \text{ emissions} = \text{Surface mining emissions of } CH_4 + \text{Post-mining emission of } CH_4$</p> <p style="text-align: center;">$CO_2 \text{ emissions} = \text{Surface mining emissions of } CO_2$</p>

4.1.4.1 CHOICE OF METHOD

It is not yet feasible to collect mine-specific Tier 3 measurement data for surface mines. The alternative is to collect data on surface mine coal production and use emission factors. For countries with significant coal production and multiple coal basins, disaggregation of data and emission factors to the coal basin level will improve accuracy. Given the uncertainty of production-based emission factors, choosing emission factors from the range specified within these guidelines can provide reasonable estimates for a Tier 1 approach.

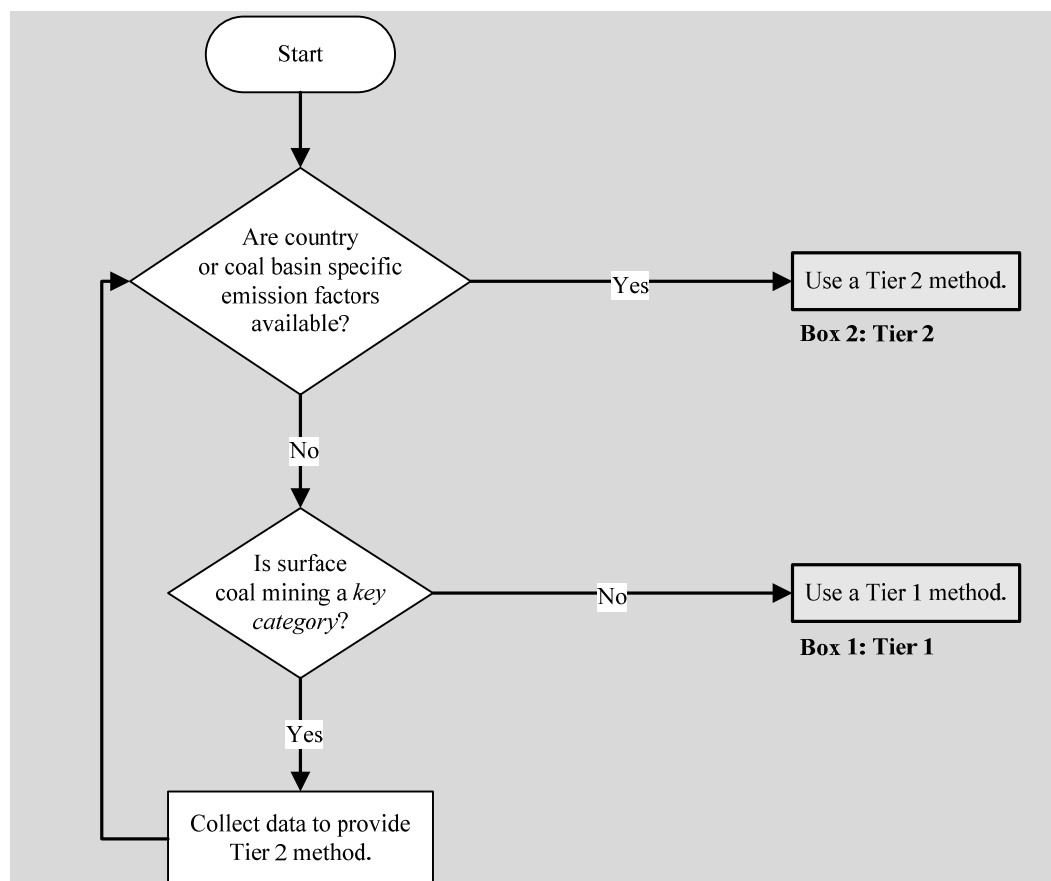
Second-order Draft

As with underground mining, direct measurement of post-mining emissions is infeasible so an emission factor approach is recommended. Tier 2 and Tier 1 methods should be reasonable for this source, given the difficulty of obtaining better data. A reliable relationship between CH₄ and CO₂ emissions levels from surface coal mining cannot be established for the purposes of emission estimation purposes. Therefore emission methods based on correlation between CH₄ and CO₂ are not provided.

Oxidation of coal in the atmosphere to produce CO₂ is known to occur at surface mines, but emissions from this are not expected to be significant, especially taking into account the effects of rehabilitation of the waste dumps. Rehabilitation practices, which involve covering the dumps with topsoil and re-vegetation, act to reduce oxygen fluxes into the dump and hence reduce the rate of CO₂ production.

Uncontrolled combustion in waste piles is a feature for some surface mines. However, these emissions, where they occur, are extremely difficult to quantify and it is infeasible to include a methodology.

Figure 4.1.2 Decision tree for surface coal mining



Note: See Volume 1 Chapter 4, “Methodological Choice and Key Categories” (noting Section 4.1.2 on limited resources) for discussion of key categories and use of decision trees

4.1.4.2 EMISSION FACTORS FOR SURFACE MINING

Although measurements of methane and carbon dioxide emissions from surface mining are increasingly available, they are difficult to make and at present no routine widely applicable methods exist. Data on *in situ* gas contents before overburden removal are also scarce for many surface mining operations.

The Tier 1 methane emission factors are shown together with the estimation method in Equation 4.1.7. The Tier 1 carbon dioxide emission factors are shown together with the estimation method in Equation 4.1.7.a

EQUATION 4.1.7

TIER 1: GLOBAL AVERAGE METHOD – SURFACE MINES – METHANE

$$\text{Methane emissions} = \text{CH}_4 \text{ Emission Factor} \bullet \text{Surface Coal Production} \bullet \text{Conversion Factor}$$

Where units are:

Methane Emissions (Gg year⁻¹)

CH₄ Emission Factor (m³ tonne⁻¹)

Surface Coal Production (tonne year⁻¹)

Emissions Factor:

Low CH₄ Emission Factor = 0.3 m³ tonne⁻¹

Average CH₄ Emission Factor = 1.2 m³ tonne⁻¹

High CH₄ Emission Factor = 2.0 m³ tonne⁻¹

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67 • 10⁻⁶ Gg m⁻³.

For the Tier 1 approach, it is *good practice* to use the low end of the specific emission range for those mines with average overburden depths of less than 25 meters and the high end for overburden depths over 50 meters. For intermediate depths, average values for the emission factors may be used. In the absence of data on overburden thickness, it is *good practice* to use the average emission factor, namely 1.2 m³/tonne.

The Tier 1 carbon dioxide emission factors are shown together with the estimation method in Equation 4.1.7.a

The emission factors are based on data reported to the Australian National Greenhouse and Energy Reporting program for years 2009-17, measurements of gas in Kazakhstan surface mines and Japan National Inventory Report 2017. (RGE "Kaz NIEK" MOOS RK 2010; Commonwealth of Australia 2017; Ministry of the Environment Japan 2017; Republic of Kazakhstan 2017)

EQUATION 4.1.7A

TIER 1: GLOBAL AVERAGE METHOD – SURFACE MINES– CARBON DIOXIDE

Carbon dioxide emissions = CO₂ Emission Factor • Surface Coal Production • Conversion Factor

Where units are:

Carbon dioxide Emissions (Gg year⁻¹)

CO₂ Emission Factor (m³ tonne⁻¹)

Surface Coal Production (tonne year⁻¹)

Emissions Factor:

Low CO₂ Emission Factor = 0.01 m³ tonne⁻¹

Average CO₂ Emission Factor = 0.44 m³ tonne⁻¹

High CO₂ Emission Factor = 0.94 m³ tonne⁻¹

Conversion Factor:

This is the density of CO₂ and converts volume of CO₂ to mass of CO₂. The density is taken at 20°C and 1 atmosphere pressure and has a value of 1.84 • 10⁻⁶ Gg m⁻³(GOST 2015).

For the Tier 1 approach, it is *good practice* to use the low end of the specific emission range for those mines with average overburden depths of less than 25 meters and the high end for overburden depths over 50 meters. Otherwise countries should use the average CO₂ emission factor of 0.65 m³/tonne unless there is country-specific evidence to support use of an alternative factor within the low/high range.

The Tier 2 method uses the same equation as for Tier 1, but with data disaggregated to country-specific, or coal basin level. For countries using a Tier 2 approach, carbon dioxide emission factors may be obtained from sampling and analysis of gas content within carbonaceous strata of surface mines, prior to undertaking mining activities.

POST-MINING EMISSIONS – SURFACE MINING

For a Tier 1 approach the post-mining emissions can be estimated using the emission factors shown in Equation 4.1.8.

EQUATION 4.1.8

TIER 1: GLOBAL AVERAGE METHOD – POST-MINING EMISSIONS – SURFACE MINES

Methane emissions = CH₄ Emission Factor • Surface Coal Production • Conversion Factor

Where units are:

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Methane Emissions (Gg year⁻¹)

CH₄ Emission Factor (m³ tonne⁻¹)

Surface Coal Production (tonne year⁻¹)

Emission Factor:

Low CH₄ Emission Factor = 0 m³ tonne⁻¹

Average CH₄ Emission Factor = 0.1 m³ tonne⁻¹

High CH₄ Emission Factor = 0.2 m³ tonne⁻¹

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67 • 10⁻⁶ Gg m⁻³.

The average emission factor should be used unless there is country-specific evidence to support use of the low or high emission factor.

4.1.4.3 ACTIVITY DATA

As with underground coal mines, the activity data required for Tiers 1 and 2 are raw coal production. The comments relating to coal production data, made for Tier 1 and Tier 2 for underground mining in Section 4.1.3.3 also apply to surface mining.

4.1.4.4 COMPLETENESS FOR SURFACE MINING

The estimate of emissions from surface mining should include:

- Emissions during mining through the breaking of coal and from surrounding strata
- Post-mining emissions
- Waste pile/ overburden dump fires

At present only the first two sources above are taken into account. While there will be some emissions from low temperature oxidation, these are expected to be insignificant for this source.

4.1.4.5 DEVELOPING A CONSISTENT TIME SERIES

There may be missing inventory data for surface mines for certain inventory years. If there have been no major changes in the number of active surface mines, emissions can be scaled to production for the missing years. If there were changes in the number of mines, the mines involved can be removed from the scaling extrapolation and handled separately. Where new mines have started production in new coalfields, it is important that the emissions applicable to these mines be assessed as each coal basin will have different characteristic in situ gas contents and emission rates.

If coal seam degasification is practiced at surface mines, the methane should be estimated and reported in the inventory year in which the emissions and recovery operations occur.

4.1.4.6 UNCERTAINTY ASSESSMENT IN EMISSIONS**EMISSION FACTOR UNCERTAINTY**

***ELABORATED TO ADD UNCERTAINTY ESTIMATES FOR SURFACE MINING CARBON DIOXIDE EMISSION FACTORS ***

Uncertainties in the emissions from surface mines are less well quantified than for underground mining. Briefly, the sources of the uncertainty are the same as described in Section 4.1.3.6 for underground coal mines. However, the variability in the emission factors for large surface mines may be expected to be greater than for underground coal mines, because surface mines can show significant variability across the extent of the mine as a result of local geological features.

Table 4.1.4 shows the Tier 1 and Tier 2 uncertainties associated with surface mining emissions.

839

TABLE 4.1.4 (ELABORATION)		
ESTIMATES OF UNCERTAINTY FOR SURFACE MINING FOR TIER 1 AND TIER 2 APPROACHES		
Likely Uncertainties of Coal Mine Methane Emission Factors for Surface Mining (Expert Judgement*)		
Method	Surface	Post-Mining
Tier 2	Factor of 2 greater or lower	± 50%
Tier 1	Factor of 3 greater or lower	Factor of 3 greater or lower
GPG, 2000 - <i>IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories</i> (2000)		
Likely Uncertainties of Coal Mine Carbon Dioxide Emission Factors for Surface Mining *		
Method	Surface	Post-Mining
Tier 2	Factor of 2 greater or lower	Not applicable
Tier 1	Factor of 3 greater or lower	Not applicable
* Uncertainties set to be consistent with methane emission factors		

840 **ACTIVITY DATA UNCERTAINTY**

841 The comments made for underground mining in Section 4.1.3.6 also apply to surface mining.

842 **4.1.5 Abandoned underground coal mines**

843 Closed, or abandoned, underground coal mines may continue to be a source of greenhouse gas emissions for some
 844 time after the mines have been closed or decommissioned. For the purpose of the emissions inventory, it is critical
 845 that each mine is classified in one and only one inventory database (e.g., active or abandoned).

846 As abandoned mines appear in these guidelines for the first time, the Tier 1 and Tier 2 approaches are described
 847 in some detail. The Tier 1 and Tier 2 approaches presented below are largely based on an approach originally
 848 developed by the USEPA (Franklin et al, 2004) and have been adapted to be more globally applicable. It is
 849 anticipated that, where country-specific data exists for abandoned mines, the country-specific data will be used.

850 The Tier 3 approach provides flexibility for use of mine-specific data. The Tier 3 methodology outlined below has
 851 been adapted from the USA methodology (Franklin et al 2004; US EPA 2004). Other relevant work has been
 852 sponsored by the UK (Kershaw, 2005), which provides another example of a Tier 3 approach.

853 **4.1.5.1 CHOICE OF METHOD**

854 The fundamental equation for estimating emissions from abandoned underground coal mines is shown in Equation
 855 4.1.9.

<p style="text-align: center;">EQUATION 4.1.9</p> <p style="text-align: center;">GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM ABANDONED UNDERGROUND COAL MINES</p> $CH_4 \text{ emissions} = \text{Emissions from abandoned mines} - CH_4 \text{ emissions recovered}$

860

861 Developing emissions estimates from abandoned underground coal mines requires historical records. Figure 4.1.3
 862 is a decision tree that shows how to determine which Tier to use.

863 **Tier 1 and 2**

864 The two key parameters used to estimate abandoned mine emissions for each mine (or group of mines) are the
 865 time (in years) elapsed since the mine was abandoned, relative to the year of the emissions inventory, and emission
 866 factors that take into account the mine's gassiness. If applicable and appropriate, methane recovery at specific
 867 mines can be incorporated for specific mines in a hybrid Tier 2 – Tier 3 approach (see below).

- 868 • Tier 2 incorporates coal-type-specific information and narrower time intervals for abandonment of coal mines.

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- Tier 1 includes default values and broader time intervals.

For a Tier 1 approach, the emissions for a given inventory year can be calculated from Equation 4.1.10.

$$\text{Methane Emissions} = \text{Number of Abandoned Coal Mines remaining unflooded} \bullet \text{Fraction of gassy Coal Mines} \bullet \text{Emission Factor} \bullet \text{Conversion Factor}$$

Where units are:

Methane Emissions (Gg year⁻¹)

Emission Factor (m³ year⁻¹)

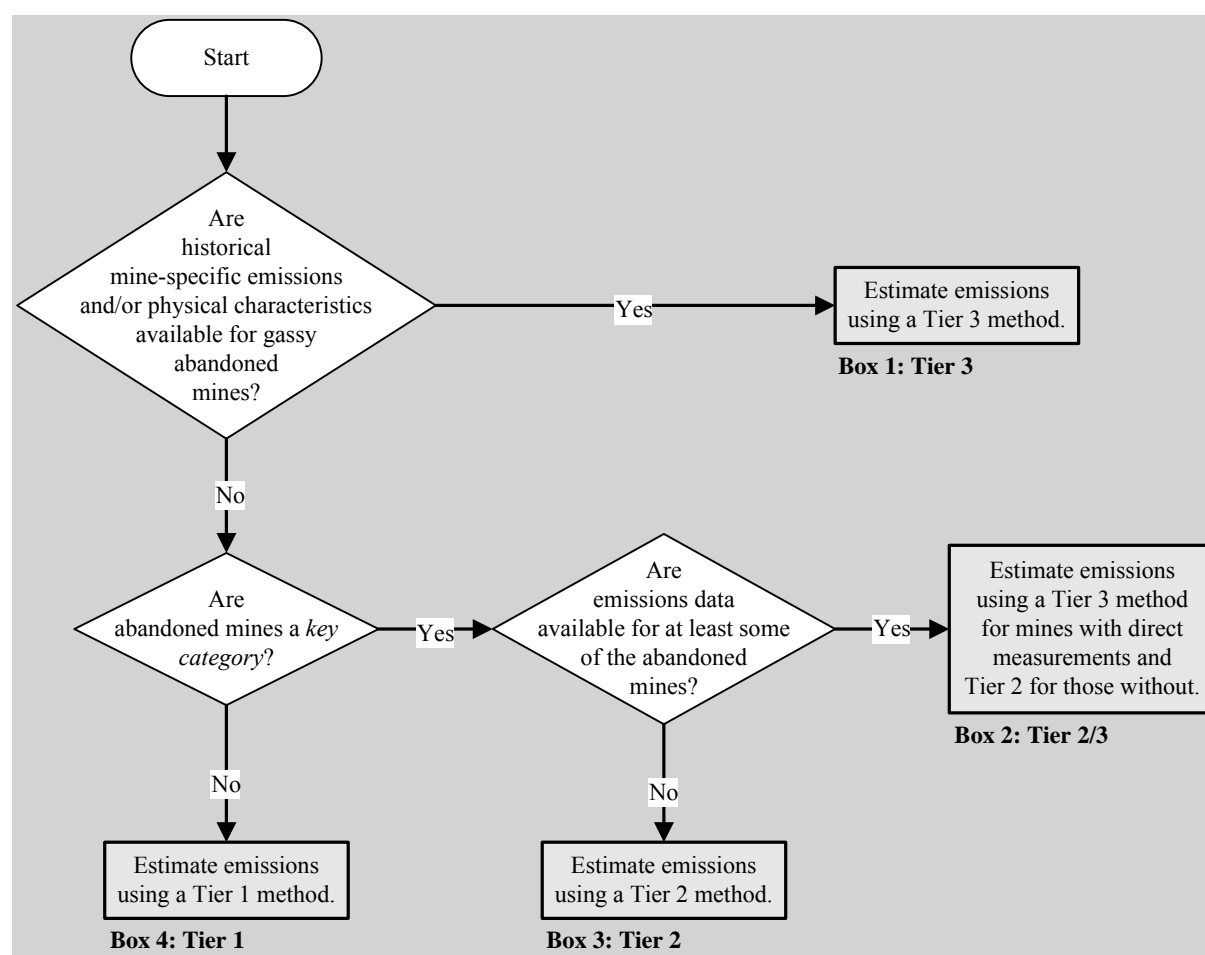
Note: the Emission Factor has different units here compared with the definitions for underground, surface and post-mining emissions. This is because of the different method for estimating emissions from abandoned mines compared with underground or surface mining.

This equation is applied for each time interval, and emissions from each time interval are added to calculate the total emissions.

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67•10⁻⁶ Gg m⁻³.

Figure 4.1.3 Decision tree for abandoned underground coal mines



Note: See Volume 1 Chapter 4, “Methodological Choice and Key Categories” (noting Section 4.1.2 on limited resources) for discussion of key categories and use of decision trees

Tier 3

The Tier 3 approaches (Franklin et al, 2004 and Kershaw, 2005) require mine-specific information such as ventilation emissions from the mine when active, characteristics of the mined coal seam, mine size and depth, and the condition of the abandoned mine (e.g., hydrologic status, flooding or flooded, and whether sealed or vented). Each country may generate its own profiles of abandoned mine emissions as a function of time (also known as emission decline curves) based on known national- or basin-specific coal properties, or it may use more generic curves based on coal rank, or measurements possibly in combination with mathematical modelling methods. If there are any methane recovery projects occurring at abandoned mines, data on these projects are expected to be available. A mine-specific Tier 3 methodology would be appropriate for calculating emissions from a mine that has associated methane recovery projects and could be incorporated as part of a hybrid approach with a national level Tier 2 emissions inventory.

In general, the Tier 3 process for developing a national inventory of abandoned mine methane (AMM) emissions consists of the following steps:

1. Creating a database of gassy abandoned coal mines.
2. Identifying key factors affecting methane emissions: hydrologic (flooding) status, permeability mine condition (whether sealed or vented) and time elapsed since abandonment.
3. Developing mine- or coal basin-specific emission rate decline curves, or equivalent models.
4. Validating mathematical models through a field measurement programme.
5. Calculating a national emissions inventory for each year.
6. Adjusting for emissions reductions due to methane recovery and utilization.
7. Determining the net total emissions.

Hybrid Approaches

A combination of different Tier methodologies may be used to reflect the best data availability for different historical periods. For example, for a given country, emissions from mines abandoned in the distant past may need to be determined using a Tier 1 method. For that same country, it may be possible to determine emissions from mines abandoned more recently using a Tier 2 or 3 method if more accurate data are available.

Fully Flooded Mines

It is *good practice* to include mines that are known to be fully flooded in databases and other records used for inventory development, but they should be assigned an emission of zero as the emissions from such mines are negligible.

Emissions Reductions through Recovery and Utilization

In some cases, methane from closed or abandoned mines may be recovered and utilised or flared. Methane recovery from abandoned mines generally entails pumping which increases, or “accelerates”, the amount of methane recovered above the amount that would have been emitted had pumping not taken place.

Under a mine-specific (Tier 3) approach in which emissions decline curves or models are used to estimate emissions, if emissions reductions are less than the projected emissions that would have occurred at the mine had recovery not taken place for a given year, then the emissions reductions from the recovery and utilization should be subtracted from the projected emissions to provide the net emissions. If the methane recovered and utilized in a given year exceeds the emission that would have occurred had recovery not taken place, then the net emissions from that mine for that year are considered to be zero.

If a Tier 3 method is not used (singly or in combination with Tier 2), the total amount of methane recovered and utilized from abandoned mines should be subtracted from the total emissions inventory for abandoned mines, per Equation 4.1.9, subject to the reported emissions being no less than zero. The Tier 3 method should be used where suitable data are available.

4.1.5.2 CHOICE OF EMISSION FACTORS

Tier 1: Global Average Approach – Abandoned Underground Mines

A Tier 1 approach for determining emissions from abandoned underground mines is described below and is largely based on methods developed by the USEPA (Franklin et al, 2004). It incorporates a factor to account for the fraction of those mines that, when they were actively producing coal, were considered gassy. Thus, this methodology is based on the total number of coal mines abandoned, adjusted for the fraction considered gassy, as described below. Abandoned mines that were considered non-gassy when they were actively mined are presumed to have negligible emissions. In the US methodology, the term gassy mines refers to coal mines that, when they

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were active, had average annual ventilation emissions that exceeded the range of 2 800 to 14 000 cubic meters per day (m³/d), or 0.7 to 3.4 Gg per year.

The Tier 1 – approach for abandoned underground coal mines is as follows:

1. Determine the approximate time (year interval) from the following time intervals when gassy coal mines were abandoned:
 - a. 1901 – 1925
 - b. 1926 – 1950
 - c. 1951 – 1975
 - d. 1976 – 2000
 - e. 2001 – present
2. Multiple intervals may be used where appropriate. It is recommended that the number of gassy coal mines abandoned during each time interval be estimated using the smallest time intervals possible based on available data. Ideally, for more recent periods, time intervals will decrease (e.g., intervals of ten years prior to 1990; annual intervals since 1990). Information for different coal mine-clusters abandoned during different time periods should be considered, since multiple time periods may be combined in the Tier 1 approach
3. Estimate the total number of abandoned mines in each time band since 1901 remaining unflooded. If there is no knowledge on the extent of flooding it is *good practice* to assume that 100 percent of mines remain unflooded. For the purposes of estimating the number of abandoned mines, prospect excavations and hand cart mines of only a few acres in size should be disregarded.
4. Determine the percentage of coal mines that would be considered gassy at the time of mine closure. Based on the time intervals selected above, choose an estimated percentage of gassy coal mines from the high and low default values listed in Table 4.1.5. Actual estimates can range anywhere from 0 to 100 percent. When choosing within the high and low default values listed in Table 4.1.5, a country should consider all available historical information that may contribute to the percentage of gassy mines, such as coal rank, gas content, and depth of mining. Countries with recorded instances of gassy mines (e.g., methane explosions or outbursts) should choose the high default values in the early part of the century. From 1926 to 1975, countries where mines were relatively deep and hydraulic equipment was used should choose the high default value. Countries with deep longwall mines or with evidence of gassiness should choose the high values for the time periods after 1975. The low range of the default values may be appropriate for a given time interval for specific regions, coal basins, or nations, based on geologic conditions or known mining practices.
5. For the inventory year of interest (between 1990 and the present), select the appropriate emissions factor from Table 4.1.6. For example, for mines abandoned in the interval 1901 to 1925 and for the inventory reporting year 2005, the Emission Factor for these mines would have a value of 0.256 million m³ of methane per mine.
6. Calculate for each time band the total methane emissions from Equation 4.1.10 to the inventory year of interest.
7. Sum the emissions for each time interval to derive the total abandoned mine emissions for each inventory year.

TABLE 4.1.5 TIER 1 – ABANDONED UNDERGROUND MINES DEFAULT VALUES - PERCENTAGE OF COAL MINES THAT ARE GASSY		
Time Interval	Low	High
1900-1925	0%	10%
1926-1950	3%	50%
1950-1976	5%	75%
1976-2000	8%	100%
2001-Present	9%	100%

TABLE 4.1.6 TIER 1 – ABANDONED UNDERGROUND MINES EMISSION FACTOR, MILLION M³ METHANE / MINE					
	Interval of mine closure				
Inventory Year	1901 – 1925	1926 – 1950	1951 – 1975	1976 – 2000	2001 – Present
1990	0.281	0.343	0.478	1.561	NA
1991	0.279	0.340	0.469	1.334	NA
1992	0.277	0.336	0.461	1.183	NA
1993	0.275	0.333	0.453	1.072	NA
1994	0.273	0.330	0.446	0.988	NA
1995	0.272	0.327	0.439	0.921	NA
1996	0.270	0.324	0.432	0.865	NA
1997	0.268	0.322	0.425	0.818	NA
1998	0.267	0.319	0.419	0.778	NA
1999	0.265	0.316	0.413	0.743	NA
2000	0.264	0.314	0.408	0.713	NA
2001	0.262	0.311	0.402	0.686	5.735
2002	0.261	0.308	0.397	0.661	2.397
2003	0.259	0.306	0.392	0.639	1.762
2004	0.258	0.304	0.387	0.620	1.454
2005	0.256	0.301	0.382	0.601	1.265
2006	0.255	0.299	0.378	0.585	1.133
2007	0.253	0.297	0.373	0.569	1.035
2008	0.252	0.295	0.369	0.555	0.959
2009	0.251	0.293	0.365	0.542	0.896
2010	0.249	0.290	0.361	0.529	0.845
2011	0.248	0.288	0.357	0.518	0.801
2012	0.247	0.286	0.353	0.507	0.763
2013	0.246	0.284	0.350	0.496	0.730
2014	0.244	0.283	0.346	0.487	0.701
2015	0.243	0.281	0.343	0.478	0.675
2016	0.242	0.279	0.340	0.469	0.652

As abandoned underground mines are included for the first time an example calculation has been included in Table 4.1.7.

TABLE 4.1.7 TIER 1 – ABANDONED UNDERGROUND MINES EXAMPLE CALCULATION						
	Interval of mine closure					
	1901 – 1925	1926 – 1950	1951 – 1975	1976 – 2000	2001 – Present	Total for inventory year 2005
Number of mines closed per time band	20	15	10	5	1	
Fraction of gassy mines	0.1	0.5	0.75	1.0	1.0	
Emission factor for Inventory year, 2005 (from Table 4.1.6)	0.256	0.301	0.382	0.601	1.265	
Total emissions (Gg CH ₄ per year from Eqn 4.1.10)	0.34	1.51	1.92	2.07	0.85	6.64

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Tier 2 – Country- or Basin-Specific Approach

The Tier 2 approach for developing an abandoned mine methane emission inventory follows a similar approach to Tier 1, but it incorporates country- or basin-specific data. The methodology presented below is intended to utilize coal basin-specific or country-specific data wherever possible (for example, for active mine emissions prior to abandonment, for basin-specific parameters for emissions factors, etc.).

In some cases, default parameters have been provided for these values but these should be used only if country-specific or basin-specific data are not available.

Calculate emissions for a given inventory year using Equation 4.1.11:

EQUATION 4.1.11**TIER 2 APPROACH FOR ABANDONED UNDERGROUND MINES WITHOUT METHANE RECOVERY AND UTILIZATION**

$$\text{Methane Emissions} = \text{Number of Coal Mines Abandoned Remaining Unflooded} \bullet \text{Fraction of Gassy Mines} \bullet \text{Average Emissions Rate} \bullet \text{Emission Factor} \bullet \text{Conversion Factor}$$

Where units are:

Emissions of methane (Gg year⁻¹)

Emission Rate (m³ year⁻¹)

Emission Factor (dimensionless, see Equation 4.1.11)

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67•10⁻⁶ Gg m⁻³

If individual mines are known to be completely flooded, they may be assigned an emissions value of zero. Methane emissions reductions due to recovery projects that utilize or flare methane at abandoned mines should be subtracted from the emissions estimate. For either of these cases, it is recommended that a hybrid Tier 2 – Tier 3 approach be used to incorporate such mine-specific information (see the discussion of methane recovery and utilization projects from abandoned mines, Sections 4.1.5.1 and 4.1.5.3).

The basic steps in the Tier 2 approach for abandoned underground coal mines are as follows:

- Determine the approximate time interval(s) when significant numbers of gassy coal mines were closed. Multiple intervals may be used where appropriate. It is recommended that the number of gassy coal mines abandoned during each time interval be estimated using the smallest time intervals possible based on available data. Ideally, for more recent periods, time intervals will decrease (e.g., intervals of ten years prior to 1990; annual intervals since 1990).
- Estimate the total number of abandoned mines in each time interval selected remaining unflooded. If there is no available information on the flooded status of the abandoned mines, assume 100 percent remain unflooded.
- Determine the number (or percentage) of coal mines that would be considered gassy at the time of mine closure.
- For each time interval, determine the average emissions rate. If country or basin-specific data do not exist, low and high estimates for active mine emissions prior to abandonment can be selected from Table 4.1.8.
- For each time interval, calculate an appropriate emissions factor using Equation 4.1.12, based on the difference in years between the estimated data of abandonment and the year of the emissions inventory. Note that default values for this emissions factor equation are provided in Table 4.1.9, but these default values should be used only where country- or basin-specific information are not available.
- Calculate the emissions for each time interval using Equation 4.1.11.
- Sum the emissions for each time interval to derive the total abandoned mine emissions for each inventory year.

TABLE 4.1.8
TIER 2 – ABANDONED UNDERGROUND COAL MINES
DEFAULT VALUES FOR ACTIVE MINE EMISSIONS PRIOR TO ABANDONMENT

Parameter	Emissions, million m ³ /yr
Low	1.3
High	38.8

EQUATION 4.1.12**TIER 2 – ABANDONED UNDERGROUND COAL MINES EMISSION FACTOR**

$$\text{Emission Factor} = (1 + aT)^b$$

Where:

a and *b* are constants determining the decline curve. Country or basin-specific values should be used wherever possible. Default values are provided in Table 4.1.9, below.

T = years elapsed since abandonment (difference of the mid point of the time interval selected and the inventory year) and inventory year.

A separate emission factor must be calculated for each time interval selected. This emission factor is dimensionless.

TABLE 4.1.9		
COEFFICIENTS FOR TIER 2 – ABANDONED UNDERGROUND COAL MINES		
Coal Rank	A	b
Anthracite	1.72	-0.58
Bituminous	3.72	-0.42
Sub-bituminous	0.27	-1.00

Tier 3-Mine-Specific Approach

Tier 3 provides a great deal of flexibility. Directly measured emissions, where available, can be used in place of estimates and calculations. Models may be used in conjunction with measured data to estimate time series emissions. Each country may generate their own decline curves or other characterizations based on measurements, known basin-specific coal properties, and/or hydrological models. Equation 4.1.13 describes one possible approach.

EQUATION 4.1.13**EXAMPLE OF TIER 3 EMISSIONS CALCULATION – ABANDONED UNDERGROUND MINES**

$$\text{Methane Emissions} = (\text{Emission rate at closure} \bullet \text{Emission Factor} \bullet \text{Conversion Factor}) - \text{Methane Emissions Reductions from Recovery and Utilisation}$$

Where units are:

Methane Emissions (Gg year⁻¹)

Emission rate at Closure (m³ year⁻¹)

Emission Factor (dimensionless, see Franklin *et al.*, 2004)

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67 • 10⁻⁶ Gg m⁻³.

The basic steps in the Tier 3 methodology involve the following:

- Determine a database of mine closures with relevant geological and hydrological information and the approximate abandonment dates (when all active mine ventilation ceased) consistently for all mines in the country's inventory.
- Estimate emissions based on measured emissions and/or an emissions model. This may be based on the average emission rate at time of mine closure, determined by the last measured emission rate (or preferably, an average of several measurements taken the year prior to abandonment), or estimated methane reserves susceptible to release.
- If actual measurements have not been taken at a given mine, emissions may be calculated using an appropriate decline curve or modelling approach for openly vented mines, sealed mines, or flooded mines. Use the selected decline equation or modelling approach for the mine and the number of years between abandonment and the inventory year to calculate emissions or an appropriate emission factor for each mine.
- Sum abandoned mine emissions to develop an annual inventory.

4.1.5.3 CHOICE OF ACTIVITY DATA

Estimating emissions from abandoned mines requires historical data, rather than current activity data. For Tier 1, country experts should estimate the number of mines abandoned by time interval in Table 4.1.5, on the basis of historical data available from appropriate national international agencies or regional experts.

For Tier 2, the total number of abandoned mines and the time period of their abandonment are required. These data may be obtained from appropriate national, state, or provincial agencies, or companies active in the coal industry. If a country consists of more than one coal region or basin, production and emissions data may be disaggregated by region. Expert judgment and statistical analysis may be used to estimate ventilation emissions or specific emissions based on measurements from a limited number of mines (see Franklin et al (2004)).

For Tier 3, abandoned coal mine emissions estimates should be based on detailed data about the characteristics, data of abandonment and geographical location of individual mines. In the absence of direct measurements of the abandoned mine, Tier 3 emissions factors may be based on mine-specific emissions data, including historical emissions data from degasification and ventilation systems when the mine(s) were active (see Franklin et al, 2004).

EMISSIONS REDUCTIONS FROM METHANE RECOVERY AT ABANDONED MINES

Abandoned mines where recovery and utilisation or flaring of abandoned mine methane is taking place should be accounted for by comparing the amount of methane recovered and utilized with the amount expected to have been emitted naturally. The method for accounting for methane recovered from abandoned coal mines is described in Section 4.1.5.1.

The CO₂ emissions produced from combustion of methane from abandoned mine recovery and utilization projects should be included in the energy sector estimates where there is utilisation, or under fugitive abandoned mine emissions where there is flaring. To make this estimate, abandoned mine methane project recovery or production data may be publicly available through appropriate government agencies depending on the end use. This information may be in the form of metered gas sales and is often publicly available in oil and gas industry or governmental databases. An additional 3 to 8 percent of undocumented abandoned mine methane is typically recovered and used as fuel for compression of the gas. The actual percentage of methane used will depend on the efficiency of the compression equipment. The emissions from this energy use should be reported under Volume 2, Chapter 2 'Stationary Combustion'. For projects that use recovered methane from abandoned mines for electricity generation, metered flow rates and compression factors, if available, can be used. If public data accurately reflect electricity produced, then the heat rate or efficiency of the electricity generator can be used to determine its fuel consumption rate.

4.1.5.4 COMPLETENESS

The emissions estimates from abandoned underground mines should include all emissions leaking from the abandoned mines. Until recently, there were no methods by which these emissions could be estimated. *Good practice* is to record the date of mine closure and the method of sealing. Data on the size and depth of such mines would be useful for any subsequent estimation.

4.1.5.5 DEVELOPING A CONSISTENT TIME SERIES

It is unlikely that comprehensive mine-by-mine (Tier 3) data will be available for all years. Therefore, in order to prepare hybrid Tier 2 – Tier 3 inventories, as well as Tier 1 or Tier 2 inventories, the number of abandoned mines may need to be estimated for years for which there are sparse data.

These inventory guidelines recommend that methane emissions associated with abandoned mines should be accounted for in the inventory year in which the emissions and recovery operations occur.

For situations where the emissions of greenhouse gases from active underground mines have been well characterized and the mines have passed from being considered 'active' to 'abandoned', data from the active mine emissions (during the year in which the mine was closed) should be collected. Great care should be taken in transferring mines from the active to the abandoned inventory so that no double-counting or omissions occur.

4.1.5.6 UNCERTAINTY ASSESSMENT

TIER 1

The primary causes of the uncertainty related to the Tier 1 methodology include the following:

• *The global nature of the emission factors.* The range of uncertainty of these emission factors is intentionally large to account for the uncertainty in the determining parameters such as mine size, mine depth, and coal rank.

• *Time of abandonment.* Because emissions from abandoned mines are strongly time dependent, selecting a single interval that best represents the dates of closure for all mines is critical in establishing an emissions rate.

• *The activity data.* Both the number of gassy abandoned mines and the amount of coal that has been produced from gassy mines are strongly country-dependent. The uncertainty will be defined by the availability of historic mining and production records.

The total estimated range of uncertainty associated with Tier 1 estimations will depend on each of the factors discussed above. Actual emissions are likely to be in the range of one-third to three times the estimated emissions value.

TIER 2

The primary causes of uncertainty related to the Tier 2 approaches include the following:

• *The country- or basin-specific emission factors.* Uncertainty is associated with the emission factor decline equations for each coal rank. This uncertainty is a function of the inherent variability of gas content, adsorption characteristics, and permeability within a given coal rank.

• The number of mines producing a given coal rank.

• The number of mines abandoned through time.

• The percentage of gassy mines as a function of time.

The total estimated uncertainty associated with Tier 2 estimations depends on the range of uncertainty associated with each of these factors. These parameters should be more narrowly defined than for Tier 1. Thus, total actual emissions are likely to be in the range of one-half to twice the estimated value.

TIER 3

The primary uncertainties associated with emissions inventories generated using the Tier 3 methodology include the following:

• Active mine emission rate

• Decline curve equation or modelling approach that describes the function relating adsorption characteristics and gas content of the coal, mine size, and coal permeability

• Hydrological status of the abandoned mine (flooded or flooding) and condition (sealed or vented).

The Tier 3 methodology has lower associated uncertainty than Tiers 1 and 2 because the emissions inventory is based either on direct measurements or on mine-specific information including active emission rates and mine closure dates. Although the range of uncertainty associated with estimated emissions from an individual mine may be large (in the ± 50 percent range), summing the uncertainty range of a sufficient number of individual mine emissions actually reduces the range of uncertainty of the final inventory, per the central limits theorem (Murtha, 2002), provided the uncertainties are independent. Given the expected range of the number of abandoned coal mines across different countries, the overall uncertainty associated with Tier 3 methodology for abandoned mines may vary from ± 20 percent for countries with a large number of abandoned mines to ± 30 percent for a country with a fewer number of abandoned mines whose emissions are included in the inventory.

A combination of different Tiers may be used. For example, the emissions from mines abandoned during the first half of the twentieth century may be determined using a Tier 1 method, while emissions from mines abandoned after 1950 may be determined using a Tier 2 method. The Tier 1 and Tier 2 methods will each have their own uncertainty distribution. It is important to properly sum these distributions in order to arrive at the appropriate range of uncertainty for the final emissions inventory.

4.1.6 Coal Exploration

4.1.6.1 CHOICE OF METHOD

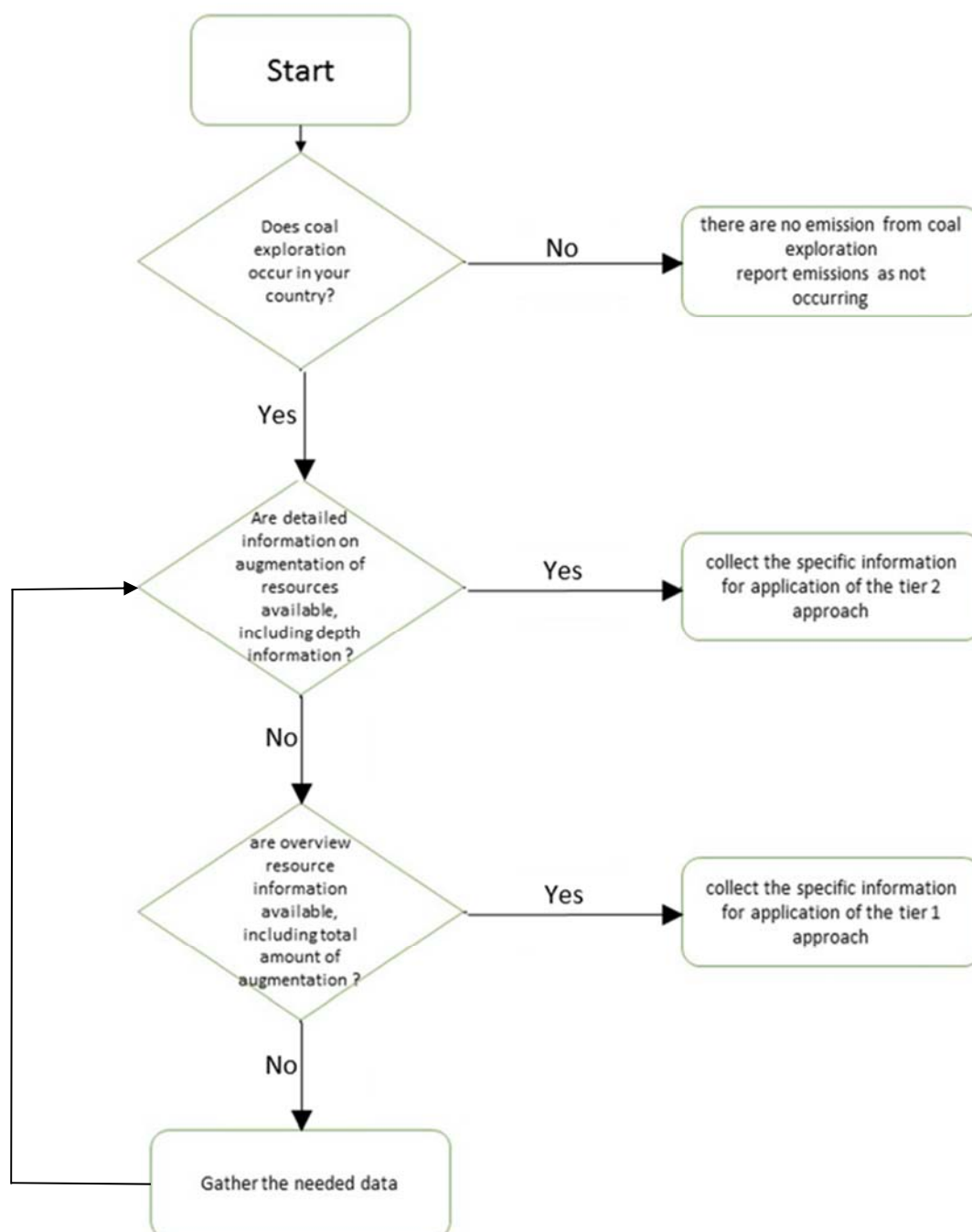
Fugitive methane emissions from exploration boreholes in a coalfield are a function of the gas content, cumulative thickness of the coal seams encountered during exploratory drilling, as well as geological discontinuity, if any, near the borehole. This information is not readily available in exploration reports or any other publication.

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However, annual updating of the national quantity of coal and lignite resources is an integral part of exploration for these minerals. Therefore, augmentation of coal resources in a reporting year over that of the preceding year can be easily estimated by subtracting the resources of the current year from that of the preceding year. This annual change, or augmentation may be used as activity data for exploration boreholes.

The augmentation of coal resources is the additional resource of coal found as a result of exploration during a reporting year which, when added to the previous year's resource, gives current resource. Further, the augmentation of coal or lignite resource is linked to the drilling performed in a year and hence to the number of exploration boreholes drilled.

Figure 4.1.4 Decision tree for coal exploration



4.1.6.2 CHOICE OF EMISSION FACTORS

No results are available in the literature on measurement of fugitive methane emission specifically from coal exploration boreholes. Therefore emission factors provided below are as per expert opinion. Since the exploration boreholes are filled with water or mud, the hydrostatic pressure on the coal seams encountered will be significant. Accordingly, emission factors for exploration boreholes are assumed to be small compared to those of other coal mining activities.

Tier 1 – Global Average Approach – Fugitive Emission from Coal Exploration Boreholes

For a Tier 1 approach the exploratory borehole emissions factors are shown below together with the estimation method:

EQUATION 4.1.14
TIER 1: GLOBAL AVERAGE METHOD - - FUGITIVE EMISSION FROM COAL
EXPLORATION BOREHOLES

$$\text{Methane emissions} = \text{CH}_4 \text{ Emission Factor} \bullet \text{Augmentation of Resource} \bullet \text{Conversion Factor}$$

Where units are:

Methane Emissions (Gg year⁻¹)

CH₄ Emission Factor (m³ tonne⁻¹)

Augmentation of Resource (tonne year⁻¹)

Emission Factor:

Low CH₄ Emission Factor = 0.005 m³ tonne⁻¹

Average CH₄ Emission Factor = 0.01 m³ tonne⁻¹

High CH₄ Emission Factor = 0.02 m³ tonne⁻¹

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67•10⁻⁶ Gg m⁻³.

Tier 2 – Depth-wise Approach

For a Tier 2 approach the exploratory borehole emissions factors are shown below together with the estimation method:

EQUATION 4.1.15
TIER 2: DEPTH-WISE METHOD

$$\begin{aligned} \text{Methane emissions from a coal seam at a depth} &= \text{CH}_4 \text{ Emission Factor for the depth} \bullet \\ &\text{Augmentation of Resource for the depth} \bullet \text{Conversion Factor} \\ \text{Methane Emission from Exploration} &= \Sigma \text{Methane Emission from coal seams at different depths} \end{aligned}$$

Where units are:

Methane Emissions (Gg year⁻¹)

CH₄ Emission Factor (m³ tonne⁻¹)

Augmentation of Resource (tonne year⁻¹)

Emission Factor:

CH₄ Emission Factor = 0.005 m³ tonne⁻¹ for depth range 0 – 300m

CH₄ Emission Factor = 0.01 m³ tonne⁻¹ for depth range 300 – 600m

CH₄ Emission Factor = 0.03 m³ tonne⁻¹ for depth range 600 – 1200m

CH₄ Emission Factor = 0.05 m³ tonne⁻¹ for depth > 1200 m

Conversion Factor:

This is the density of CH₄ and converts volume of CH₄ to mass of CH₄. The density is taken at 20°C and 1 atmosphere pressure and has a value of 0.67•10⁻⁶ Gg m⁻³.

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Tier 3 – Borehole Specific Approach

Coal exploration companies often determine in-situ gas content and other desorption characteristics such as sorption time of coal seams encountered during exploratory drilling of boreholes. Release of gas from a coal seam is highly dependent on these parameters. Models are also available to calculate emissions if the gas desorption parameters are available. A Tier 3 approach can be developed if gas desorption parameters are available.

4.1.6.3 CHOICE OF ACTIVITY DATA

Augmentation of resources or new addition of resources in the year may be used as activity data, which may be available in the inventory of coal or lignite resources or can be easily obtained by subtracting the resources for a year and the resources for the previous year as follows:

Augmentation or New Addition = Resource for a year – Resource for the previous year

The above activity data may be used for Tier 1 estimates. A precise value for activity data may be available for net increase of depth-wise resource. Often coal resources are reported in the depth ranges such as 0-300m, 300-600m and 600-1200m. Since gas content of coal seams generally increases with depth, emission from deeper seams will be higher compared to the seams at shallow depths. These values of activity data may correspond to Tier 2 estimates.

4.1.6.4 COMPLETENESS

Exploration for coal is generally carried out in two broad categories, often called as Regional and Detailed Exploration. During regional exploration, coal resources of inferred or indicated categories using data obtained from boreholes few kilometres apart (typically 2 to 4 km) are estimated. Detailed exploration is carried out to arrive at measured or proved resource using data from boreholes normally drilled less than a kilometre apart (typically 400 m). The number and distribution of boreholes during detailed exploration are sufficient to allow a realistic estimate of average coal thickness, areal extent, depth range, quality and mineable reserve of coal. The estimate of fugitive methane emission from coal exploration boreholes should include all emissions from the following:

- Gas released from boreholes during regional exploration
- Emission of gas from boreholes during detailed exploration

4.1.6.5 DEVELOPING A CONSISTENT TIME SERIES

Time series consistency should be maintained in a manner consistent with guidance set out in Volume 1, Chapter 5.

A complete borehole specific data may not be available for the base year and also for the succeeding years. It may be imperative, therefore, to prepare a combination of Tier 1, Tier 2 and Tier 3 estimates.

Tier 1 (Global Average Method) emission factor should be appropriately selected for a specific basin. The gassiness of a basin should be ascertained on the basis of gas potential of a nearby operating mine or a neighbouring CBM field and the suitable emission factor (low, average or high) should be applied.

If Tier 2 or Tier 3 methods are used for exploration boreholes for certain inventory years, emissions should be scaled-up or scaled-down for the remaining years using an appropriate value (low, average or high) of Tier 1 emission factor.

4.1.6.6 UNCERTAINTY ASSESSMENT

ACTIVITY DATA UNCERTAINTIES

The activity data of resource augmentation in Tier 1 and Tier 2 methods is reasonably accurately known (± 2 percent). However, there may be uncertainties on account of extrapolation techniques used for estimation of inferred and indicated categories of coal resources. Thus, combining the errors in estimation of different category of resources (such as proved, inferred and indicated), the activity data of resource augmentation may have an uncertainty of ± 10 percent. In borehole specific approach (Tier 3 method), where number of boreholes, number of coal seams encountered, their thicknesses and *in-situ* gas content etc. are known, uncertainty be in the range of $\pm 1 - 2$ percent.

EMISSION FACTOR UNCERTAINTIES

Uncertainties in Tier 1 approach mainly arise because of use of global emission factors. There may be some intrinsic uncertainties in the emission factors as well. A combination of the above two types of sources, the uncertainties in Tier 1 approach may be greater or smaller by a factor of 2.

Tier 2 estimates may also have liability to vary due to inherent uncertainties associated with basin level characteristics. Uncertainties in Tier 2 approach may be ± 50 -75%.

Coal characteristics, *in-situ* gas content and other gas desorption parameters are often determined for a selected number of exploration boreholes. These parameters vary considerably in lateral directions in an exploration field. Tier 3 estimates may be accurate to ± 30 percent depending on number of boreholes tested for gas desorption parameters.

4.1.7 Completeness for coal mining

These are abandoned surface mines and uncontrolled combustion.

ABANDONED SURFACE MINES

After closure, emissions from abandoned surface mines may include the following:

- The standing highwall
- Leakage from the pit floor
- Low temperature oxidation
- Uncontrolled combustion

At present, no comprehensive methods to quantify these emissions have been developed and therefore they have not been included in these guidelines. They remain subjects for further research.

EMISSIONS FROM UNCONTROLLED COMBUSTION AND BURNING COAL DEPOSITS

While emissions from this source may be significant for an individual coal mine, it is unclear as to how significant these emissions may be for an individual country. In some countries where such fires are widespread, the emissions may be very significant. There are no clear methods available at present to systematically measure or precisely estimate the activity data, though where countries have data on amounts of coal burned, the CO₂ should be estimated on the basis of the carbon content of the coal and reported in the relevant subcategory of 1.B.1.b. It is noted that uncontrolled combustion only due to coal exploration activities is considered here. Care should be taken to avoid double counting with fugitive CH₄ and low oxidation CO₂ emissions.

4.1.8 Inventory Quality Assurance/Quality Control (QA/QC)

4.1.8.1 QUALITY CONTROL AND DOCUMENTATION

EMISSION FACTORS

• Quality control

- a) Tier 1: reviewing the national circumstances and documenting the rationale for selecting specific values.
- b) Tier 2: checking the equations and calculations used to determine the emissions factor, and ensuring that sampling follows consistent protocols so that conditions are representative and uniform
- c) Tier 3: working with mine operators to ensure the quality of data from degasification systems. Individual operating mines should already have in place QA/QC procedures for monitoring ventilation emissions.

• Documentation

Provide transparent information on the steps to calculate emissions factors or measure emissions, including the numbers and the sources of any data collected.

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ACTIVITY DATA

• Quality control

Describe activity data collection methods, including an assessment of areas requiring improvement.

• Documentation

a) Comprehensive description of the methods used to collect the activity data

b) Discussion of potential areas of bias in the data, including a discussion of whether the characteristics are representative of the country

INVENTORY COMPILER REVIEW (QA)

The inventory compiler should ensure that suitable methodologies are used to calculate emissions from coal mining, including use of the highest applicable Tier for a given country, taking into account what are considered *key category* for that country as well as the availability of data. The inventory compiler should ensure that appropriate emission factors are used. For active underground and surface mines, the best available activity data should be used in accordance with the appropriate Tiers, especially the amount of methane recovered and utilized wherever possible. For abandoned mines, the compiler should ensure the most accurate available historical information is used.

INVENTORY COMPILER QC ON COMPILING NATIONAL EMISSIONS

Methods the inventory compiler can employ to provide quality control for the national inventory may include, for example:

- Back-calculating national and regional emission factors from Tier 3 measurement data, where applicable
- Ensuring that emission factors are representative of the country (for Tier 1 and Tier 2)
- Ensuring that all mines are included
- Comparing with national trends to look for anomalies

EXTERNAL INVENTORY QUALITY ASSURANCE (QA/QC) SYSTEMS

The inventory compiler should arrange for an independent, objective review of calculations, assumptions, and/or documentation of the emissions inventory to be performed to assess the effectiveness of the QC programme. The peer review should be performed by expert(s) who are familiar with the source category and who understand inventory requirements.

4.1.8.2 REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Chapter of the *2006 IPCC Guidelines*.

The national inventory report should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced. However, to ensure transparency, the following information should be supplied:

- Emissions by underground, surface, and post-mining components of CH₄ and CO₂ (where appropriate), the method used for each of the sub-source categories, the number of active mines in each sub-source category and the reasons for the chosen emission factors (e.g. depth of mining, data on *in situ* gas contents etc.). The amount of drained gas and the degree of any mitigation or utilisation should be presented with a description of the technology used, where appropriate.
- Activity data: Specify the amount and type of production, underground and surface coal, listing raw and saleable amounts where available.
- Where issues of confidentiality arise, the name of the mine need not be disclosed. Most countries will have more than three mines, so mine-specific production cannot be back calculated from the emission estimates.

It is important to ensure that in the transition of mines from 'active' to 'abandoned' each mine is included once and only once in the national inventory.

4.2 FUGITIVE EMISSIONS FROM OIL AND NATURAL GAS SYSTEMS

UPDATED TO REFLECT INCLUSION OF TOWN GAS AND BIOGAS, PROVIDE CLARIFICATION ON COALBED METHANE AND ON SYSTEM BOUNDARY (I.E. INCLUDES LEAKS FROM APPLIANCES)

This section is an update of Section 4.2 in Vol.2 of the *2006 IPCC Guidelines*. Fugitive emissions from oil and natural gas systems are accounted for in IPCC subcategory 1.B.2 of the energy sector. For reporting purposes, this category is subdivided as shown in Figure 4.2.1. The main distinction is made between oil and natural gas systems, with each being subdivided into the different parts (or segments) of the oil or gas system according to the type of activity.² Fuel gases other than natural gas, such as town gas³ and biogas, are often handled in natural gas systems (such as transmission and distribution systems), and are discussed here as well. Where coalbed methane is produced into a natural gas gathering system, any associated fugitive emissions should be reported under the appropriate natural gas exploration and production categories.

The term fugitive emissions is broadly applied here to mean all greenhouse gas emissions from oil and gas systems except contributions from fuel combustion. Fugitive emissions include vented emissions, leak emissions, and flaring emissions. Oil and natural gas systems comprise all infrastructure required to produce, collect, process or refine and deliver natural gas and petroleum products to market. The system begins at the wellhead, or oil and gas source, and ends at the consumer (including fugitive emissions from appliances). Emissions excluded from this category are as follows:

- Fuel combustion for the production of useful heat or energy by stationary or mobile sources (see Chapters 2 and 3 of the Energy Volume).
- Fugitive emissions from carbon capture and storage projects, the transport and disposal of acid gas from oil and gas facilities by injection into secure underground formations, or the transport, injection and sequestering of CO₂ as part of enhanced oil recovery (EOR), enhanced gas recovery (EGR) or enhanced coal bed methane (ECBM) projects (see Chapter 5 of the Energy Volume on carbon dioxide capture and storage systems). Note that fugitive emissions from the oil and gas production portions of EOR, EGR and ECBM projects are part of Category 1.B.2.
- Fugitive emissions that occur at industrial facilities other than oil and gas facilities (see the Industrial Processes and Product Use Volume).
- Fugitive emissions from waste disposal activities that occur outside the oil and gas industry (see the Waste Volume).
- Where a coal formation is degassed for the purposes of coal exploration or coal mining and handling, the associated emissions should be allocated to the coal sector under the appropriate section of IPCC category 1.B.1.

When determining fugitive emissions from oil and natural gas systems it may be necessary to apply greater disaggregation than is shown in Figure 4.2.1 to better account for local factors affecting the amount of emissions (i.e., reservoir conditions, processing/treatment requirements, design and operating practices, age of the industry, market access, regulatory requirements and the level of regulatory enforcement), and to account for changes in activity levels in progressing through the different parts of the system. The percentage contribution by each category in Figure 4.2.1 to total fugitive emissions by the oil and gas sector will vary according to a country's circumstances and the amount of oil and gas imported and exported. Some examples of the potential distribution of fugitive emissions by subcategory are provided in the API (2009) Compendium.

² Definitions for oil wells versus gas wells can vary from country to country and organization to organization. Guidance for making this distinction when applying tier 1 factors is available in section 4.2.2.3 below.

³ Town gas (also called coal gas) is a manufactured gaseous fuel produced for sale to commercial and residential consumers. Town gas contains hydrogen (around 50%), carbon monoxide (around 10%), methane (around 35%) and volatile hydrocarbons (around 5%) together with carbon dioxide and nitrogen (each less than 1%). It was used in Europa until the end of the last millennium and is still used in China (<http://www.hks.harvard.edu/m-rcbg/heep/papers/HEEP%20Discussion%2012.pdf>).

4.2.1 Overview, description of sources

UPDATED TO REFLECT UPDATED PRACTICES, INCLUDING TWO UPDATED FIGURES

The sources of fugitive emissions on oil and gas systems include, but are not limited to, equipment leaks, evaporation and flashing losses, venting, flaring, incineration and accidental releases (e.g., pipeline dig-ins, well blow-outs and spills). Venting and flaring emission sources are engineered or intentional (e.g., vents from tanks, seal and process vents and flare systems), while leak emissions (e.g. working losses from tanks, and leaks from other equipment) are unintentional (or uncontrolled). Some emissions are relatively well-characterized, with use of measurement systems in certain cases, where losses or flows are tracked as part of routine production accounting procedures, or where engineering estimates are made. Uncertainties associated with such estimates include those due to an inability to cover the wide range of flows and variations in composition that may occur, and inconsistencies in the activities that are included. A lack of data on activities and practices in place in a country can also contribute to uncertainty. Throughout this chapter, an effort is made to state the precise type of fugitive emission source being discussed, and to only use the term fugitive emissions or fugitive emission sources when discussing these emissions or sources at a higher, more aggregated, level.

Streams containing pure or high concentrations of CO₂ may occur at oil production facilities where CO₂ is being injected into an oil reservoir for EOR, ECBM or EGR. They may also occur at gas processing, oil refining and heavy oil upgrading facilities as a by-product of gas treating to meet sales or fuel gas specifications, and at refineries and heavy oil upgraders as a by-product of hydrogen production. Where CO₂ occurs as a process by-product it is usually vented to the atmosphere, injected into a suitable underground formation for disposal or supplied for use in EOR projects. Fugitive CO₂ emissions from these streams should be accounted for under the appropriate subcategories of 1.B.2. Fugitive CO₂ emissions from CO₂ capture should be accounted for in the industry where capture occurs, while the fugitive CO₂ emissions from transport, injection and storage activities shall be accounted for separately in category 1.C (refer to Chapter 5).

EOR is the recovery of oil from a reservoir by means other than using the natural reservoir pressure. It can begin after a secondary recovery process or at any time during the productive life of an oil reservoir. EOR generally results in increased amounts of oil being removed from a reservoir in comparison to methods using natural pressure or pumping alone. The three major types of enhanced oil recovery operations are chemical flooding (alkaline flooding or micellar-polymer flooding), miscible displacement (CO₂ injection or hydrocarbon injection), and thermal recovery (steamflood or *in-situ* combustion).

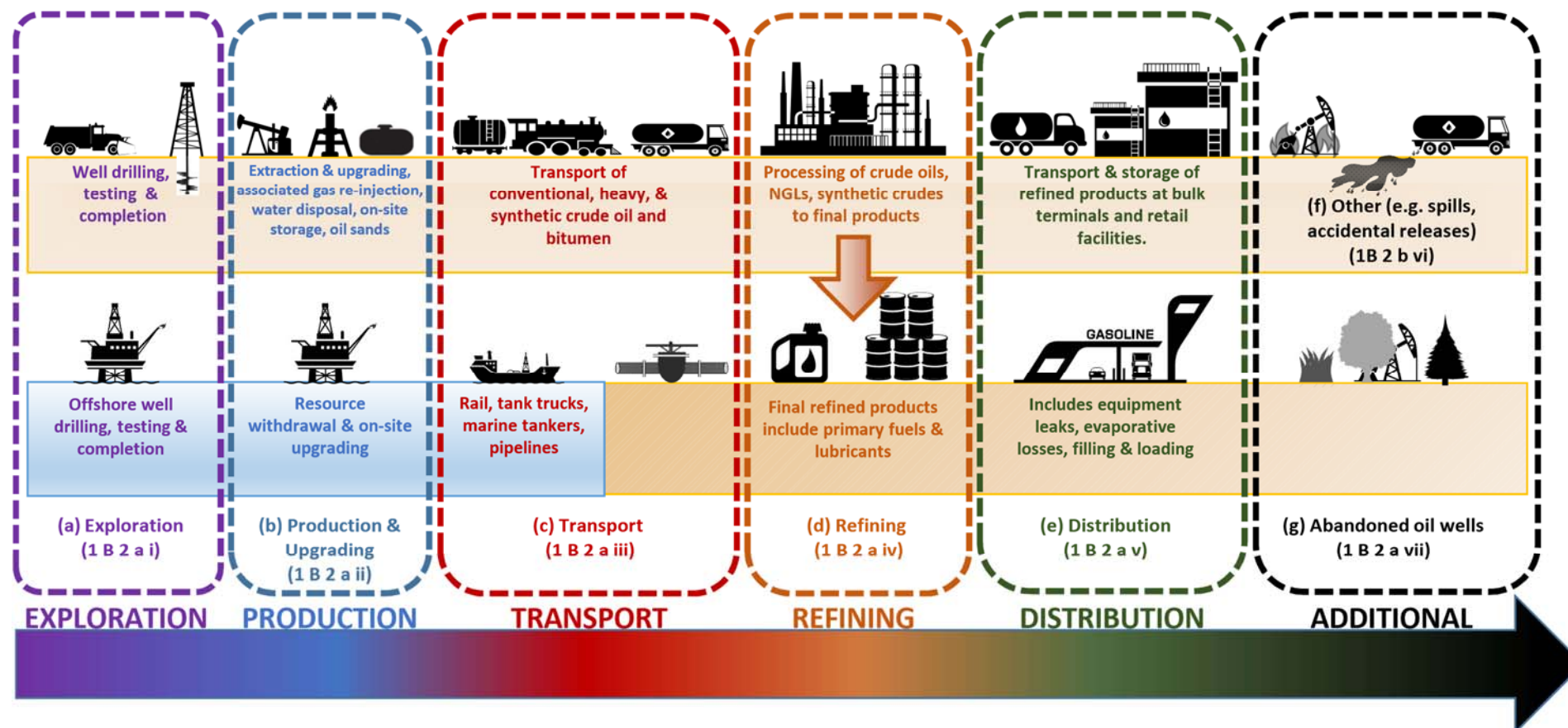
Emissions from oil and gas exploration are disaggregated to reflect that unconventional completions (e.g., conducted with hydraulic fracturing⁴) have a different emissions profile than conventional completions (e.g. conducted without hydraulic fracturing). Conventional reservoirs are those in which hydrocarbons are sealed below a capstone and from which hydrocarbons readily flow due to natural buoyant forces. Unconventional reservoirs, such as shale and tight gas, are those for which their characteristics (e.g. porosity, permeability) differ from conventional reservoirs. In the case of unconventional resources, additional techniques, such as hydraulic fracturing, are required to stimulate the release and flow of oil and gas from low-permeability unconventional formations such as shale. Different hydraulic fracturing practices can greatly impact emissions levels. For example, hydraulic fracturing completions with flaring or reduced emissions completions (REC) technologies will have lower emissions than completions without those practices. In this chapter, unconventional exploration refers to exploration that includes well completions with hydraulic fracturing and conventional exploration refers to exploration that does not include well completions with hydraulic fracturing.

⁴ There are potential other types of unconventional exploration (e.g. hydrates) but currently hydraulic fracturing is the most common type of unconventional exploration. Emission factors for unconventional exploration were developed from data from hydraulic fracturing.

Figure 4.2.1 Key segments included in natural gas and petroleum systems

For a detailed description of each segment, please see Section 4.2.2.3, Choice of Emission Factors, below.

Segments included in Oil Systems (1 B 2 a)

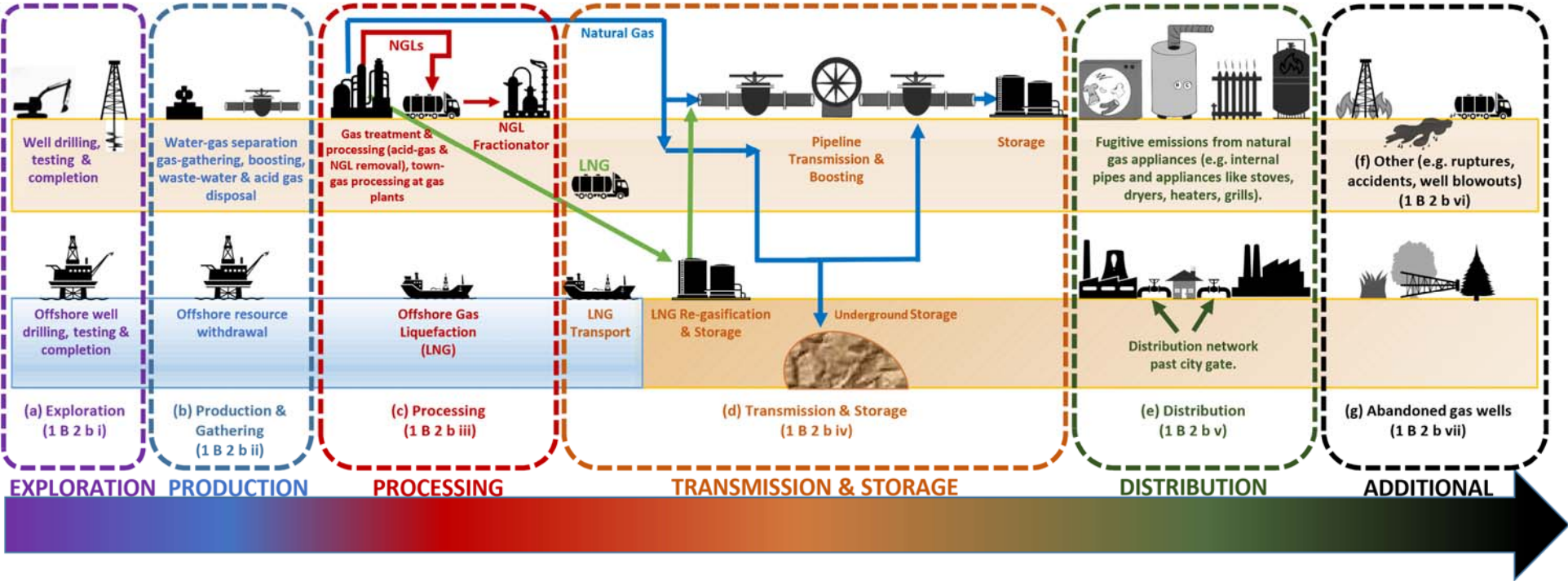


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Figure 4.2.1(Continued) Key segments included in natural gas and petroleum systems

For a detailed description of each segment, please see Section 4.2.2.3, Choice of Emission Factors, below.

Segments included in Natural Gas Systems (1 B 2 b)



4.2.2 Methodological issues

MINOR UPDATES TO CLARIFY THAT FUGITIVES INCLUDES VENTING, FLARING, AND LEAKS

Fugitive emissions are a direct source of greenhouse gases due to the release of methane (CH₄) and formation carbon dioxide (CO₂) (i.e., CO₂ present in the produced oil and gas when it leaves the reservoir), plus some CO₂ of and nitrous oxide (N₂O) from non-productive combustion activities (primarily waste gas flaring). In this chapter, fugitive emissions include emissions from venting, flaring, and leaks.

Venting comprises all engineered or intentional discharges of waste gas streams and process by-products to the atmosphere, including emergency discharges. These releases may occur on either a continuous or intermittent basis, and may include the following:

- Use of pressurized natural gas instead of compressed air as the supply medium for pneumatic devices (e.g., chemical injection pumps, starter motors on compressor engines and instrument control loops).
- Pressure relief and disposal of off-specification product during process upsets.
- Purging and blowdown events related to maintenance and tie-in activities.
- Disposal of off-gas streams from oil and gas treatment units (e.g., still-column off-gas from glycol dehydrators, emulsion treater overheads and stabilizer overheads).
- Gas releases from drilling, well-testing and pipeline pigging activities.
- Disposal of waste associated gas at oil production facilities and casing-head gas at heavy oil wells where there is no gas conservation, re-injection, or flaring.
- Solution gas emissions from storage tanks, evaporation losses from process sewers, API separators, dissolved air flotation units, tailings ponds and storage tanks, and biogenic gas formation from tailings ponds.
- Discharge of CO₂ extracted from the produced natural gas or produced as a process byproduct.

Some or all of the vented gas may be captured for storage or utilization. In this instance, the inventory of vented emissions should include only the net emissions to the atmosphere.

Flaring means broadly all burning of waste natural gas and hydrocarbon liquids by flares or incinerators as a disposal option rather than for the production of useful heat or energy. The decision on whether to vent or flare depends largely on the amount and energy content of gas to be disposed of and the specific circumstances (e.g., public, environmental and safety issues as well as local regulatory requirements). Normally, waste gas is only vented if it is non-odorous and non-toxic, and even then may often be flared. Flaring is most common at production, processing, upgrading and refining facilities but may occur in other segments as well. Waste gas volumes are usually vented on gas transmission systems and may be vented on gas distribution systems, depending on the circumstances and the company's policies. Sometimes fuel gas may be used to enrich a waste gas stream so it will support stable combustion during flaring. Fuel gas may also be used for other purposes where it may ultimately be vented or flared, such as purge or blanket gas and supply gas for gas-operated devices (e.g., for instrument controllers). The emissions from these types of fuel uses should be reported under the appropriate venting and flaring subcategories rather than under Category 1.A (Fuel Combustion Activities).

Formation CO₂ removed from natural gas by the sweetening units at gas processing plants and released to the atmosphere is a fugitive emission and should be reported under subcategory 1.B.2.b.iii The CO₂ resulting from the production of hydrogen at refineries and heavy oil/bitumen upgraders should be reported under subcategory 1.B.2.a.iv Care should be taken to ensure that the feedstock for the hydrogen plant is not also reported as fuel in these cases.

Leak emissions occur in all segments of the oil and natural gas systems and consist of unintentional (i.e., not vented or flared) emissions from equipment components such as valves, connectors, open ended lines, and flanges.

Fugitive emissions from oil and natural gas systems are often difficult to quantify accurately. This is largely due to the diversity of the industry, the large number and variety of potential emission sources, the wide variations in emission-control levels and the limited availability of emission-source data. The main emission assessment issues are:

- The use of simple production-based emission factors introduces large uncertainty;
- The application of rigorous bottom-up approaches requires expert knowledge and detailed data that may be difficult and costly to obtain;

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- Measurement programmes are time consuming and very costly to perform.
- Certain emissions, such as those from tanks, can be difficult to access for measurement.

It is *good practice* to involve technical representatives from the industry and others with expert knowledge in the development of the inventory for the use of technology- or practice-specific Tier 1 emission factors and/or for input on Tier 2 or 3 approaches.

4.2.2.1 CHOICE OF METHOD, DECISION TREES, TIERS

MINOR UPDATES TO IMPROVE CONSISTENCY BETWEEN SECTIONS

There are three methodological tiers for determining fugitive emissions from oil and natural gas systems, as set out in Section 4.2.2.2. It is *good practice* to disaggregate the activities into the segments in the Oil and Gas Industry (see Figure 4.2.1 in Section 4.2.1), and then evaluate the emissions separately for each of these. The methodological tier applied to each segment should be commensurate with the amount of emissions and the available resources. Consequently, it may be appropriate to apply different methodological tiers to different segments and sub-segments, and possibly even include actual emission measurement or monitoring results for some larger sources. The overall approach, over time, should be one of progressive refinement to address the areas of greatest uncertainty and consequence, and to capture the impact of control measures.

Figure 4.2.2 provides a general decision tree for selecting an appropriate approach for a given segment of the natural gas industry. The decision tree is intended to be applied successively to each segment within the natural gas system (e.g., gas exploration, gas production, then gas processing, then gas transmission, then gas storage, then LNG, then gas distribution, then other). Similarly, Figures 4.2.3 and 4.2.4 apply to crude oil production and transport systems, and to oil upgraders and refineries, respectively. Figure 4.2.5 applies to abandoned wells for both oil and natural gas.

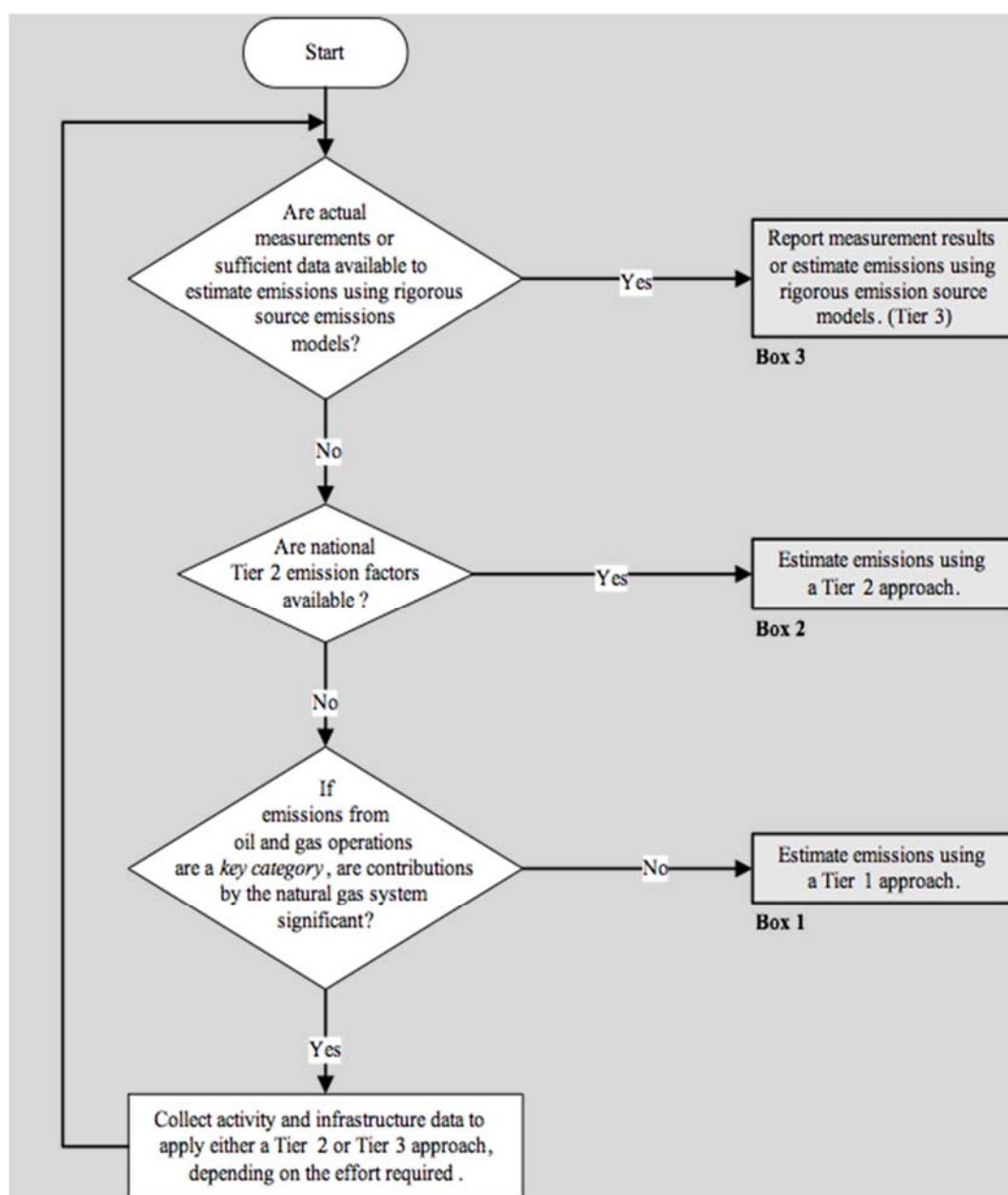
The basic decision process is as follows:

- check if the detailed data needed to apply a Tier 3 approach are readily available, and if so, then apply a Tier 3 approach (i.e., regardless of whether the category is key and the segment is significant), otherwise, if these data are not readily available:
- check if the detailed data needed to apply a Tier 2 approach are readily available, and if so, then apply a Tier 2 approach, otherwise, if these data are not readily available:
- check to see if the category is key and the specific segment being considered is significant based on the IPCC definitions of key and significant, and if so, go back and gather the data needed to apply a Tier 3 or Tier 2 approach, otherwise, if the segment is not significant:
- apply a Tier 1 approach.

The ability to use a Tier 3 approach will depend on the availability of detailed production statistics and infrastructure data (e.g., information regarding the numbers and types of facilities and the amount and type of equipment used at each site), and it may not be possible or appropriate to apply it under all circumstances. As noted above, oil and gas systems can show significant variability across regions and over time. Compilers should make efforts to ensure that emission factors are nationally and temporally appropriate. A Tier 1 approach is the simplest method to apply but is susceptible to substantial uncertainties and may easily be in error by an order-of-magnitude or more. For this reason, it should only be used as a last resort option. Where a Tier 3 approach is used in one year and the results are used to develop Tier 2 emission factors for use in other years, the applied methodology should be reported as Tier 2 in those other years.

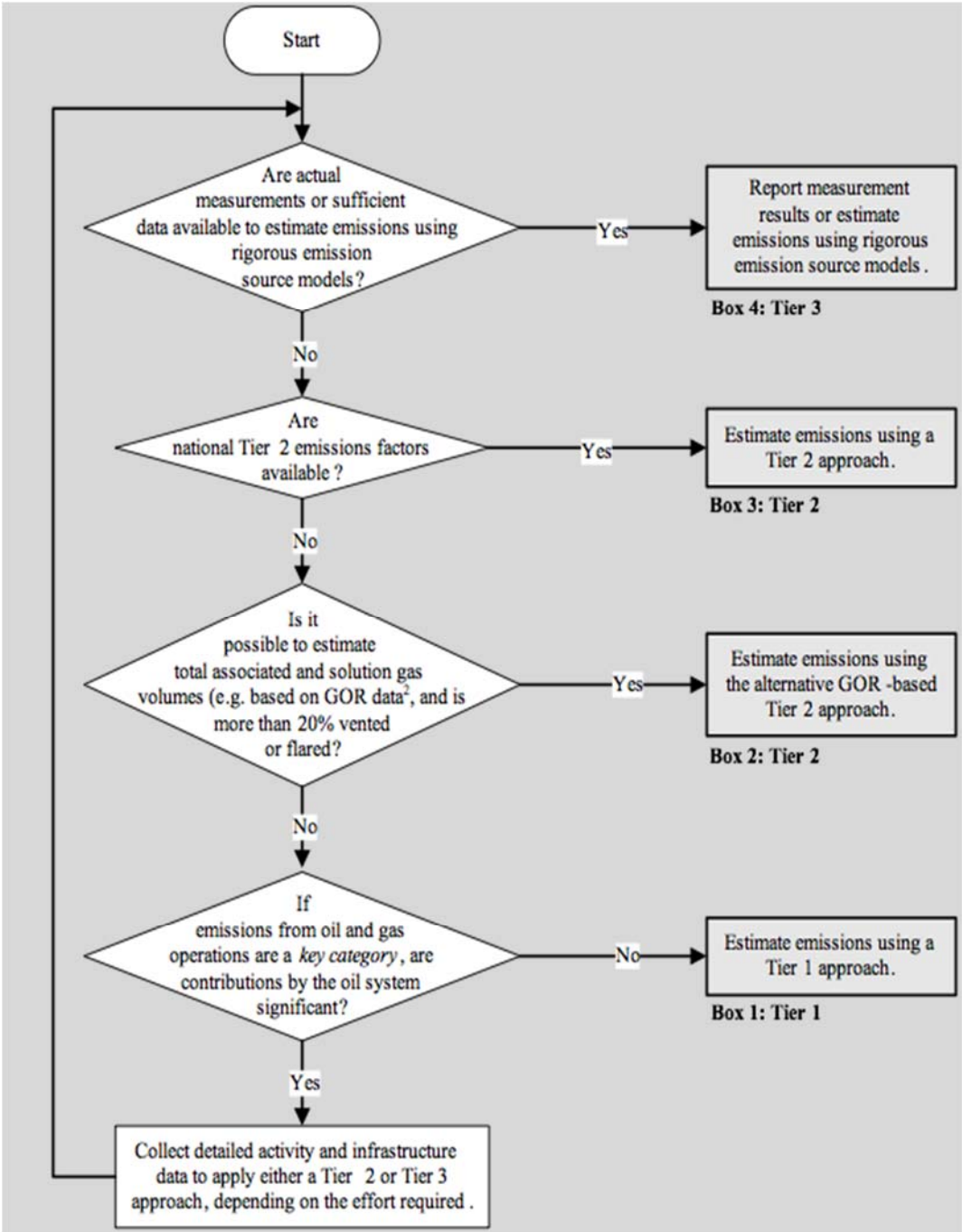
Where a country has estimated fugitive emissions from oil and gas systems based on a compilation of estimates reported by individual oil and gas companies, this may either be a Tier 2 or Tier 3 approach, depending on the actual approaches applied by individual companies and facilities. In both cases, care needs to be taken to ensure there is no omitting or double counting of emissions.

It is likely that most countries will estimate emissions from oil and natural gas system using a combination of tiers across and even within segments and subsegments. Tier 1 EFs disaggregated by segment are provided in Section 4.2.2.3. The Tier 1 factors presented in this section are aggregates of venting, flaring, and leak emissions. To develop separate estimates for venting, flaring, and leak emissions, default fractions of emissions in each category for relevant emission factors are provided in Annex 4A.2.

Figure 4.2.2 Decision tree for natural gas systems

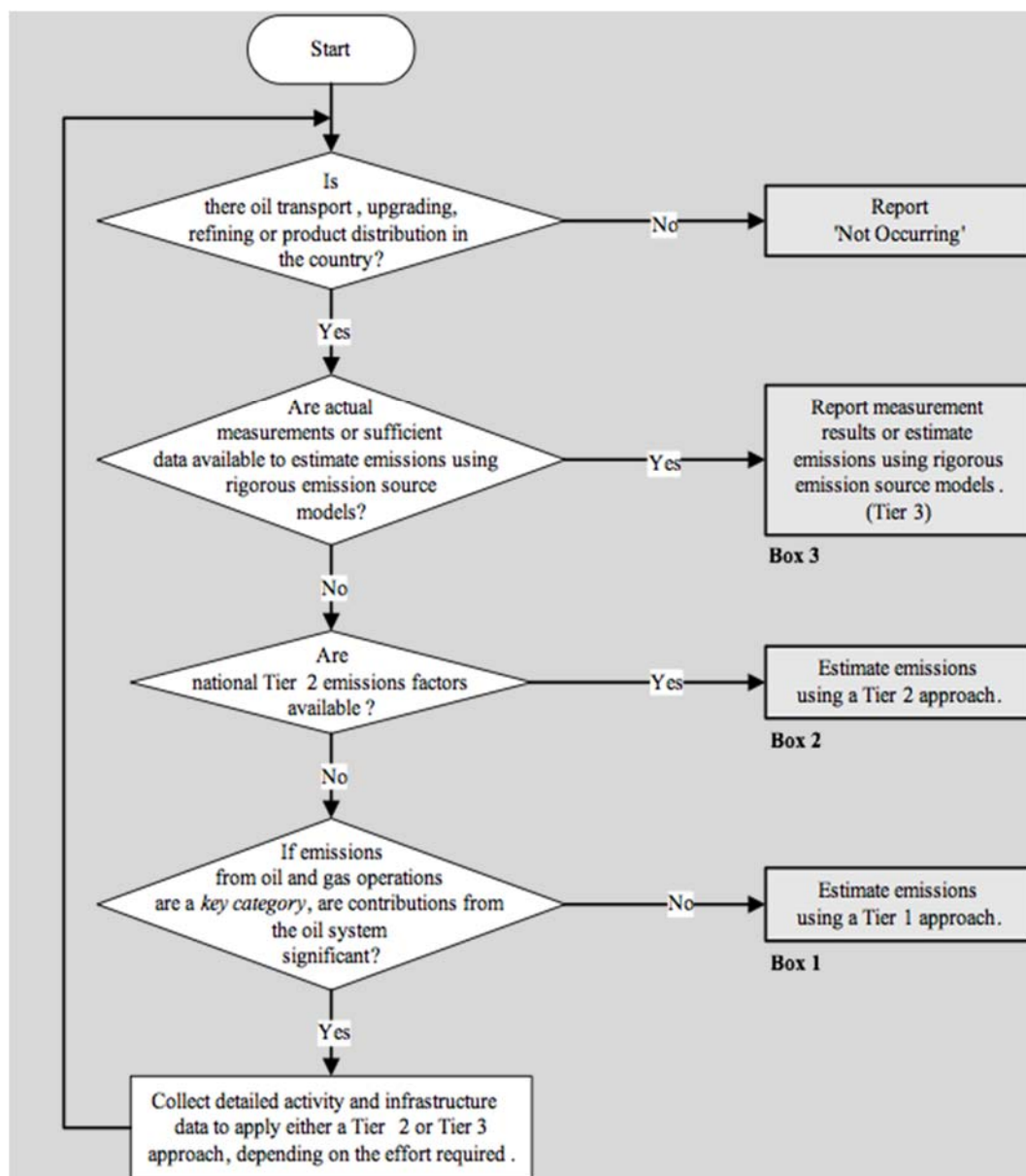
Note: See Volume 1 Chapter 4, “Methodological Choice and Key Categories” (noting Section 4.1.2 on limited resources) for discussion of *key categories* and use of decision trees

Figure 4.2.3 Decision tree for crude oil production



Note 1: See Volume 1 Chapter 4, “Methodological Choice and Key Categories” (noting Section 4.1.2 on limited resources) for discussion of *key categories* and use of decision trees

Note 2: GOR stands for gas/Oil Ratio (see Section 4.2.2.2).

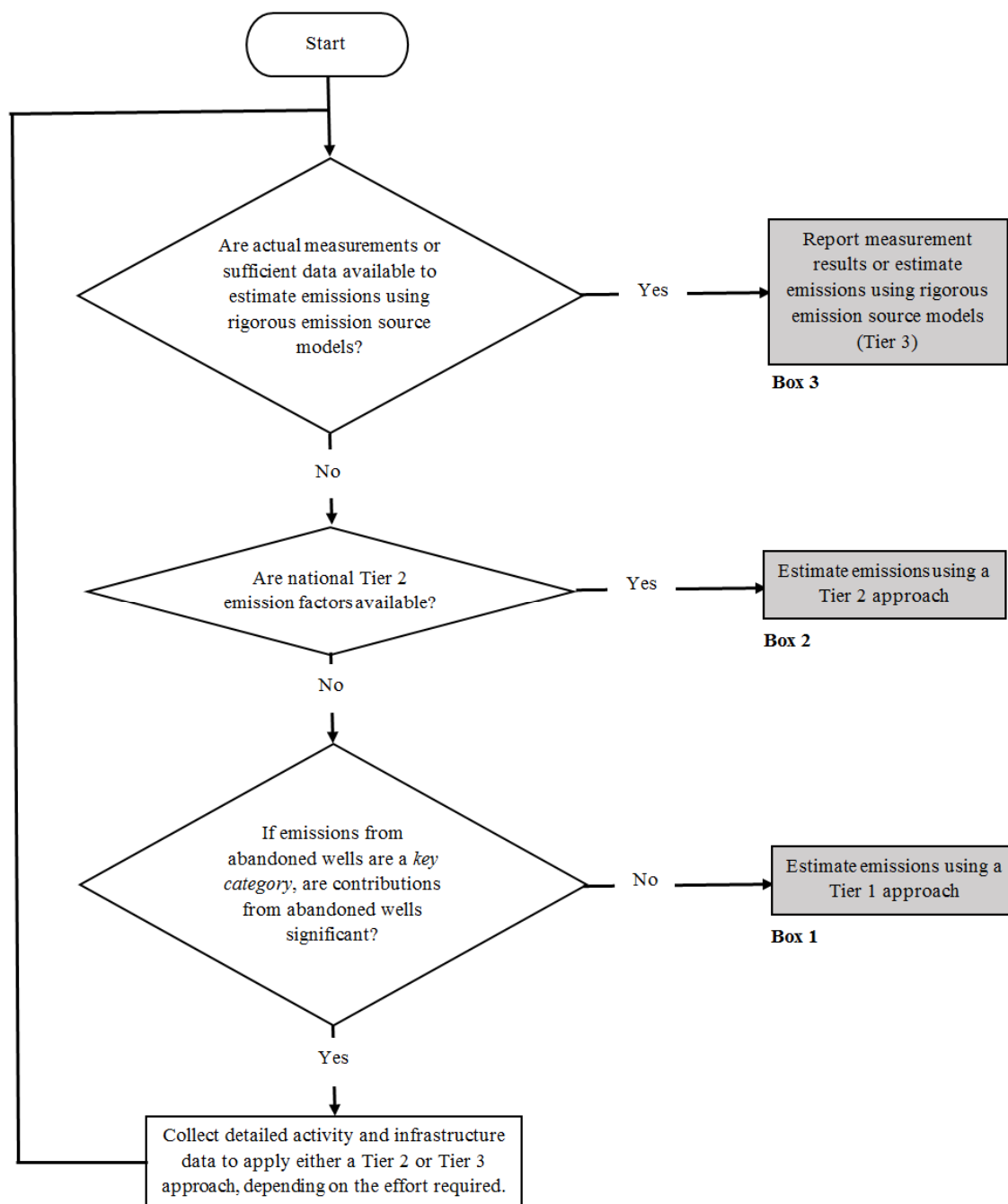
Figure 4.2.4 Decision tree for crude oil transport, refining and upgrading

Note 1: See Volume 1 Chapter 4, “Methodological Choice and *Key Categories*” (noting Section 4.1.2 on limited resources) for discussion of *key categories* and use of decision trees

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Figure 4.2.5 Decision tree for abandoned wells

UPDATED TO INCLUDE ABANDONED WELLS



4.2.2.2 CHOICE OF METHOD

UPDATED TO PROVIDE BACKGROUND ON TECHNOLOGY AND PRACTICE-SPECIFIC FACTORS

The three methodological tiers for estimating fugitive emissions from oil and natural gas systems are described below.

TIER 1

Tier 1 comprises the application of appropriate default emission factors to a representative activity parameter (usually throughput) for each applicable segment or subcategory of a country's oil and natural gas industry and should only be used for non-key sources. The application of a Tier1 approach is done using Equations 4.2.1 and 4.2.2 presented below:

EQUATION 4.2.1

TIER 1: ESTIMATING FUGITIVE EMISSIONS FROM AN INDUSTRY SEGMENT

$$E_{\text{gas, industry segment}} = A_{\text{industry segment}} \cdot EF_{\text{gas, industry segment}}$$

EQUATION 4.2.2

TIER 1: TOTAL FUGITIVE EMISSIONS FROM INDUSTRY SEGMENTS

$$E_{\text{gas}} = \sum_{\text{industry segments}} E_{\text{gas, industry segment}}$$

Where:

$E_{\text{gas, industry segment}}$ = Annual emissions (tonnes)

$EF_{\text{gas, industry segment}}$ = emission factor (tonnes/unit of activity),

$A_{\text{industry segment}}$ = activity value (units of activity),

The industry segments to be considered are listed in Table 4.2.1. Not all segments will necessarily apply to all countries. For example, a country that only imports natural gas and does not produce any will probably only have gas transmission and distribution emissions. The available Tier 1 default emission factors are presented in Tables 4.2.3 through 4.2.13 in Section 4.2.2.3. Several options for activity data are available for many of the factors. For each segment, at least one factor option has been related to throughput, because production, imports and exports, and consumption are the only national oil and gas statistics that are consistently available. Throughput emission factors are applicable to throughput at standard conditions of 15°C and 101.325 kPa. For more information on standard temperature and pressure conditions, and conversions from different conditions, see Annex 4A.1. Fugitive emissions may be more dependent on other factors. An improved basis for estimating emissions for many sources would use other activity data (e.g. length of pipeline). The Tables 4.2.3 through 4.2.13 in Section 4.2.2.3 provide options for emission factors to be applied to other activity data where possible, and where appropriate.

In addition, for many segments, technology- or practice-specific emission factors are available. Information on the appropriate use of each factor is included in Section 4.2.2.3 for each technology-specific factor.

Compilers are to assess which Tier 1 factors are most appropriate and should consider other sources or a more disaggregated EF (by emission type; see Annex 4A.2) if the emission factors presented here are expected to vary significantly from national circumstances.

Fugitive greenhouse gas emissions from oil and gas related CO₂ capture and injection activities (e.g., acid gas injection and EOR projects involving CO₂ floods) will normally be small compared to the amount of CO₂ being injected (e.g., less than 1 percent of the injection volumes). At the Tier 1 or 2 methodology levels they are indistinguishable from fugitive greenhouse gas emissions by the associated oil and gas activities. The emission contributions from CO₂ capture and injection were included in the original data from which the presented Tier 1 factors were developed (i.e., through the inclusion of acid gas injection and EOR activities, along with conventional oil and gas activities, with consideration of CO₂ concentrations in the leaked, vented and flared natural gases, vapours and acid gases). Losses from CO₂ capture should be accounted for in the industry where capture occurs, while losses from, transport, injection and storage activities are assessed separately in Chapter 5.

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TABLE 4.2.1 MAJOR CATEGORIES AND SUBCATEGORIES IN THE OIL AND GAS INDUSTRY ***TABLE UPDATED TO INCLUDE UNCONVENTIONAL EXPLORATION AND ABANDONED WELLS, AND TO IMPROVE CLARITY***	
Industry Segment	Activities/Emission Sources^a
Gas Exploration	Includes well drilling, well testing, and well completions in both conventional and unconventional formations.
Gas Production	Onshore gas production
	Offshore gas production
	Gathering and boosting stations (with multiple emission sources on site, such as compressors, pneumatic controllers and tanks) and gathering pipelines
Gas Processing	Gas Processing Plants without Acid Gas Removal
	Sour Gas or Acid Gas Removal Plants
Gas Transmission	Transmission pipeline Systems, compressor stations
	Storage Facilities
	Liquefied Natural Gas System import stations, export stations, storage stations
Gas Distribution	Pipelines
	Metering and regulating stations, consumer appliances
Other	Anomalous leak events can occur across natural gas systems. Examples of such events include leakage of storage wells (such as the 2015-2016 Aliso Canyon leak event ^b), emergency pressure releases, and unintentional gas spills (e.g. after prospecting).
Abandoned Gas Wells	Unplugged and plugged wells
Oil Exploration	Includes well drilling, well testing, and well completions.
Oil Production	Onshore Production
	Offshore Production
	Crude Bitumen or Heavy Oil Upgrading to Synthetic Crude Oil (From Oil Sands or Oil Shales)
Oil Transport	Marine
	Pipelines
	Tanker Trucks and Rail Cars

Oil Refining	Heavy Oil
	Conventional and Synthetic Crude Oil
Refined Product Distribution	Gasoline
	Diesel
	Aviation Fuel
	Jet Kerosene
	Gas Oil (Intermediate Refined Products)
Other	Anomalous leak events can occur across segments of Petroleum Systems
Abandoned Oil Wells	Unplugged and plugged wells
<p>^a See Annex 4A.3 Definition of terminologies used in Section 4.2.</p> <p>^b For more information on the Aliso Canyon leak event, please see California Air Resources Board 2016 “Determination of Total Methane Emissions from the Aliso Canyon Natural Gas Leak Incident,” available at https://www.arb.ca.gov/research/aliso_canyon/aliso_canyon_methane_emissions-arb_final.pdf.</p>	

TIER 2

UPDATED TO REFLECT THAT TECHNOLOGIES AND PRACTICES CHANGE OVER TIME, CLARITY ON SPLIT BETWEEN VENTING, FLARING, AND LEAKS, AND INFORMATION ON GOR

Tier 2 consists of using Tier 1 equations (4.2.1 and 4.2.2) with country-specific, instead of default, emission factors. It should be applied to *key categories* where the use of a Tier 3 approach is not practicable. The country-specific values may be developed from studies and measurement programmes, or be derived by initially applying a Tier 3 approach and then back-calculating Tier 2 emission factors using Equations 4.2.1 and 4.2.2. For example, some countries have been applying Tier 3 approaches for particular years and have then used these results to develop Tier 2 factors for use in subsequent years until the next Tier 3 assessment is performed. In general, all emission factors (including Tier 1 and Tier 2 values) should be periodically re-affirmed or updated. The frequency at which such updates are performed shall be commensurate with the rates at which new technologies, practices, standards and other relevant factors (e.g., changes in the types of oil and gas activities, aging of the fields and facilities, etc.) are penetrating the industry. New data shall be assessed to determine whether it is actually representing different practices or if it is an additional data point to be included in the emission factor applied across all time series years. For example, a survey of operations for information on practices over time could be used. If new emission factors developed in this manner account for real changes within the industry, they should not be applied backwards through the time series.

An alternative Tier 2 approach that may be applied to estimate the amount of venting and flaring emissions from the production segment of oil systems consists of performing a mass balance using country-specific production volumes, gas-to-oil ratios (GORs), gas compositions and information regarding the level of gas conservation. This approach may be applied using equations 4.2.3 to 4.2.8 below and is appropriate where reliable venting and flaring values are unavailable but representative GOR data can be obtained and venting and flaring emissions are expected to be the dominant sources of fugitive emissions (i.e., most of the associated gas production is not being captured/conserved or utilized). Under these circumstances, the alternative Tier 2 approach may also be used to estimate fugitive greenhouse gas emissions from EOR activities provided representative associated gas and vapour analyses are available and contributions due to fugitive emissions from the CO₂ transport and injection systems are small in comparison (as would normally be expected). Where the alternative Tier 2 approach is applied, any reported venting or flaring data that may be available for the target sources should not also be accounted for as this would result in double counting. However, it is *good practice* to compare the estimated gas vented and flared volumes determined using the GOR data to the available reported vented and flared data to identify and resolve any potential anomalies (i.e., the calculated volumes should be comparable to the available reported data, or greater if these latter data are believed to be incomplete). In the case that Tier 2 vented and flared data are applied for certain segments, leak emissions should be calculated separately using other data, for example, disaggregated Tier 1 emissions factors (see Annex 4A.2)

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Table 4.2.2 shows examples of typical GOR values for oil wells from selected locations. Actual GOR values may vary from 0 to very high values depending on the local geology, state of the producing reservoir and the rate of production. Notwithstanding this, average GOR values for large numbers of oil wells tend to be more predictable. A review of limited data for a number of countries and regions indicates that average GOR values for conventional oil production would usually be in the range of about 100 to 350 m³/m³, depending on the location. When country-specific GORs are used, care should be taken to ensure that GOR measurements are performed with enough frequency to ensure representative results.

TABLE 4.2.2
TYPICAL RANGES OF GAS-TO-OIL RATIOS FOR DIFFERENT TYPES OF PRODUCTION

Type of Crude Oil Production	Location	Typical GOR Values (m ³ /m ³)	
		Range ⁶	Average
Conventional Oil	Alaska (Prudhoe Bay)	142 to 6,234 ^{2, 3}	NA
	Canada	0 to 2,000+ ^{1, 2}	Not Available (NA)
	Qatar (Onshore, 1 Oil Field)	167 to 184 ⁴	173
	Qatar (Offshore, 3 Oil Fields)	316 to 386 ⁴	333
Primary Heavy Oil	Canada	0 to 325+ ^{1, 5}	NA
Thermal Heavy Oil	Canada	0 to 90 ¹	NA
Crude Bitumen	Canada	0 to 20 ¹	NA

¹ Source: Based on unpublished data for a selection of wells in Canada.

² Appreciably higher GOR values may occur, but these wells are normally either classified as gas wells or there is a significant gas cap present and the gas would normally be reinjected until all the recoverable oil had been produced.

³ Source: Mohaghegh, S.D., L.A. Hutchins and C.D. Sisk. 2002. Prudhoe Bay Oil Production Optimization: Using Virtual intelligence Techniques, Stage One: Neural Model Building. Presented at the SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, 29 September–2 October 2002.

⁴ Source: Corporate HSE, Qatar Petroleum, Qatar-Doha 2004.

⁵ Values as high as 7,160 m³/m³ have been observed for some wells where there is a significant gas cap present. Gas reinjection is not done in these applications. The gas is conserved, vented or flared.

⁶ Referenced at standard conditions of 15°C and 101.325 kPa.

To apply a mass balance method in the alternative Tier 2 approach, it is necessary to consider the fate of all of the produced gas and vapour. This is done, in part, through the application of a conservation efficiency (CE) factor which expresses the amount of the produced gas and vapour that is captured and used for fuel, produced into gas gathering systems or re-injected. A CE value of 1.0 means all gas is conserved, utilized or re-injected and a value of 0 means all of the gas is either vented or flared. Values may be expected to range from about 0.1 to 0.95. The lower limit applies where only process fuel is drawn from the produced gas and the rest is vented or flared. A value of 0.95 reflects circumstances where there is, generally, good access to gas gathering systems and local regulations emphasize vent and flare gas reduction.

EQUATION 4.2.3

ALTERNATIVE TIER 2 APPROACH (EMISSIONS DUE TO VENTING)

$$E_{\text{gas, oil prod, venting}} = \text{GOR} \cdot Q_{\text{OIL}} \cdot (1 - \text{CE}) \cdot (1 - X_{\text{Flared}}) \cdot M_{\text{gas}} \cdot y_{\text{gas}} \cdot 42.3 \times 10^{-6}$$

EQUATION 4.2.4

ALTERNATIVE TIER 2 APPROACH (CH₄ EMISSIONS DUE TO FLARING)

$$E_{\text{CH}_4, \text{ oil prod, flaring}} = \text{GOR} \cdot Q_{\text{OIL}} \cdot (1 - \text{CE}) \cdot X_{\text{Flared}} \cdot (1 - \text{FE}) \cdot M_{\text{CH}_4} \cdot y_{\text{CH}_4} \cdot 42.3 \times 10^{-6}$$

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EQUATION 4.2.5**ALTERNATIVE TIER 2 APPROACH (CO₂ EMISSIONS DUE TO FLARING)**

$$E_{CO_2, oil prod, flaring} = GOR \cdot Q_{OIL} \cdot (1 - CE) \cdot X_{Flared} \cdot M_{CO_2} \cdot [y_{CO_2} + (N_{CCH_4} \cdot y_{CH_4} + N_{CNM VOC} \cdot y_{NM VOC})(1 - X_{Soot})] \cdot 42.3 \times 10^{-6}$$

EQUATION 4.2.6**CH₄ EMISSIONS FROM FLARING AND VENTING**

$$E_{CH_4, oil prod} = E_{CH_4, oil prod, venting} + E_{CH_4, oil prod, flaring}$$

EQUATION 4.2.7**CO₂ EMISSIONS FROM VENTING AND FLARING**

$$E_{CO_2, oil prod} = E_{CO_2, oil prod, venting} + E_{CO_2, oil prod, flaring}$$

EQUATION 4.2.8**N₂O EMISSIONS FROM FLARING**

$$E_{N_2O, oil prod, flaring} = GOR \cdot Q_{OIL} (1 - CE) X_{Flared} EF_{N_2O}$$

Where:

$E_{i, oil prod, venting}$ = Direct amount (Gg/y) of GHG gas i emitted due to venting at oil production facilities.

$E_{i, oil prod, flaring}$ = Direct amount (Gg/y) of GHG gas i emitted due to flaring at oil production facilities.

GOR = Average gas-to-oil ratio (m³/m³) referenced at 15°C and 101.325 kPa.

Q_{OIL} = Total annual oil production (10³ m³/y).

M_{gas} = Molecular weight of the gas of interest (e.g., 16.043 for CH₄ and 44.011 for CO₂).

$N_{C,i}$ = Number of moles of carbon per mole of compound i (i.e., 1 for CH₄, 2 for C₂H₆, 3 for C₃H₈, 1 for CO₂, 2.1 to 2.7 for the NMVOC fraction in natural gas and 4.6 for the NMVOC fraction of crude oil vapours)

y_i = Mol or volume fraction of the associated gas that is composed of substance i (i.e., CH₄, CO₂ or NMVOC).

CE = Gas conservation efficiency factor.

X_{Flared} = Fraction of the waste gas that is flared rather than vented. With the exception of primary heavy oil wells, usually most of the waste gas is flared.

FE = flaring destruction efficiency (i.e., fraction of the gas that leaves the flare partially or fully burned). Typically, a value of 0.995 is assumed for flares at refineries and a value 0.98 is assumed for those used at production and processing facilities.

X_{soot} = fraction of the non-CO₂ carbon in the input waste gas stream that is converted to soot or particulate matter during flaring. In the absence of any applicable data this value may be assumed to be 0 as a conservative approximation.

EF_{N_2O} = emission factor for N₂O from flaring (Gg/10³ m³ of associated gas flared). Refer to the IPCC emission factor database (EFDB), manufacturer's data or other appropriate sources for the value of this factor.

42.3×10^{-6} = is the number of kmol per m³ of gas referenced at 101.325 kPa and 15°C (i.e. 42.3×10^{-3} kmol/m³) times a unit conversion factor of 10⁻³ Gg/Mg which brings the results of each applicable equation to units of Gg/y.

The values of $E_{CH_4, oil prod, venting}$ and $E_{CO_2, oil prod, venting}$ in Equations 4.2.6 and 4.2.7 are estimated using Equation 4.2.3.

It should be noted that Equation 4.2.5 accounts for emissions of CO₂ using a similar approach to what is done for fuel combustion in Section 1.3 of the Introduction chapter of the Energy Volume. The term $y\text{CO}_2$ in this equation effectively accounts for the amount of raw (or formation CO₂) present in the waste gas being flared. The terms $N\text{cCH}_4 \bullet y\text{CH}_4$ and $N\text{cNMVOC} \bullet y\text{NMVOC}$ in Equation 4.2.5 account for the amount of CO₂ produced per unit of CH₄ and NMVOC oxidized.

TIER 3

Tier 3 comprises the application of a rigorous bottom-up assessment by primary type of source (e.g., venting, flaring, equipment leaks, evaporation losses and accidental releases) at the individual facility level with appropriate accounting of contributions from temporary and minor field or well-site installations. It should be used for *key categories* where the necessary activity and infrastructure data are readily available or are reasonable to obtain. Tier 3 should also be used to estimate emissions from surface facilities where EOR, EGR and ECBM are being used in association with CCS. Approaches that estimate emissions at a less disaggregated level than this (e.g., relate emissions to the number of facilities or the amount of throughput) are deemed to be equivalent to a Tier 1 approach if the applied factors are taken from the general literature, or a Tier 2 approach if they are country-specific values.

The key types of data that would be utilized in a Tier 3 assessment would include the following:

- Facility inventory, including an assessment of the type and amount of equipment or process units at each facility, and major emission controls (e.g., vapour recovery, waste gas incineration, etc.).
- Inventory of wells and minor field installations (e.g., field dehydrators, line heaters, well site metering, etc.).
- Country-specific flare, vent and process gas analyses for each subcategory.
- Facility-level acid gas production, analyses and disposition data.
- Reported atmospheric releases due to well blow-outs and pipeline ruptures.
- Country-specific emission factors for fugitive equipment leaks, unaccounted/unreported venting and flaring, flashing losses at production facilities, evaporation losses, etc.
- The amount and composition of acid gas that is injected into secure underground formations for disposal.

Oil and gas projects that involve CO₂ injection as a means of enhancing production (e.g., EOR, EGR and ECBM projects) or as a disposal option (e.g., acid gas injection at sour gas processing plants) should distinguish between the CO₂ capture, transport, injection and sequestering part of the project, and the oil and gas production portion of the project. The net amount of CO₂ sequestered and the fugitive emissions from the CO₂ systems should be determined based on the criteria specified in Chapter 5 for CO₂ capture and storage. Any fugitive emissions from the oil and gas systems in these projects should be assessed based on the guidance provided here in Chapter 4 and will exhibit increasing concentrations of CO₂ over time in the emitted natural gas and hydrocarbon vapours. Accordingly, the applied emission factors may need to be periodically updated to account for this fact. Also, care should be taken to ensure that proper total accounting of all CO₂ between the two portions of the project occurs.

4.2.2.3 CHOICE OF EMISSION FACTOR

UPDATED TO REFLECT THE LATEST DATA, INCLUDING INFORMATION ON UPDATED PRACTICES, INCLUDING ABANDONED WELLS, AND MORE DETAILED DESCRIPTIONS OF EACH SEGMENT

Oil and gas technologies and practices and therefore, emissions, can vary greatly from country to country and over time. The level of available data also varies. Tier 1 emission factors are listed in tables below by segment. Tier 2 and 3 emission factors are also discussed below. It is likely that many countries will use a combination of tiers to calculate emissions across petroleum and natural gas systems.

TIER 1

Tier 1 default emission factors for each segment of oil and natural gas systems are presented in tables below. Each factor represents emissions per year.

Several options for activity data are available for many of the factors. For each segment, at least one factor option has been related to throughput, because production, imports and exports, and consumption are often the only national oil and gas statistics that are consistently available in many countries. However, fugitive emissions may be more dependent on other factors. An improved basis for estimating emissions for many sources might use other activity data (e.g. length of pipeline). The tables in Section 4.2.2.3 provide options for emission factors to be applied to other activity data where possible, and where appropriate. In addition, for many segments, technology-

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or practice-specific emission factors are available. Information on the appropriate use of each factor is included for each technology-specific factor. Compilers are to assess which Tier 1 factors are most appropriate and should consider other sources or a more disaggregated EF (see Annex 4A.2) if the emission factors presented here are expected to vary significantly from national circumstances.

The Tier 1 factors presented in this section are aggregates of venting, flaring, and leak emissions. To develop separate estimates for venting, flaring, and leak emissions, default fractions of emissions in each category for relevant emission factors are provided in Annex A.2.

It should be noted that the default EFs listed in Tables 4.2.3 to 4.2.13 are sensitive to temperature and pressure. Activity data must be consistent with the EFs standard conditions. For more information on conversions to standard temperature and pressure, please see Annex 4A.1.

The factors in Tables 4.2.3 to 4.2.13 are derived using detailed emission inventory results from the United States, Canada, Australia, Germany, and other countries, and, where possible, have been updated from the values previously presented in the IPCC Guidelines for National Greenhouse Gas Inventories (2006) document to reflect the results of more current and refined emissions inventories. In many cases, technology- and practice-specific emission factors are presented, so that an inventory compiler may select factors that best represent industry practices in the country. While the emission factor options are meant to cover technologies and practices that are common in the oil and gas industries, technologies and practices can vary significantly.

Oil Systems

1 B 2 a i Exploration.

This segment includes fugitive emissions (including equipment leaks, venting and flaring) from oil well drilling, drill stem testing and well completions. In this segment, guidance will not go in-depth to drilling, testing and servicing operation; EFs are applied to the whole segment.

In the table below, several options for emission factors are presented. For some emission factors, the factors are presented both in units of tonne per oil well drilled, tonne per active oil well, and in tonnes per thousand cubic meter oil produced. The count of wells drilled is thought to best reflect emissions from exploration and if available should be applied. However, the inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country.

Emission factors are available for both unconventional and conventional oil exploration. Here, unconventional oil exploration refers to exploration where hydraulic fracturing well completion practices are used, and conventional oil exploration refers to exploration where hydraulic fracturing well completion practices are not used.

The extent of any hydraulic fracturing activities in the country should be assessed. Unconventional completions (i.e., conducted with hydraulic fracturing) have a different emissions profile than conventional completions (i.e., completed without hydraulic fracturing). This is reflected in the emission factors below. Where possible, the compiler should separate national activity data into conventional and unconventional categories and apply the relevant emission factors. If only total oil wells or total oil production data are available, the compiler should develop an estimate of the annual split between conventional and unconventional wells or production in the country to develop the activity data. Unconventional factors are to be applied to the unconventional activity data basis. Where wells drilled are completed with hydraulic fracturing and flaring and gas recovery is not practiced, or where the extent of flaring or recovery practices is unknown, the first set of factors (“Unconventional without flaring or recovery”) should be used. Where wells drilled are completed with hydraulic fracturing and flaring and gas recovery is used, the fraction of the relevant activity data (i.e. unconventional wells drilled, total unconventional well population, or unconventional production) that uses flaring and/or gas recovery should be determined. The second set of factors (“Unconventional with flaring”) is used for that fraction, while the first set of factors is applied to the wells or production that are not using flaring or recovery. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series. Conventional factors (“Conventional”) are to be applied to the conventional activity data basis.

Definitions for oil wells versus gas wells can vary from country to country and organization to organization. The Tier 1 EFs in the table below were developed from emissions occurring in U.S. basins identified as having predominantly oil production. Emission factors were developed using data on exploration emissions for wells with a gas oil ratio of $\leq 17,000$ cubic meters gas to cubic meters oil.

For each segment/sub-segment listed in Table 4.2.3 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all sub-segments (i.e. technologies or practices) occurring.

EQUATION 4.2.9**GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS
FROM EXPLORATION**

$$\begin{aligned}
 E_{\text{exploration}} = & A_{\text{unconventional oil without flaring or recovery}} \cdot EF_{\text{unconventional oil without flaring or recovery}} \\
 & + A_{\text{unconventional oil with flaring or recovery}} \cdot EF_{\text{unconventional oil with flaring or recovery}} \\
 & + A_{\text{conventional oil}} \cdot EF_{\text{conventional oil}}
 \end{aligned}$$

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TABLE 4.2.3 TIER 1 EMISSION FACTORS FOR OIL EXPLORATION, 1.B.2.A.I											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	

Oil exploration	Unconventional without flaring or recovery ^{a,d}	All	6.74	-30% to +30%	17.81	-30% to +30%	1.01	-12.5 to +800%	NA	NA	Tonnes/unconventional onshore oil wells drilled
			0.38	-30% to +30%	0.98	-30% to +30%	0.057	-12.5 to +800%	NA	NA	Tonnes/total unconventional onshore oil well population without flaring or recovery
			1.64	-30% to +30%	4.24	-30% to +30%	0.25	-12.5 to +800%	NA	NA	Tonnes/thousand cubic meters onshore unconventional onshore oil production without flaring or recovery
Oil exploration	Unconventional with flaring or recovery ^{b,d}	All	0.82	-30% to +30%	11.72	-30% to +30%	0.12	-12.5 to +800%	8.5E-05	-10 to +1000%	Tonnes/unconventional onshore oil wells drilled
			0.08	-30% to +30%	1.14	-30% to +30%	0.012	-12.5 to +800%	8.3E-06	-10 to +1000%	Tonnes/total unconventional onshore oil well population with flaring or recovery
			0.07	-30% to +30%	1.09	-30% to +30%	0.011	-12.5 to +800%	7.9E-06	-10 to +1000%	Tonnes/thousand cubic meters onshore unconventional oil production with flaring or recovery
Oil exploration	Conventional ^c	All	0.58	-30% to +30%	13.70	-30% to +30%	0.087	-12.5 to +800%	9.9E-05	-10 to +1000%	Tonnes/onshore conventional oil wells drilled
			0.01	-30% to +30%	0.24	-30% to +30%	0.001	-12.5 to +800%	1.7E-06	-10 to +1000%	Tonnes/total conventional onshore oil well population
			0.02	-30% to +30%	0.47	-30% to +30%	0.003	-12.5 to +800%	3.4E-06	-10 to +1000%	Tonnes/thousand cubic meters onshore conventional oil production

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NA – Not Applicable

- a. Emission factors for CH₄ and CO₂ developed from EPA (2015) memo on production segment method updates for unconventional oil well completions, Radian/API, Global Emissions of Methane from Petroleum Sources (1992) for drilling emissions, and U.S. Greenhouse Gas Reporting Program (GHGRP) data on well testing, as applied in the 2018 U.S. GHG Inventory; factor is an average of 2003-2007 calculated implied emission factors for emissions from well drilling, well testing, and from well completions with hydraulic fracturing that do not flare or use gas capture. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from an EPA analysis (2015) for unconventional oil well completions, from Radian/API, Global Emissions of Methane from Petroleum Sources (1992) for drilling emissions, and GHGRP data on well testing, as applied in the 2018 U.S. GHG Inventory. Factor is the average of 2012-2016 calculated implied emission factors for emissions from well drilling, well testing, and from well completions with hydraulic fracturing that flare or use gas capture. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- c. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996) for conventional oil well completions, GHGRP for well testing, and Radian/API, Global Emissions of Methane from Petroleum Sources (1992), for drilling emissions, as applied in the 2018 U.S. GHG Inventory. Factor is the average of 2004-2016 calculated implied emission factors for emissions from well drilling, well testing and from conventional completions. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- d. Unconventional oil exploration refers to exploration that includes well completions with hydraulic fracturing. Conventional oil exploration emission factors should be applied where hydraulic fracturing well completion practices are not used.

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1 B 2 a ii Production and Upgrading

This segment includes fugitive emissions from oil production (including leaks, venting, and flaring) from the oil wellhead or at the oil sands or shale oil mine through to the start of the oil transmission system. Emissions arise from the wells themselves (e.g., as wellhead leaks and from well workovers), and well-site equipment such as pneumatic controllers, dehydrators and separators. This includes fugitive emissions related to oil sands or shale oil mining, transport of untreated production (i.e. well effluent, emulsion, oil shale and oil sands) to treating or extraction facilities, activities at extraction and upgrading facilities, associated gas re-injection systems and produced water disposal systems. Fugitive emissions from upgraders are grouped with those from production rather than those from refining since the major product from upgraders (i.e. synthetic crude oil) requires further processing at refineries. Upgraders are often integrated with extraction facilities and may also be integrated with refineries, co-generation plants or other industrial facilities, making their relative contributions difficult to establish.

The table below presents factors for onshore oil production, and offshore oil production. For some emission factors, the factors are presented both in units of tonne per active oil well, and in tonnes per thousand cubic meter oil produced. The inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country. The types of technologies and practices in use in the country should be assessed. Where this information is unknown, or where there is limited use of lower-emitting technologies, the first set of emission factors for oil production (“Most activities occurring with higher-emitting technologies and practices”) should be used. Examples of higher-emitting technologies and practices include venting of associated gas and uncontrolled tanks. Where lower-emitting technologies are used extensively, the second set of emission factors (“Most activities occurring with lower-emitting technologies and practices”) for oil production should be used. Examples of lower-emitting technologies and practices include limited venting or flaring of associated gas, and tanks with controls. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series.

Countries with onshore oil production should apply a factor for onshore production to the relevant activity data for onshore production. Countries with offshore oil production should apply a factor for offshore oil production. The emission factors for onshore production were developed from data sets that included a mix of production from wells in conventional formations and wells in unconventional formations and are considered to be applicable to both. Production from oil sands is treated separately and should use emission factors for “Oil Sands Mining and Ore Processing” and “Oil Sands Upgrading” to calculation emissions for that subset of oil production. If no data are available to estimate the share of onshore versus offshore production, EF for onshore production should be applied to the total quantity of oil production.

Factors presented are inclusive of venting, flaring, and leak emissions. For cases where country-specific data are available for a subcomponent of the factor (e.g. venting and flaring emissions), disaggregated Tier 1 EF that could be applied to estimate the remaining emission types are available—see Annex 4A.2 for information (including examples) on how to calculate disaggregated emissions.

Definitions for oil wells versus gas wells can vary from country to country and organization to organization. The Tier 1 EFs in the table below were developed from emissions occurring in U.S. basins identified as having predominantly oil production. Well-based emission factors were developed using well counts for wells with a gas oil ratio of $\leq 17,000$ cubic meters gas to cubic meters oil.

Oil sands are a type of unconventional petroleum deposit made of up a mixture of sand, clay, and water, saturated with a highly viscous form of petroleum called crude bitumen. Crude bitumen is an extra-heavy oil with an API gravity below 10° API. In its natural state, it is not usually recoverable at commercial rates through a well because it is too thick to flow. There are two methods that are used to recover crude bitumen, depending on the depth of the deposit. Bitumen that occurs near the surface can be recovered by open-pit mining. In this method, overburden is removed, oil sands ore is mined, and bitumen is recovered from the mined material in large facilities using hot water and solvents. When the resource is located too deep to make surface mining economical, in situ extraction methods are utilized. In situ extraction takes place both by primary extraction methods, similar to conventional crude oil, and enhanced extraction. The two main methods of enhanced recovery are cyclic steam stimulation (CSS) and steam-assisted gravity drainage (SAGD). Both methods use steam to heat the reservoir allowing the bitumen to flow to a vertical or horizontal wellbore. Due to the large quantities of both hot water and steam needed to extract the bitumen, co-generation plants are often co-located with the extraction facilities.

Once the bitumen is produced using surface mining or in situ methods, it can be upgraded to synthetic crude oil (SCO) or lighter hydrocarbon products at an upgrader and then transported to a refinery for further processing. Upgraders improve the quality of the crude bitumen by adding hydrogen, removing carbon, or both. During the upgrading process, most of the sulphur and other impurities are removed. The produced bitumen can also be mixed

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with a less viscous material (referred to as diluent), such as SCO or condensate, allowing the mixture to flow through a pipeline.

Fugitive emissions from in situ extraction include leaks, venting and flaring that occur at the well pad through to the start of the oil transmission system. Open pit mining extraction of crude bitumen also includes fugitive emissions from leaks, venting and flaring. Additional methane present in the oil sands ore is released during mining, mine dewatering, and ore transport, crushing and handling activities. Waste tailings are created during the extraction process consisting of unrecovered solvent, bitumen, water, sand, clay and other impurities. Fugitive emissions from tailings ponds occur as microbial and bacterial degradation of hydrocarbons and vegetation present at the bottom of the ponds produces methane gas. The upgrading process produces fugitive emissions of leaks, venting and flaring, including CO₂ venting from sulphur recovery operations and the hydrogen production process.

For each segment/sub-segment listed in Table 4.2.4 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all segments and sub-segments occurring.

EQUATION 4.2.10
GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM OIL PRODUCTION AND
UPGRADING

$$E_{oil\ production} = A_{onshore\ oil\ production} \cdot EF_{onshore\ oil\ production} \\ + A_{offshore\ oil\ production} \cdot EF_{offshore\ oil\ production} \\ + A_{oil\ sands} \cdot EF_{oil\ sands}$$

1909

TABLE 4.2.4 TIER 1 EMISSION FACTORS FOR OIL PRODUCTION, 1.B.2.A.II											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	

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Oil Production	Onshore: Most activities occurring with higher-emitting technologies and practices ^a	All	3.43	-30% to +30%	12.40	-30% to +30%	1.48	-100 to +800%	1.9E-04	-10-+1000%	Tonnes/thousand cubic meters onshore oil production
			2.35	-30% to +30%	8.47	-30% to +30%	1.01	-100 to +800%	1.3E-04	-10-+1000%	Tonnes per active oil well
Oil Production	Onshore: Most activities occurring with lower-emitting technologies and practices ^b	All	2.91	-30% to +30%	44.99	-30% to +30%	1.25	-100 to +800%	6.7E-04	-10-+1000%	Tonnes/thousand cubic meters onshore oil production
			2.19	-30% to +30%	33.83	-30% to +30%	0.94	-100 to +800%	5.1E-04	-10-+1000%	Tonnes per active oil well
Oil Production	Onshore: Oil Sands Mining and Ore Processing ^c	All	0.74	±29.4%	7.56	±21.5%	0.65	-26.5 to +95%	1.1E-05	-30 to +520%	Tonnes/thousand cubic meters crude bitumen production from surface mining
Oil Production	Onshore: Oil Sands Upgrading ^d	All	0.13	-34.2 to +119%	90.73	±13.4	0.07	-60.3 to +75%	2.8E-05	-22.1 to +313%	Tonnes/thousand cubic meters synthetic crude oil production
Oil Production	Offshore ^e	All	2.45	-30% to +30%	0.11	-30% to +30%	1.05	-100 to +800%	1.6E-06	-10-+1000%	Tonnes/thousand cubic meters offshore oil production

- a. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), and data reported to the U.S. Greenhouse Gas Reporting Program (GHGRP), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 1992 (when EPA/GRI study was conducted). Examples of higher-emitting technologies and practices include venting of associated gas and uncontrolled tanks. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from data reported to the GHGRP, and EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2016 (the most recent year of GHGRP data availability). Examples of lower-emitting technologies and practices include limited venting or flaring of associated gas, and tanks with controls. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- c. Emission factors developed from An Inventory of GHG, CAC and Other Priority Emissions by the Canadian Oil Sands Industry: 2015, prepared by Clearstone Engineering Ltd. for Environment and Climate Change Canada (2017) and production data from the Alberta Energy Regulator (AER), ST39: Alberta Mineable Oil Sands Plant Statistics. Fugitive emission from tailings ponds and the exposed mine surface of oil sanding mining is included here.
- d. Emission factors developed from An Inventory of GHG, CAC and Other Priority Emissions by the Canadian Oil Sands Industry: 2015, prepared by Clearstone Engineering Ltd. for Environment and Climate Change Canada (2017) and production data from the Alberta Energy Regulator (AER), ST39: Alberta Mineable Oil Sands Plant Statistics.
- e. Emission factors for CH₄ and CO₂ developed from U.S. Bureau of Ocean Energy Management's (BOEM) Gulf Offshore Activity Data System (GOADS), as applied in the 2018 U.S. GHG Inventory, to estimate emissions for 2011 (the year of the BOEM survey). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.

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1 B 2 a iii Transport.

This segment includes fugitive emissions (including leaks, venting, and flaring) related to the transport of marketable crude oil (including conventional, heavy and synthetic crude oil and bitumen), etc. to upgraders and refineries. The transportation systems may comprise pipelines, marine tankers, tank trucks and rail cars. Evaporation losses from storage, filling and unloading activities and fugitive equipment leaks are the primary sources of these emissions.

For each segment/sub-segment listed in Table 4.2.5 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all segments and sub-segments occurring.

EQUATION 4.2.11

GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM OIL TRANSPORTATION

$$E_{oil\ transport} = A_{pipelines} \cdot EF_{pipelines} \\ + A_{tanker\ trucks\ and\ rail\ cars} \cdot EF_{tanker\ trucks\ and\ rail\ cars} \\ + A_{marine\ tanks} \cdot$$

TABLE 4.2.5 TIER 1 EMISSION FACTORS FOR OIL TRANSPORT, 1.B.2.A.III											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	

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Oil Transport	Pipelines ^a	All	0.0054	±100%	0.00049	±100%	0.054	-50% to +200%	NA	NA	Tonne per thousand cubic meters oil transported by pipeline
Oil Transport	Tanker Trucks and Rail Cars ^b	All	0.025	±50%	0.0023	±50%	0.25	-50% to +200%	NA	NA	Tonne per thousand cubic meters oil transported by tanker truck or rail car
Oil Transport	Tanks ^c	All	0.002	±50%	NA	NA	NA	NA	NA	NA	Tonne per thousand cubic meters crude oil feed
Oil Transport	Loading of offshore production on tanker ships without VRU ^d	All	0.093	±50%	ND	ND	ND	ND	ND	ND	Tonne per thousand cubic meters oil loaded onto tanker ship
Oil Transport	Loading of offshore production on tanker ships with VRU ^e	All	0.066	±50%	ND	ND	ND	ND	ND	ND	Tonne per thousand cubic meters oil loaded onto tanker ship
<p>NA – Not Applicable, ND – Not Determined</p> <p>a. From 2006 GL values for both developed and developing and economies in transition.</p> <p>b. From 2006 GL values for both developed and developing and economies in transition. Note from IPCC 2006: “NMVOC values are derived from methane values based on the ratio of the mass fractions of NMVOC to CH₄. Values of 0.0144 kg/kg for gas transmission and distribution, 9.951 kg/kg for oil and condensate transportation and 0.3911 kg/kg for synthetic crude oil production are used.”</p> <p>c. Emission factors for CH₄ developed from and Radian/API, Global Emissions of Methane from Petroleum Sources (1992), as applied in the 2018 U.S. GHG Inventory for all years.</p> <p>d. Emission factors for CH₄ and CO₂ developed from 2017 Norway GHG Inventory implied emission factors for 1990-2002, for loading of offshore production on tanker ships without vapor recovery units (VRU).</p> <p>e. Emission factors for CH₄ and CO₂ developed from 2017 Norway GHG Inventory implied emission factors for 2003-2015, for loading of offshore production on tanker ships with VRU.</p>											

1927 **1 B 2 a iv Refining**

1928 This segment includes fugitive emissions (including leaks, venting, and flaring) at petroleum refineries. Refineries
1929 process crude oils, natural gas liquids and synthetic crude oils to produce final refined products (e.g., primarily
1930 fuels and lubricants) and in some plants even hydrogen (please note box below). Methane emission sources include
1931 storage tanks, blowdowns, asphalt blowing, equipment leaks, vents, loading operations, wastewater treating,
1932 cooling towers, catalytic cracking/reforming/fluid cracking, flares, delayed coking, and coke calcining. Carbon
1933 dioxide emissions included under 1.B.2.a.iv include asphalt blowing, calcination, anode production, process vents,
1934 and flaring. Where refineries are integrated with other facilities (for example, upgraders or co-generation plants)
1935 their relative emission contributions can be difficult to establish in measurement studies. The emission factors
1936 below represent petroleum refinery emissions only.

1937 **Box 4.2.1**1938 **HYDROGEN PRODUCTION, FUGITIVE EMISSIONS AND REFINERIES**

1939 When hydrogen is produced as a by-product or intermediate product in *Refineries*, it is *good practice*
1940 to report the greenhouse gas emissions (stationary and fugitive) in the **Energy sector**.

1941 When hydrogen is produced as main product at a stand-alone facility, the methodological guidance
1942 to estimate greenhouse gas emissions is given in IPPU Sector (see **Chapter 3.11 Volume 3 of 2019**
1943 ***Refinement***).

1944 Inventory compilers should avoid double counting or omitting emissions from hydrogen production.

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TABLE 4.2.6 TIER 1 EMISSION FACTORS FOR OIL REFINING, 1.B.2.A.IV											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
Oil Refining	All ^a	All	0.028	-50 to +130%	5.848	-50 to +130%	0.261	-100 to +100%	8.77E-05	-100 to +100%	Tonnes/thousand cubic meters oil refined
^a Emission factors for CH ₄ , NMVOC, and CO ₂ developed as an average of 2018 German GHG Inventory data (1990 to 2016) with a range of 0.016 to 0.065 tonnes CH ₄ /thousand cubic meters, 0.151 to 0.584 tonnes NMVOC/thousand cubic meters and 5.437 to 6.143 tonnes CO ₂ /thousand cubic meters. N ₂ O values were developed from IPCC 2006 GL by calculating a ratio of N ₂ O to CO ₂ from oil production (N ₂ O values from refineries were unavailable) in IPCC 2006, which was then applied to corresponding CO ₂ values for refineries in this table. The factors include fugitive equipment leaks, flaring, storage, handling, calcination and anode production.											

1946

1947 **1 B 2 a v Distribution of Oil Products**

1948 This segment includes fugitive emissions (including leaks, venting and flaring) from the transport and distribution
 1949 of refined products, including those at bulk terminals and retail facilities. Evaporation losses from storage, filling
 1950 and unloading activities and equipment leaks are the primary sources of these emissions. Many products are
 1951 directly used in chemical industry and should be considered in the appropriate subcategory (e.g. 2.B.8). Table 4.2.7
 1952 below provides emission factors for major fuel types. The emission factors regard emissions from refinery dispatch
 1953 or border dispatch stations, to depots and further distribution to end-users (e.g. gas stations and airports). It is
 1954 assumed that a fractional distillation in the refinery separated gaseous components from fuels. Therefore, only
 1955 NMVOC emissions factors are provided. Tier 1 emission factors are currently available for only a subset of the
 1956 total types of oil products distributed.

1957 For each segment/sub-segment listed in Table 4.2.7 below that is occurring in the country, compilers must calculate
 1958 emissions, and sum them according to the equation below. It is recognized that not all countries will have all
 1959 segments and sub-segments occurring.

EQUATION 4.2.12
GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM DISTRIBUTION OF OIL
PRODUCTS

$$E_{distribution\ of\ oil\ productions} = A_{gasoline\ distribution} \cdot EF_{gasoline\ distribution} \\ + A_{other\ distribution} \cdot EF_{other\ distribution}$$

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TABLE 4.2.7 TIER 1 EMISSION FACTORS FOR DISTRIBUTION OF OIL PRODUCTS, 1.B.2.A.V											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
Refined Product Distribution	Gasoline ^a	All	NA	NA	NA	NA	2.27	+/-20%	NA	NA	Tonnes per thousand cubic meters product consumed
Refined Product Distribution	Other (e.g. diesel, aviation fuel, jet kerosene)	All	NA	NA	NA	NA	0.15	+/-20%	NA	NA	Tonnes per thousand cubic meters product consumed
<p>NA – Not Applicable</p> <p>The NMVOC emission factors are developed from the 2018 German inventory values for 2016 for unabated distribution of fuels and include transshipping from tanker to tanks, refuelling of cars, permeation in refuelling hoses and dripping losses. Several techniques like vapour-balancing and vapour-recovery along with use of automatic monitoring systems will have a significant influence of the factor.</p> <p>Note from IPCC 2006 GL: “Estimated based on assumed average evaporation losses of 0.15 percent of throughput at the distribution terminal and additional losses of 0.15 percent of throughput at the retail outlet. These values will be much lower where Stage 1 and Stage 2 vapour recovery occurs and may be much greater in warmer climates.”</p>											

1966

1 B 2 a vi Other

Fugitive emissions (including leaks, venting and flaring) from oil systems not otherwise accounted for in the above categories. This includes fugitive emissions from spills and other accidental releases, waste oil treatment facilities and oilfield waste disposal facilities.

Anomalous leak events can occur across oil systems and can have highly variable emissions. Examples of such events include releases from emergency pressure relieving equipment such as emergency shutdowns (ESD), emergency safety blowdowns (ESB), pressure relief valves (PRV), and breakout/surge tanks (API, 2009). It is *good practice* to quantify and report such emissions whenever possible under 1 B 2 a iii 6. There is no Tier 1 method available for such events, which need to be evaluated on a case-by-case basis, often using a combination of emission factors and engineering calculations. An example of calculating emissions during emergency conditions though an engineering calculation approach is given in the 2009 American Petroleum Institute's *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry*.

1 B 2 a vii Abandoned Oil Wells

When production activities are completed, oil and gas wells may be abandoned. Several reasons of well abandonment exist: if wells have fulfilled their purpose; after the surrender of a production license; due to geological reasons; due to technical reasons; due to technological, ecological and other reasons. Countries with a long history of oil and gas production may have a significant abandoned well population and should estimate emissions for this source.

For onshore wells ending production in recent decades, the abandonment process is often covered by national (or regional) well abandonment regulations. Regulated wells are often treated with plugging and other practices prior to abandonment/decommissioning to prevent leakage from the wells and migration of oil, gas or brine to surrounding strata. That process can be generally described as follows. The wells are plugged (with the use of plugging materials, e.g. cement) and sealed according to the regulations and considering reasons of decommissioning, geological conditions, and other well specifics. If these steps are implemented effectively and the long-term integrity of the well does not fail over time, it is unlikely that the well will leak substantial amounts of methane. However, in practice integrity failure of some abandoned wells may occur and the well may start leaking methane to the atmosphere. This is consistent with findings of recent studies in the U.S. and U.K., which have found that the majority of effectively plugged wells are not leaking, but a small number will have some emissions (e.g., Townsend-Small et al. 2016, Kang et al. 2016, Boothroyd et al. 2016).

Tier 1 default emission factors are presented in Table 4.2.8. All of the presented emission factors are expressed in units of mass of emissions per abandoned well. All the EFs are developed from data for both abandoned oil and gas wells. It should be noted that factors provided for both oil and gas wells have high uncertainty, which is reflected in the uncertainty ranges provided in the table. The EFs of abandoned wells are split into either "plugged" (or, properly decommissioned per regulations) and "unplugged" well sub-segments. The distinction requires the number of each type of abandoned well (plugged or unplugged). Existing data on abandoned oil and gas wells as well as practices for its plugging status may be limited and is difficult to collect. If insufficient data on plugging practices is available to disaggregate activity data in such a way, the default EF for all type wells is to be used. More limited data are available on offshore wells and disaggregated (i.e. plugged versus unplugged) factors for offshore abandoned wells are developed from onshore wells data considering that most methane (around 80%) from offshore abandoned wells is dissolved in marine water.

Based on available data, emission factors (and leak frequency) do not vary over the time series per well; according to the latest research, well integrity failure rate shows no significant trend over time. If failures do exist, they more likely occur early on in the decommissioned life of a well (Boothroyd I.M. et al, 2016). Based on the latest research, gas well emission rates may be higher than oil well emissions rates. However, due to limited data points in the currently available data, Tier 1 EFs were not disaggregated into oil-specific and gas-specific factors. In cases where national circumstances are different from listed above, a country should consider using a Tier 2 or Tier 3 approach.

Activity data for this source are counts of abandoned onshore and offshore wells in each year of the time series, and for onshore wells, the fraction of wells that are effectively plugged. It may be challenging to compile a total national count of abandoned wells and to assess whether wells are plugged or unplugged. There is likely significant variation between post-well closure practices internationally and even within countries.

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TABLE 4.2.8 TIER 1 EMISSION FACTORS FOR ABANDONED OIL WELLS, 1.B.2.A.VII											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
Abandoned wells ^a	Onshore: Plugged ^a	Leaks	0.02	-87% to +130%	NA	NA	NA	NA	NA	NA	Kg CH ₄ / onshore plugged well
	Onshore: Unplugged	Leaks	87.78	-99% to +150%	NA	NA	NA	NA	NA	NA	Kg CH ₄ / onshore unplugged well
	Onshore: All wells (plugged and unplugged) ^a	Leaks	12.09	-83% to +124%	NA	NA	NA	NA	NA	NA	Kg CH ₄ / onshore well
Abandoned wells ^b	Offshore: Plugged ^b	Leaks	3.5E-04	-87% to +130%	NA	NA	NA	NA	NA	NA	Kg CH ₄ / offshore plugged well
	Offshore: Unplugged ^b	Leaks	1.76	-99% to +150%	NA	NA	NA	NA	NA	NA	Kg CH ₄ / offshore unplugged well
	Offshore: All wells (plugged and unplugged) ^b	Leaks	0.24	-83% to +124%	NA	NA	NA	NA	NA	NA	Kg CH ₄ / offshore well
NA – Not Applicable a. From Townsend-Small et al. 2016, which includes data collected from wells across the U.S. It should be noted that the emission factors for “All wells (plugged and unplugged)” uses the Townsend-Small data set plugging rate of 86.2%. b. Developed by using the onshore abandoned wells emission factors in this table, and applying a factor of 0.02 to reflect that most methane from such wells is dissolved in marine water. Factor of 0.02 based on Vielstädte et al. (2015).											

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Natural Gas Systems

1 B 2 b i Exploration

This segment includes emissions (including equipment leaks, venting and flaring) from gas well drilling, drill stem testing and well completions. In the table below, several options for emission factors are presented. For some emission factors, the factors are presented both in units of tonne per gas well drilled, tonne per active gas well, and in tonnes per million cubic meter gas produced. The count of wells drilled is thought to best reflect emissions from exploration and if available should be applied. However, the inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country.

Emission factors are available for both unconventional and conventional gas exploration. Here, unconventional gas exploration refers to exploration where hydraulic fracturing well completion practices are used, and conventional gas exploration refers to exploration where hydraulic fracturing well completion practices are not used.

The extent of any hydraulic fracturing activities in the country should be assessed. Unconventional completions (e.g., conducted with hydraulic fracturing) have a different emissions profile than conventional completions (e.g. conducted without hydraulic fracturing). This is reflected in the emission factors below. Where possible, the compiler should separate national activity data into conventional and unconventional and apply the relevant emission factors. If only total gas wells or total gas production data are available, the compiler should develop an estimate of the annual split between conventional and unconventional wells or production in the country to develop the activity data.

Here, unconventional factors are to be applied to the unconventional activity data basis. Where wells drilled are completed with hydraulic fracturing and flaring and gas recovery is not practiced, or where the extent of flaring or recovery practices is unknown, the first set of factors (“Unconventional gas exploration without flaring or gas capture”) should be used. Where wells drilled are completed with hydraulic fracturing and flaring and gas recovery is used, the fraction of the relevant activity data (i.e. unconventional wells drilled, total unconventional well population, or unconventional production) that uses flaring and/or gas recovery should be determined. The second set of factors (“Unconventional gas exploration with flaring or gas capture”) is used for that fraction, while the first set of factors is applied to the wells or production that is not using flaring or recovery. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series. Conventional factors (“Conventional Gas exploration”) are to be applied to the conventional activity data basis. For each segment/sub-segment listed in Table 4.2.9 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all segments and sub-segments occurring.

Definitions for oil wells versus gas wells can vary from country to country and organization to organization. The Tier 1 EFs in the table below were developed from emissions occurring in U.S. basins identified as having predominantly gas production. Well-based emission factors were developed using data for wells with a gas oil ratio of >17,000 cubic meters gas to cubic meters oil.

EQUATION 4.2.13

GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM EXPLORATION

$$E_{\text{exploration}} = A_{\text{unconventional gas without flaring or recovery}} \cdot EF_{\text{unconventional gas without flaring or recovery}} \\ + A \cdot EF_{\text{unconventional gas with flaring or recovery}} \\ + A_{\text{conventional gas}} \cdot EF_{\text{conventional gas}}$$

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TABLE 4.2.9 TIER 1 EMISSION FACTORS FOR NATURAL GAS EXPLORATION SEGMENT, 1.B.2.B.I											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncer- tainty (% of value)	Value	Uncer- tainty (% of Value)	Value	Uncer- tainty (% of value)	Value	Uncer- tainty (% of value)	

Gas Exploration	Unconventional gas exploration without flaring or gas capture ^{a, d}	All	20.1	-20% to +20%	1.50	-20% to +20%	3.01	-12.5 to +800%	NA	NA	Tonnes/new gas wells drilled in onshore unconventional formations
			4.35	-20% to +20%	0.32	-20% to +20%	0.65	-12.5 to +800%	NA	NA	Tonnes/million cubic meters onshore unconventional gas production
			2.52	-20% to +20%	0.19	-20% to +20%	0.38	-12.5 to +800%	NA	NA	Tonnes/total gas wells in onshore unconventional formations
Gas Exploration	Unconventional gas exploration with flaring or gas capture ^{b, d}	All	1.30	-20% to +20%	47.0	-20% to +20%	0.19	-12.5 to +800%	3.4E-04	-10 to +1000%	Tonnes/new gas wells drilled in onshore unconventional formations
			0.05	-20% to +20%	1.93	-20% to +20%	0.0071	-12.5 to +800%	1.4E-05	-10 to +1000%	Tonnes/million cubic meters onshore unconventional gas production
			0.08	-20% to +20%	3.16	-20% to +20%	0.013	-12.5 to +800%	2.3E-05	-10 to +1000%	Tonnes/total gas wells in onshore unconventional formations
Gas Exploration	Conventional Gas exploration ^c	All	7.17	-20% to +20%	6.13	-20% to +20%	1.08	-12.5 to +800%	4.4E-05	-10 to +1000%	Tonnes/new gas wells drilled in onshore conventional formations
			0.03	-20% to +20%	0.03	-20% to +20%	0.0052	-12.5 to +800%	2.1E-07	-10 to +1000%	Tonnes/million cubic meters onshore conventional gas production
			0.07	-20% to +20%	0.06	-20% to +20%	0.0098	-12.5 to +800%	4.0E-07	-10 to +1000%	Tonnes/total gas wells in onshore conventional formations

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NA – Not Applicable

- a. Emission factors for CH₄ and CO₂ developed from data reported to the U.S. Greenhouse Gas Reporting Program (GHGRP) for unconventional completions and well testing, and Radian/API, Global Emissions of Methane from Petroleum Sources (1992), for drilling emissions, as applied in the 2018 U.S. GHG Inventory. Factor is the average of 2006-2010 calculated implied emission factors for emissions from well drilling, well testing, and from well completions with hydraulic fracturing that do not flare or use gas capture. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from data reported to the GHGRP for unconventional completions and well testing, and from Radian/API, Global Emissions of Methane from Petroleum Sources (1992) for drilling emissions, as applied in the 2018 U.S. GHG Inventory. Factor is the average of 2013-2016 calculated implied emission factors for emissions from well drilling, well testing, and from well completions with hydraulic fracturing that flare or use gas capture. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- c. Emission factors for CH₄ and CO₂ developed from GHGRP for conventional completions and well testing, and Radian/API, Global Emissions of Methane from Petroleum Sources (1992), for drilling emissions, as applied in the 2018 U.S. GHG Inventory. Factor is the average of 2006-2010 calculated implied emission factors for emissions from well drilling and from conventional completions. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- d. Unconventional gas exploration refers to exploration that includes well completions with hydraulic fracturing. Conventional gas exploration emission factors should be applied where hydraulic fracturing well completion practices are not used.

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1 B 2 b ii Production and Gathering

This segment includes fugitive emissions (including leaks, venting and flaring) from the gas wellhead through to the inlet of gas processing plants, or, where processing is not required, to the tie-in points on gas transmission systems. In the production stage, wells are used to withdraw raw gas from underground formations. Emissions arise from the wells themselves (e.g., as wellhead leaks and from well workovers), and well-site equipment such as pneumatic controllers, dehydrators and separators. Gathering and boosting emission sources are included within the production sector. The gathering and boosting sources include gathering and boosting stations (with multiple emission sources on site, such as compressors, pneumatic controllers and tanks) and gathering pipelines. The gathering and boosting stations receive natural gas from production sites and transfer it, via gathering pipelines, to processing facilities or transmission pipelines.

The table below presents factors for onshore gas production, gathering systems, and offshore gas production. Several options for emission factors for onshore production are presented. For some emission factors, the factors are presented both in units of tonne per active gas well, and in tonnes per million cubic meter gas produced. The inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country. The types of technologies and practices in use in the country should be assessed. Where this information is unknown, or where there is limited use of lower-emitting technologies, the first set of emission factors (“Most activities occurring with higher-emitting technologies and practice”) for onshore gas production should be used. Examples of higher-emitting technologies and practices include venting for liquids unloading without plunger lifts, unconventional workovers that vent, and use of high-bleed pneumatic controllers. Where lower-emitting technologies are used extensively, the second set of emission factors (“most activities occurring with lower-emitting technologies and practices”) for gas production should be used. Examples of lower-emitting technologies and practices include venting for liquids unloading with plunger lifts, unconventional workovers using reduced emission completion technologies, and low-bleed pneumatic controllers. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series.

Countries with onshore gas production should apply a factor for onshore production and the factor for gathering to the quantity of onshore gas produced in each year. Countries with offshore gas production should apply a factor for offshore gas production. The emission factors for onshore production were developed from data sets that included a mix of production from wells in conventional formations and wells in unconventional formations and are considered to be applicable to both. If data on coal bed methane production are available, the factor for coal bed methane production may be applied to the portion of gas production that is from coal bed methane. In case of lack of data disaggregated on offshore and onshore gas production it is recommended to disaggregate volumes of gas produced according to the data on share of onshore/offshore production, if available. If no data are available to estimate the share of onshore versus offshore production, EF for onshore production should be applied to the total quantity of gas production.

Factors presented are inclusive of venting, flaring, and leak emissions. For cases where country-specific data are available for a subcomponent for the factor (e.g. venting and flaring emissions using the GOR method discussed in Section 4.2.2.2), disaggregated Tier 1 EF are available in Annex 4A.2.

Definitions for oil wells versus gas wells can vary from country to country and organization to organization. The Tier 1 EFs in the table below were developed from emissions occurring in U.S. basins identified as having predominantly gas production. Well-based emission factors were developed using data for wells with a gas oil ratio of >17,000 cubic meters gas to cubic meters oil.

For each segment/sub-segment listed in Table 4.2.10 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all segments and sub-segments occurring.

EQUATION 4.2.14
GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM GAS PRODUCTION AND GATHERING

$$E_{\text{production}} = A_{\text{onshore gas production}} \cdot EF_{\text{onshore gas production}} + A_{\text{gathering}} \cdot EF_{\text{gathering}} + A_{\text{offshore gas production}} \cdot EF_{\text{offshore gas production}}$$

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TABLE 4.2.10 TIER 1 EMISSION FACTORS FOR NATURAL GAS PRODUCTION SEGMENT, 1.B.2.B.II											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncer- tainty (% of value)	Value	Uncer- tainty (% of Value)	Value	Uncer- tainty (% of value)	Value	Uncer- tainty (% of value)	

Gas Production	Onshore: Most activities occurring with higher- emitting technologies and practices ^a	All	4.09	-20% to +20%	1.45	-20% to +20%	0.98	-75 to +250%	2.5E-05	-10 to +1000%	Tonnes/million cubic meters onshore gas production
			7.07	-20% to +20%	2.51	-20% to +20%	1.70	-75 to +250%	4.3E-05	-10 to +1000%	Tonnes/active gas well
Gas Production	Onshore: Most activities occurring with lower-emitting technologies and practices ^b	All	2.54	-20% to +20%	3.60	-20% to +20%	0.61	-75 to +250%	6.1E-05	-10 to +1000%	Tonnes/million cubic meters onshore gas production
			4.37	-20% to +20%	6.21	-20% to +20%	1.05	-75 to +250%	1.1E-04	-10 to +1000%	Tonnes per active gas well
Gas Production	Onshore Coal Bed Methane ^c	All	1.95	-20% to +20%	19.57	-20% to +20%	0.23	-75 to +250%	7.2E-04	-10 to +1000%	Tonnes/million cubic meters onshore gas production
Gas Production	Gathering ^d	All	3.20	-10% to +10%	0.35	-10% to +10%	0.77	-75 to +250%	6.0E-06	-10 to +1000%	Tonnes/million cubic meters onshore gas production
Gas Production	Offshore ^e	All	2.93	-20% to +20%	7.33	-20% to +20%	0.70	-75 to +250%	1.2E-04	-10 to +1000%	Tonnes/million cubic meters offshore gas production

Second-order Draft

NA – Not Applicable

- a. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), and data reported to the U.S. Greenhouse Gas Reporting Program (GHGRP), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 1992 (when EPA/GRI study was conducted). Examples of higher-emitting technologies and practices include venting for liquids unloading without plunger lifts, unconventional workovers that vent, and use of high-bleed pneumatic controllers. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), and data reported to the GHGRP, as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2016 (the most recent year of GHGRP data availability). Examples of lower-emitting technologies and practices include venting for liquids unloading with plunger lifts, unconventional workovers using reduced emission completion technologies, and low-bleed pneumatic controllers. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- c. Emission factors for CH₄ and CO₂ developed from data reported to the Australian National Greenhouse and Energy Reporting program (NGER), as applied in the 2018 Australian National Inventory and is the average of emissions for the financial years 2016-17.
- d. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), and Marchese et al. 2015, as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2012 (when the measurements used in Marchese were conducted). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- e. Emission factors for CH₄ and CO₂ developed from U.S. Bureau of Ocean Energy Management's (BOEM) Gulf Offshore Activity Data System (GOADS), as applied in the 2018 U.S. GHG Inventory, to estimate emissions for 2011 (the year of the BOEM survey). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.

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1 B 2 b iii Processing

This segment includes fugitive emissions (including leaks, venting and flaring) from gas processing facilities. In this stage, natural gas liquids (NGLs) and various other constituents (e.g. sulphur) from the raw gas are removed, resulting in “pipeline quality” gas, which is injected into the transmission system. Emission sources include compressors, equipment leaks, pneumatic controllers, uncombusted gas from engines and flaring, and CO₂ from flaring and sour gas removal. In the Table 4.2.11 below, several options for emission factors are presented. For some emission factors, the factors are presented both in units of tonne per million cubic meter gas processed, and in tonnes per million cubic meter gas produced. The inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country. The extent of any leak detection and repair (LDAR) programs in the country should be assessed. Where this information is unknown, or where there are limited or no LDAR programs, the “without LDAR, less than 50% of centrifugal compressors are dry seal” emission factors for Gas Processing should be used. Where leak detection and repair programs are in use, use the “With LDAR, around 50% or more of centrifugal compressors are dry seal” emission factors for Gas Processing. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series. Where sour gas (or “acid gas”) removal is occurring, the factor for that source should also be applied to the portion of gas processed with sour gas removal, and added to the overall gas processing total. Information for disaggregating the Tier 1 EFs for processing into leak, vent, and flare emissions is available in Annex 4A.2.

The emissions from gas processing ($E_{\text{processing}}$) are computed by multiplying the appropriate emission factor from Table 4.2.11 by the amount of gas processed (units of millions of cubic meter of gas). If sour gas is removed, this emission should be added to the overall processing emissions, where the emissions from sour gas removal is computed as the product of the emission factor for sour gas removal from Table 4.2.11 and the amount of sour gas that is processed (in units of millions of cubic meters of sour gas). The compiler should attempt to determine the fraction of the gas processed that is sour gas using nationally available statistics or industry information on the characteristics of processing plants. If no data is available, it is *good practice* to assume the fraction, for example by considering the study of Burgers et al 2011⁵ or comparing to adjacent countries. If none of the proposals works, a value of 32% sour gas⁶ can be applied.

Town gas originates from outgassing of hard coal under air exclusion in retort furnace or chamber kilns. Emissions from these processes are considered in Volume 3 Chapter 3.11 “Hydrogen Production”. If town gas is processed in a gas processing plant, the emissions should be added, where emissions are computed as the product of the emission factor for town gas processing times the amount of town gas processed at the gas processing plant (in units of millions of cubic meters of town gas). For each segment/sub-segment listed in Table 4.2.11 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all segments and sub-segments occurring.

EQUATION 4.2.15**GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM GAS PROCESSING**

$$E_{\text{processing}} = A_{\text{gas processed}} \cdot EF_{\text{LDAR or no LDAR}} \\ + A_{\text{sour gas processed}} \cdot EF_{\text{acid gas removal}} \\ + A_{\text{town gas processed at gas plant}} \cdot EF_{\text{town gas processing}}$$

⁵ <http://www.sciencedirect.com/science/article/pii/S1876610211003018>

⁶ Developed as an unweighted mean value from Germany (40%) and Austria (25%), from 2018 German and Austrian NIRs, <https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2018>.

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TABLE 4.2.11 TIER 1 EMISSION FACTORS FOR GAS PROCESSING SEGMENT, 1.B.2.B.III											
Segment	Sub-segment	Emission source	CH ₄		CO ₂		NMVOC		N ₂ O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	

Processing	Without LDAR, less than 50% of centrifugal compressors are dry seal ^a	All	1.83	-10% to +10%	0.12	-10% to +10%	0.15	-75 to +250%	1.3E-06	-10 to +1000%	Tonnes/million cubic meters gas processed
			1.65	-10% to +10%	0.11	-10% to +10%	0.13	-75 to +250%	1.2E-06	-10 to +1000%	Tonnes/million cubic meters gas produced
Processing	With LDAR, around 50% or more of centrifugal compressors are dry seal ^b	All	0.75	-10% to +10%	9.45	-10% to +10%	0.06	-75 to +250%	1.0E-04	-10 to +1000%	Tonnes/million cubic meters gas processed
			0.57	-10% to +10%	7.21	-10% to +10%	0.05	-75 to +250%	7.9E-05	-10 to +1000%	Tonnes/million cubic meters gas produced
Processing	Sour gas (acid gas removal) ^c	All	0.1	-100% to +100%	66.7	-100% to +100%	0.15	-75 to +250%	1.3E-06	-10 to +1000%	Tonnes/million cubic meters sour gas processed

NA – Not Applicable

- a. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 1992 (when EPA/GRI study was conducted). Emissions from acid gas removal were deducted prior to EF development. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from data reported to the U.S. Greenhouse Gas Reporting Program (GHGRP), and from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2016 (most recent year of GHGRP data availability). Emissions from acid gas removal were deducted prior to EF development. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.
- c. Emission factors for CH₄ and CO₂ from the 2006 IPCC GL. NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table. N₂O values were developed from IPCC 2006 GL by calculating a ratio of N₂O to CO₂ from IPCC 2006, which was then applied to corresponding CO₂ values in this table.

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1 B 2 b iv Transmission and Storage

This segment includes fugitive emissions (including leaks, venting and flaring) from systems used to transport processed natural gas to market (i.e., to industrial consumers and natural gas distribution systems), including natural gas storage systems. Natural gas transmission involves high pressure, large diameter pipelines that transport gas long distances from field production and processing areas to distribution systems or large volume customers such as power plants or chemical plants. Compressor station facilities are used to move the gas throughout the transmission system. Emissions from natural gas liquids extraction plants on gas transmission systems should be reported as part of natural gas processing (Sector 1.B.2.b.iii). Fugitive emissions related to the transmission of natural gas liquids should be reported under 1.B.2.a.iii. Emissions sources include compressors, pneumatic controllers, storage wells, leaks and venting from transmission lines, equipment leaks from compressor stations. This source also includes LNG stations and import and export terminals; further details on the LNG sector can be found in *Liquefied Natural Gas (LNG) Operations: Consistent Methodology for estimating Greenhouse Gas Emissions* (API, 2015). In the table below, several options for emission factors are presented. The extent of any leak detection and repair programs, and types of compressors in the country should be assessed. Where this information is unknown, or where there are limited or no leak detection or repair programs, and little use of centrifugal compressors, the first set of emission factors (“Most activities occurring with higher-emitting technologies and practices”) for gas transmission should be used. Where there are leak detection or repair programs, and use of centrifugal compressors with dry seals, the second set of emission factors (“Most activities occurring with lower-emitting technologies and practices”) for gas transmission should be used. For both sets of emission factors, the factors are presented both in units of tonne per million cubic meter gas consumption, and in tonnes per km transmission pipeline. The inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country. For the storage segment, the extent of any leak detection and repair programs should be assessed. Where this information is unknown, or where there are limited or no leak detection or repair programs, the first set of emission factors for gas storage (“Most activities occurring with higher-emitting technologies and practices”) should be used. Where there are leak detection or repair programs, the second set of emission factors for gas storage (“Most activities occurring with lower-emitting technologies and practices”) should be used. Emission factors for storage are presented in units of tonne per million cubic meter gas consumption. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series. Where LNG imports and exports or storage occur, the number of stations should be determined, and the emission factors for LNG should be used. See API (2015) for further elaboration of emission estimation methods for the LNG sector (e.g. Tiers 2 and 3). Information for disaggregating the Tier 1 EF for transmission into leak, vent, and flare emissions is available in Annex 4A.2.

For each segment/sub-segment listed in Table 4.2.12 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all segments and sub-segments occurring.

EQUATION 4.2.16
GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM GAS TRANSMISSION AND STORAGE

$$\begin{aligned}
 E_{\text{transmission and storage}} = & A_{\text{gas transmission}} \cdot EF_{\text{transmission}} \\
 & + A_{\text{storage}} \cdot EF_{\text{storage}} \\
 & + A_{\text{LNG import/export}} \cdot EF_{\text{LNG import/export}} \\
 & + A_{\text{LNG storage}} \cdot EF_{\text{LNG storage}}
 \end{aligned}$$

TABLE 4.2.12 TIER 1 EMISSION FACTORS FOR GAS TRANSMISSION AND STORAGE SEGMENT, 1.B.2.B.IV											
Segment	Sub-segment	Emission source	CH4		CO2		NMVOC		N2O		Units of measure
			Value	Uncer- tainty (% of value)	Value	Uncer- tainty (% of Value)	Value	Uncer- tainty (% of value)	Value	Uncer- tainty (% of value)	

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Gas Transmission and Storage	Transmission: Most activities occurring with higher-emitting technologies and practices ^a	All	3.36	-20 to +30%	0.23	-20 to +30%	0.05	-100 to +250%	NA	NA	Tonnes per million cubic meter gas consumption
			4.10	-20 to +30%	0.28	-20 to +30%	0.06	-100 to +250%	NA	NA	Tonnes per km pipeline
Gas Transmission and Storage	Transmission: Most activities occurring with lower-emitting technologies and practices ^b	All	1.29	-20 to +30%	0.15	-20 to +30%	0.02	-100 to +250%	NA	NA	Tonnes per million cubic meter gas consumption
			2.08	-20 to +30%	0.25	-20 to +30%	0.03	-100 to +250%	NA	NA	Tonnes per km pipeline
Gas Transmission and Storage	Storage: Most activities occurring with higher-emitting technologies and practices ^c	All	0.67	-20 to +30%	0.06	-20 to +30%	0.0094	-20 to +500%	NA	NA	Tonnes per million cubic meter gas consumption
Gas Transmission and Storage	Storage: Most activities occurring with lower-emitting technologies and practices ^d	All	0.29	-20 to +30%	0.04	-20 to +30%	0.0040	-20 to +500%	NA	NA	Tonnes per million cubic gas consumption
Gas Transmission and Storage	LNG: Import/Export ^e	All	1,660	-20 to +30%	14,687	-20 to +30%	NA	NA	NA	NA	Tonnes per station
Gas Transmission and Storage	LNG: Storage ^f	All	22	-20 to +30%	277	-20 to +30%	NA	NA	NA	NA	Tonnes per station

NA – Not Applicable

- a. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), and the Greenhouse Gas Reporting Program (GHGRP), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 1992 (when EPA/GRI study was conducted). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from data reported to the GHGRP, Zimmerle et al. 2015, and from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2016 (most recent year of GHGRP data availability). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- c. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), and the GHGRP, as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 1992 (when EPA/GRI study was conducted). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- d. Emission factors for CH₄ and CO₂ developed from data reported to the U.S. Greenhouse Gas Reporting Program (GHGRP), Zimmerle et al. 2015, and from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2016 (most recent year of GHGRP data availability, without anomalous leak event). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- e. Emission factors for CH₄ and CO₂ developed from U.S. GHGRP data for years 2015 and 2016.
- f. Emission factors for CH₄ and CO₂ developed from U.S. GHGRP data for years 2015 and 2016.

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1 B 2 b v Distribution

This segment includes fugitive emissions (including leaks, venting, and flaring) from the distribution of natural gas to end users. Distribution pipelines take the high-pressure gas from the transmission system at “city gate” stations, reduce the pressure and distribute the gas through primarily underground mains and service lines to individual end users. Emission sources include leaks from pipelines, metering and regulating stations, meters, short-term surface storage and post-meter leaks. In the table below, several options for emission factors are presented. The mix of pipeline materials and extent of any leak detection and repair programs in the country should be assessed. Where this information is unknown, or where distribution pipelines are less than 50% plastic, and where there are limited or no leak detection or repair programs, the first set of emission factors for gas distribution should be used (“Less than 50% plastic pipelines, and limited or no leak detection and repair programs”). Where greater than 50% of distribution pipelines are plastic, and leak detection and repair programs are in use, use the second set of emission factors for gas distribution (“Greater than 50% plastic pipelines, and leak detection and repair programs are in use”). For both sets of emission factors, the factors are presented both in units of tonne per million cubic meter gas consumption, and in tonnes per km pipeline. The inventory compiler should assess which activity data are available and which activity data basis best reflects emissions in that segment for that country. As technologies and practices change over time, it is possible that one EF will be used in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series. In addition, an appropriate factor for appliance emissions, and power plant post-meter leakage if applicable, should be applied. Distribution system methane emissions from biogas are to be calculated here, and can be calculated using the provided emission factors, provided that methane content of the distributed gas is not expected to significantly differ from distributed natural gas. Fugitive emissions of carbon dioxide from biogas distribution are considered to be biogenic and are not reported under 1.B.2. The composition of town gas differs from natural gas (see explanation in introduction to chapter 4.2) and therefore emissions are estimated for town gas using distinct emission factors. The emission factors for appliances and power plants include leakage emissions beyond gas meters, such as internal piping and the end of pipe appliances (e.g. home heating, water heating, saunas, stoves, barbecues). Emissions from combustion of gas are calculated in category 1.A. If the number of appliances using natural gas is unknown the number of gas meters or the number of house connections should be used instead multiplied by a typical number of appliances (e.g., 2 for countries with heaters and stoves; 1 in warm countries without heaters). Disaggregated emission factors (e.g. by pipeline material) are available in Annex 4A.2.

For each category/subcategory listed in Table 4.2.13 below that is occurring in the country, compilers must calculate emissions, and sum them according to the equation below. It is recognized that not all countries will have all categories and subcategories occurring.

EQUATION 4.2.17
GENERAL EQUATION FOR ESTIMATING FUGITIVE EMISSIONS FROM GAS DISTRIBUTION AND POST-METER LEAKAGE

$$\begin{aligned}
 E_{distribution} = & A_{gas\ distribution} \cdot EF_{gas\ distribution} \\
 & + A_{surface\ storage} \cdot EF_{surface\ storage} \\
 & + A_{Distribution\ of\ town\ gas} \cdot EF_{Distribution\ of\ town\ gas} \\
 & + A_{natural\ gas\ vehicles} \cdot EF_{natural\ gas\ vehicles} \\
 & + A_{natural\ gas\ appliances} \cdot EF_{natural\ gas\ appliances} \\
 & + A_{natural\ gas\ power\ plants} \cdot EF_{natural\ gas\ power\ plants}
 \end{aligned}$$

TABLE 4.2.13 TIER 1 EMISSION FACTORS FOR DISTRIBUTION SEGMENT, 1.B.2.B.V											
Segment	Sub-segment	Emission source	CH4		CO2		NMVOC		N2O		Units of measure
			Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	

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Gas Distribution	Less than 50% plastic pipelines, and limited or no leak detection and repair programs ^a	All	2.92	-20 to +120%	0.09	-20 to +120%	0.041	-20 to +500%	NA	NA	Tonnes per million cubic meter gas consumption
			1.17	-20 to +120%	0.03	-20 to +120%	0.016	-20 to +500%	NA	NA	Tonnes per kilometre of pipeline
Gas Distribution	Greater than 50% plastic pipelines, and leak detection and repair programs are in use ^b	All	0.62	-20 to +120%	0.02	-20 to +120%	0.009	-20 to +500%	NA	NA	Tonnes per million cubic meter gas consumption
			0.23	-20 to +120%	0.01	-20 to +120%	0.003	-20 to +500%	NA	NA	Tonnes per kilometre of pipeline
Gas Distribution	Short term surface storage ^c	All	5	-50 to 100 %	0.034	-50 to 100 %	0.125	-70 to 140 %	NA	NA	Tonnes per million cubic meter of gas stored
		All	0.003	-100 to 100 %	2.1E-05	-100 to 100 %	7.5E-05	-100 to 170 %	NA	NA	Tonnes per million cubic meter gas consumed
Gas Distribution	Town gas distribution: All ^d	All	0.58	- 25 to +25%	18.3E-03	-25 to +25%	NA	NA	NA	NA	Tonnes per kilometre of pipeline
Gas Distribution	Natural gas-fueled vehicles ^e	All	0.3E-03	-50 to 100 %	2.3E-06	-50 to 100 %	8E-06	-70 to 140 %	NA	NA	Tonnes per car
Gas Distribution	Appliances in commercial and residential sector ^f	All	4E-03	-60 to +60%	3.3E-05	-60 to +60%	0.1E-03	-60 to +60%	NA	NA	Tonnes per appliance
Gas Distribution	Leakage at industrial plants and power stations ^g	All	0.4	-60 to +60%	3.3E-03	-60 to +60%	0.01	-60 to +60%	NA	NA	Tonnes per million cubic meter Non-residential and commercial gas consumed

NA – Not Applicable

- a. Emission factors for CH₄ and CO₂ developed from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 1992 (when EPA/GRI study was conducted). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- b. Emission factors for CH₄ and CO₂ developed from data reported to the U.S. Greenhouse Gas Reporting Program (GHGRP), Lamb et al. 2015, and from EPA/GRI, Methane Emissions from the Natural Gas Industry (1996), as applied in the 2018 U.S. GHG Inventory to calculate emissions for the year 2016 (most recent year of GHGRP data availability). NMVOC values were developed from IPCC 2006 GL by calculating a ratio of NMVOC to CH₄ from IPCC 2006, which was then applied to corresponding CH₄ values in this table.
- c. Short term storage. Bender & Langer, Mueller BBM “Determination of Emission Factors and Activity Data in the Area of the IPCC (1996) 1.B.2.b.iii - Fugitive Emissions from Natural Gas Storage”; Federal Environmental Agency of Germany, 2012 Funding code (FKZ): 360 16 035; Report no. M96023/01; 38 pages
- d. Mean emission factors for CH₄ and CO₂ from German inventory data (1990-1997)
- e. Gas vehicles. Bender & Langer, Mueller BBM “Determination of Emission Factors and Activity Data in the Area of the IPCC (1996) 1.B.2.b.iii - Fugitive Emissions from Natural Gas Storage”; Federal Environmental Agency of Germany, 2012 Funding code (FKZ): 360 16 035; Report no. M96023/01; 38 pages
- f. Medium value of table 4.2.8 of 2006 GL (g) (appliances) – conversion with density of 0.72 kg/m³, a CO₂ content of 0.9% and a NMVOC content of 2.8%
- g. Value from 1996 GL table 1-5-8 (h) (power plants) – conversion with factor 35 MJ/m, a CO₂ content of 0.9% and a NMVOC content of 2.8%

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1 B 2 b vi Other

Fugitive emissions (including leaks, venting and flaring) from natural gas systems not otherwise accounted for in the above categories. This may include emissions from well blowouts and pipeline ruptures or dig-ins, accidents, and emergency pressure releases. It is *good practice* to quantify and report such emissions as part of category 1.B.2.b.iii.6 whenever possible. There is no Tier 1 method available for such events, which need to be evaluated on a case-by-case basis, often using a combination of emission factors and engineering calculations. An example of calculating emissions during emergency conditions through an engineering calculation approach is given in the 2009 American Petroleum Institute's *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry*. Other examples of quantifying anomalous leak events include ARB's Aliso Canyon report (CARB 2016).

1 B 2 b vii Abandoned Gas Wells

Available information on abandoned oil and gas wells do not indicate a clear distinction between abandoned oil and abandoned gas wells regarding practices or emission factors. As such, please refer to the discussion for 1.B.2.a.vii for background and guidance on abandoned oil wells. The emission factors are presented in Table 4.2.8. In the future, as additional data on this source become available, distinct emission factors for oil and gas may be possible.

TIER 3 AND 2

Emission factors for conducting Tier 3 and Tier 2 assessments are not provided in the IPCC Guidelines due to the large amount of such information and the fact these data are continually being updated to include additional measurement results and to reflect development and penetration of new control technologies and requirements. Rather, the IPCC has developed an Emission Factor Database (EFDB) which will be periodically updated and is available at www.ipcc-nggip.iges.or.jp/EFDB/main.php. In addition, regular reviews of the literature and country-specific data available through inventories of countries with similar circumstances should still be conducted to ensure that the best available factors are being used. The references for the chosen values should be clearly documented. Typically, emission factors are developed and published by environmental agencies, industry associations and academic literature. It may be necessary to develop inventory estimates in consultation with these organizations. For example, the American Petroleum Institute (API) maintains a *Compendium of Emissions Estimating Methodologies for the Oil and Gas Industry*, most recently updated in 2009. The API Compendium is available at:

http://www.api.org/~media/Files/EHS/climate-change/2009_GHG_COMPENDIUM.pdf A software tool for estimating greenhouse gas emissions using equations from the API Compendium is available at:

<http://ghg.api.org>

Guidance for estimating greenhouse gas emissions has also been developed by a number of national oil and gas industry associations. Such documents may be useful supplemental references and often provide tiered source-specific calculation procedures. Guidance on inventory accounting principles as they apply to the oil and gas industry, and boundary definitions is available in the *Petroleum Industry Guidelines for Reporting Greenhouse Gas Emissions* (International Petroleum Industry Environmental Conservation Association, 2011):

http://www.api.org/~media/Files/EHS/climate-change/GHG_industry-guidelines-IPIECA.pdf.

When selecting emission factors, the chosen values must be valid for the given application and be expressed on the same basis as the activity data. It also may be necessary to apply other types of factors to correct for site and regional differences in operating conditions and design and maintenance practices, for example:

- Composition profiles of gases from particular oil and gas fields to correct for the amount of CH₄, formation CO₂ and other target emissions;
- Annual operating hours to correct for the amount of time a source is in active service;
- Efficiencies of the specific control measures used.

The following are additional matters to consider in choosing emission factors:

- It is important to assess the applicability of the selected factors for the target application to ensure similar or comparable source behaviour and characteristics;
- In the absence of better data, it may sometimes be necessary to apply factors reported for other regions that practice similar levels of emission control and feature comparable types of equipment;

- Where measurements are performed to develop new emission factors, only recognised or defensible test procedures should be applied. The method and quality assurance (QA)/quality control (QC) procedures should be documented, the sampled sources should be representative of typical variations in the overall source population and a statistical analysis should be conducted to establish the 95 percent confidence interval on the average results.
- Whether and how the emission factors may change over time due to changes in technologies or practices.

4.2.2.4 CHOICE OF ACTIVITY DATA

UPDATED TO MOVE SENTENCE ON PRODUCTION STATISTICS TO THIS SECTION, AND UPDATED TABLES TO REFLECT REVISIONS TO FACTORS AND NEW SUBCATEGORIES

The activity data required to estimate fugitive emissions from oil and gas activities includes production statistics, infrastructure data (e.g., inventories of facilities/installations, process units, pipelines, and equipment components), and reported emissions from spills, accidental releases, and third-party damages. The basic activity data required for each tier and each type of primary source are summarized in Table 4.2.6, Typical Activity Data Requirements for each Assessment Approach by Type of Primary Source Category. Production statistics provided by national bureaux should be used in favour of those available from international bodies, such as the IEA or the UN, due to their generally better reliability and disaggregation. Regional, provincial/state and industry reporting groups may offer even more disaggregation.

TIER 1

The activity data required at the Tier 1 level has been limited to information that may either be obtained directly from typical national oil and gas statistics or easily estimated from this information. Table 4.2.14 below lists the relevant activity data for each of the Tier 1 emission factors presented in Tables 4.2.3 to 4.2.13, and gives appropriate guidance for obtaining or estimating each of the required activity values.

TIER 2

The activity data required for the standard Tier 2 methodological approach is the same as that required for the Tier 1 approach. If the alternative Tier 2 approach described in Section 4.2.2.2 for crude oil systems is used, then additional, more detailed, information is required including average GOR values, information on the extent of gas conservation and factors for apportioning waste associated gas volumes between venting and flaring. This additional information should be developed based on input from the industry.

TIER 3

Approaches and level of disaggregation for Tier 3 estimates can vary widely. In the case of Tier 3, Table 4.2.14 lists examples of some activity data that might be used for Tier 3 estimates.

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TABLE 4.2.14 (ELABORATION) TYPICAL ACTIVITY DATA REQUIREMENTS FOR EACH ASSESSMENT APPROACH FOR FUGITIVE EMISSIONS FROM OIL AND GAS SYSTEMS BY TYPE OF PRIMARY SOURCE		
Assessment Tier	Primary Source	Activity Data
3	Process Venting/Flaring	Reported Volumes Gas Compositions Proration Factors for Splitting Venting from Flaring
	Storage Losses	Solution Gas Factors Liquid Throughputs Tank Sizes Vapour Compositions
	Equipment Leaks	Facility/Installation Counts by Type Processes Used at Each Facility Equipment Component Schedules by Type of Process Unit Gas/Vapour Compositions
	Gas-Operated Devices	Schedule of Gas-operated Devices by Type of Process Unit Gas Consumption Factors Type of Supply Medium Gas Composition
	Accidental Releases & Third-Party Damages	Incident Reports/Summaries
	Gas Migration to the Surface & Surface Casing Vent Blows	Average Emission Factors & Numbers of Wells
	Drilling	Number of Wells Drilled Reported Vented/Flared Volumes from Drill Stem Tests Typical Emissions from Mud Tanks
	Well Servicing	Tally of Servicing Events by Types
	Pipeline Leaks	Type of Piping Material Length of Pipeline
	Exposed Oils and/Oil Shale	Exposed Surface Area Average Emission Factors
	Abandoned wells	Number of leaking abandoned wells Total annual methane volumes from abandoned wells

2	Venting and Flaring from Oil Production	Gas to Oil Ratios Flared and Vented Volumes Conserved Gas Volumes Re-injected Gas Volumes Utilised Gas Volumes Gas Compositions
	All Others	See Table 4.2.15, which is relevant to Tier 2 as well as Tier 1.
	Abandoned wells	Number of onshore and offshore abandoned oil and gas wells (plugged and unplugged)
1	All	See table 4.2.15 below.

2333

2334 Table 4.2.15 below provides a list of the activity data values used in calculating emissions with a Tier 1 approach.
 2335 In general, values should be directly referenced from national statistics. Note that not all values present in the table
 2336 will be needed to calculate emissions. For most calculations, several emission factors are provided to correspond
 2337 with different activity data options. The inventory compiler should assess which activity data are available and
 2338 which activity data basis best reflects emissions in that segment for that country.

2339

TABLE 4.2.15 (ELABORATION)
GUIDANCE ON OBTAINING THE ACTIVITY DATA VALUES REQUIRED FOR USE IN THE TIER 1 APPROACH TO ESTIMATE FUGITIVE EMISSIONS FROM OIL AND GAS SYSTEMS

Segment	Sub-segment	Activity Data Values
Oil Exploration 1B.2.a.i	Unconventional without flaring or recovery	<ul style="list-style-type: none"> Unconventional oil wells drilled (without flaring or recovery), or Unconventional active oil wells (without flaring or recovery), or Thousand cubic meters unconventional oil production (without flaring or recovery)
	Unconventional with flaring or recovery	<ul style="list-style-type: none"> Unconventional oil wells drilled (with flaring or recovery), or Unconventional active oil wells (with flaring or recovery), or Thousand cubic meters unconventional oil production (with flaring or recovery)
	Conventional	<ul style="list-style-type: none"> Conventional oil wells drilled, or Conventional active oil wells, or Thousand cubic meters total conventional oil production
Oil Production 1.B.2.a.ii	Onshore: Most activities occurring with higher- emitting technologies and practices ^a	<ul style="list-style-type: none"> Thousand cubic meters onshore oil production (where production occurs with higher-emitting technologies and practices), or Active oil wells (where production occurs with higher-emitting technologies and practices)
	Onshore: Most activities occurring with lower-emitting technologies and practices ^b	<ul style="list-style-type: none"> Thousand cubic meters onshore oil production (where production occurs with lower-emitting technologies and practices), or Active oil wells (where production occurs with lower-emitting technologies and practices)
	Oil Sands Mining and Ore Processing ^c	<ul style="list-style-type: none"> Thousand cubic meters crude bitumen production from surface mining
	Oil Sands Upgrading ^c	<ul style="list-style-type: none"> Thousand cubic meters synthetic crude oil production
	Offshore: All ^d	<ul style="list-style-type: none"> Thousand cubic meters offshore oil production
	Oil Upgrading	<ul style="list-style-type: none"> Thousand cubic meters oil upgraded
Oil Transport 1.B.2.a.iii	Pipelines	<ul style="list-style-type: none"> Thousand cubic meters oil transported by pipeline
	Tanker Trucks and Rail Cars	<ul style="list-style-type: none"> Thousand cubic meters oil transported by Tanker Truck or rail car
	Tanks	<ul style="list-style-type: none"> Thousand cubic meters crude oil feed
	Loading of Off-shore Production on Tanker Ships without VRU	<ul style="list-style-type: none"> Thousand cubic meters oil transported by Tanker Ship without VRU
	Loading of Off-shore Production on Tanker Ships with VRU	<ul style="list-style-type: none"> Thousand cubic meters oil transported by Tanker Ship with VRU

Oil Refining 1.B.2.a.iv	All	<ul style="list-style-type: none"> Thousand cubic meters oil refined.
Refined Product Distribution 1.B.2.a.v	Gasoline	<ul style="list-style-type: none"> Thousand cubic meters product distributed.
	Other	<ul style="list-style-type: none"> Thousand cubic meters (e.g. diesel, aviation fuel, jet kerosene) transported.
Abandoned wells 1.B.2.a.vii	All	<ul style="list-style-type: none"> Number of abandoned wells, onshore and offshore, plugged and unplugged.
Gas Exploration 1.B.2.b.i	Unconventional without flaring or gas capture	<ul style="list-style-type: none"> Unconventional gas wells drilled without flaring or capture, or Unconventional active gas wells where exploration occurs without flaring or capture, or Thousand cubic meters unconventional gas production where exploration occurs without flaring or capture
	Unconventional with flaring or gas capture	<ul style="list-style-type: none"> Unconventional gas wells drilled with flaring or capture, or Unconventional active gas wells where exploration occurs with flaring or capture, or Thousand cubic meters unconventional gas production where exploration occurs with flaring or capture
	Conventional	<ul style="list-style-type: none"> Conventional gas wells drilled Conventional active gas wells Thousand cubic meters unconventional gas production where exploration occurs with flaring or capture
Gas Production 1.B.2.b.ii	Most activities occurring with higher-emitting technologies and practices ^a	<ul style="list-style-type: none"> Million cubic meters onshore gas production (where production occurs with higher-emitting technologies and practices), or Active gas wells (where production occurs with higher-emitting technologies and practices)
	Most activities occurring with lower-emitting technologies and practices ^b	<ul style="list-style-type: none"> Million cubic meters onshore gas production (where production occurs with lower-emitting technologies and practices), or Active gas wells (where production occurs with lower-emitting technologies and practices)
	Onshore Production – Coal Bed Methane	<ul style="list-style-type: none"> Million cubic meters onshore CBM production
	Gathering	<ul style="list-style-type: none"> Million cubic meters onshore gas production
	Offshore production	<ul style="list-style-type: none"> Million cubic meters offshore gas production
Gas Processing 1.B.2.b.iii	Without LDAR, less than 50% of centrifugal compressors have dry seals	<ul style="list-style-type: none"> Million cubic meters gas processed (where gas is processed without LDAR, and less than 50% of centrifugal compressors have dry seals), or Million cubic meters gas produced (where gas is processed without LDAR, and less than 50% of centrifugal compressors have dry seals)
	With LDAR, 50% or more of centrifugal compressors have dry seals	<ul style="list-style-type: none"> Million cubic meters gas processed (where gas is processed without LDAR, and 50% or more of centrifugal compressors have dry seals), or Million cubic meters gas produced (where gas is processed without LDAR, and 50% or more of centrifugal compressors have dry seals)
	Sour Gas Plants	<ul style="list-style-type: none"> Million cubic meters sour gas processed

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Gas Transmission & Storage 1.B.2.b.iv	Transmission: Most activities occurring with higher- emitting technologies and practices	<ul style="list-style-type: none"> • kilometre of transmission pipeline (where transmission occurs with higher-emitting technologies and practices), or • Million cubic meters of gas consumption pipeline (where transmission occurs with higher-emitting technologies and practices)
	Transmission: Most activities occurring with lower-emitting technologies and practices	<ul style="list-style-type: none"> • kilometre of transmission pipeline (where transmission occurs with lower-emitting technologies and practices), or • Million cubic meters of gas consumption pipeline (where transmission occurs with lower-emitting technologies and practices)
	Storage: Most activities occurring with higher- emitting technologies and practices	<ul style="list-style-type: none"> • Million cubic meters of gas consumption (where storage occurs with higher-emitting technologies and practices)
	Storage: Most activities occurring with lower-emitting technologies and practices	<ul style="list-style-type: none"> • Million cubic meters of gas consumption (where storage occurs with lower-emitting technologies and practices)
	LNG Import/Export	<ul style="list-style-type: none"> • Number of LNG Import/Export stations
	LNG Storage	<ul style="list-style-type: none"> • Number of LNG Storage stations
Gas Distribution 1.B.2.b.v	Less than 50% plastic pipelines, and limited or no leak detection and repair programs	<ul style="list-style-type: none"> • kilometre of distribution pipeline (where distribution occurs with less than 50% plastic pipelines, and limited or no leak detection and repair programs), or • Million cubic meters gas consumption
	Greater than 50% plastic pipelines, and leak detection and repair programs are in use	<ul style="list-style-type: none"> • kilometre of distribution pipeline (where distribution occurs with greater than 50% plastic pipelines, and leak detection and repair program), or • Million cubic meters gas consumption
	Short term surface storage	<ul style="list-style-type: none"> • Million cubic meters of gas stored in short term surface storage
	Distribution of town gas	<ul style="list-style-type: none"> • kilometre of pipeline distributing town gas
	Natural Gas Vehicles	<ul style="list-style-type: none"> • Total natural gas vehicles
	Appliances in commercial and residential sector	<ul style="list-style-type: none"> • Total appliances
	Industrial plants and power plants	<ul style="list-style-type: none"> • Million cubic meters non-residential and commercial gas consumed
Abandoned wells 1.B.2.b.vii	All	<ul style="list-style-type: none"> • Number of abandoned wells, onshore and offshore, plugged and unplugged

2341

2342 **TIER 3**

2343 Specific matters to consider in compiling the detailed activity data required for use in a Tier 3 approach include
 2344 the following:

- 2345 • Production statistics should be disaggregated to capture changes in throughputs (e.g., due to imports, exports,
 2346 reprocessing, withdrawals, etc.) in progressing through oil and gas systems.
- 2347 • Production statistics provided by national bureaux should be used in favour of those available from
 2348 international bodies, such as the IEA or the UN, due to their generally better reliability and disaggregation.
 2349 Regional, provincial/state and industry reporting groups may offer even more disaggregation.

- 2350 • Production data used in estimating fugitive emissions should be corrected, where applicable, to account for
2351 any net imports or exports. It is possible that import and export data may be available for a country while
2352 production data are not; however, it is unlikely that the opposite would be true
- 2353 • Where coalbed methane is produced into a natural gas gathering system, any associated fugitive emissions
2354 should be reported under the appropriate natural gas exploration and production categories. This will occur
2355 by default since the produced gas becomes a commodity once it enters the gas gathering system and
2356 automatically gets accounted for the same way gas from any other well does when it enters the gathering
2357 system. The fact that gas is coming from a coal formation would only be discernable at a very disaggregated
2358 level. Where a coal formation is degassed for the purposes of coal exploration or coal mining and handling,
2359 the associated emissions should be allocated to the coal sector under the appropriate section of IPCC category
2360 1.B.1.
- 2361 • Vented and flared volumes from oil and gas statistics may be highly suspect since these values are usually
2362 estimates and not based on actual measurements. Additionally, the values are often aggregated and simply
2363 reported as flared volumes. Operating practices of each segment of the industry should be reviewed with
2364 industry representatives to determine if the reported volumes are actually vented or flared, or to develop
2365 appropriate apportioning of venting relative to flaring. Audits or reviews of each industry segment should also
2366 be conducted to determine if all vented and flared volumes are actually reported (for example, solution gas
2367 emissions from storage tanks and treaters, emergency flaring/venting, leakage into vent/flare systems, and
2368 blowdown and purging volumes may not necessarily be accounted for).
- 2369 • Infrastructure data are more difficult to obtain than production statistics. Information concerning the numbers
2370 and types of major facilities and the types of processes used at these facilities may often be available from
2371 regulatory agencies and industry groups, or directly from the actual companies.
- 2372 • Information on minor facilities (e.g., numbers of field dehydrators and field compressors) usually is not
2373 available, even from oil and gas companies. Consequently, assumptions must be made, based on local design
2374 practices, to estimate the numbers of these facilities. This may require some fieldwork to develop appropriate
2375 estimation factors or correlations.
- 2376 • Many companies use computerised inspection-and-maintenance information management systems. These
2377 systems can be a very reliable means of counting major equipment units (e.g., compressor units, process
2378 heaters and boilers, etc.) at selected facilities. Also, some departments within a company may maintain
2379 databases of certain types of equipment or facilities for various internal reasons (e.g., tax accounting,
2380 production accounting, insurance records, quality control programmes, safety auditing, license renewals, etc.).
2381 Efforts should be made to identify these potentially useful sources of information.
- 2382 • Component counts by type of process unit may vary dramatically between facilities and countries due to
2383 differences in design and operating practices. Thus, while initially it may be appropriate to use values reported
2384 in the general literature, countries should strive to develop their own values.
- 2385 • Use of consistent terminology and clear definitions is critical in developing counts of facilities and equipment
2386 components, and to allow any meaningful comparisons of the results with others.
- 2387 • Some production statistics may be reported in units of energy (based on their heating value) and will need to
2388 be converted to a volume basis, or vice versa, for application of the available emission factors. Typically,
2389 where production values are expressed in units of energy, it is in terms of the gross (or higher) heating value
2390 of the product. However, where emission factors are expressed on an energy basis it is normally in terms of
2391 the net (or lower) heating value of the product. To convert from energy data on a GCV basis to a NCV basis,
2392 the International Energy Agency assumes a difference of 5 percent for oil and 10 percent for natural gas.
2393 Individual natural gas streams that are either very rich or high in impurities may differ from these average
2394 values. Emission factors and activity data must be consistent with each other.
- 2395 • Oil and gas imports and exports will change the activity levels in corresponding downstream portions of these
2396 systems.
- 2397 • Production activities will tend to be the major contributor to fugitive emissions from oil and gas activities in
2398 countries with low import volumes relative to consumption and export volumes. Gas transmission and
2399 distribution and petroleum refining will tend to be the major contributors to these emissions in countries with
2400 high relative import volumes. Overall, net importers will tend to have lower specific emissions than net
2401 exporters.

4.2.2.5 COMPLETENESS

UPDATED TO REMOVE REFERENCE TO PREVIOUS COMPLETENESS TABLE, WHICH WAS INCONSISTENT WITH BOTH 2006GL AND THE 2019 REFINEMENTS

Completeness is a significant issue in developing an inventory of fugitive emissions for the oil and gas industry. It can be addressed through direct comparisons with other countries and, for refined inventories, through comparisons between individual companies in the same industry segment and subcategory. This requires the use of consistent definitions and classification schemes. For example, in Canada, the upstream petroleum industry has adopted a benchmarking scheme that compares the emission inventory results of individual companies in terms of production-energy intensity and production-carbon intensity. Such benchmarking allows companies to assess their relative environmental performance. It also flags, at a high level, anomalies or possible errors that should be investigated and resolved.

The Tier 1 EF and their associated uncertainty ranges presented in Tables 4.2.3 to 4.2.13 may be used to assess reasonableness of Tier 2 and Tier 3 factors. If emissions from specific segments are appreciably less than the low end or greater than the high end of the uncertainty range, this should be explained; otherwise, it may be an indication of possible missed or double counted contributions, respectively.

Where emission inventories are developed based on a compilation of individual company-level inventories, care should be taken to ensure that all companies are included. Appropriate extrapolations may be needed to account for any non-reporting companies.

Smaller individual sources, when aggregated nationally over the course of a year, may often be significant total contributors. Therefore, *good practice* is not to disregard them. Once a thorough assessment has been done, a basis exists for simplifying the approach and better allocating resources in the future to best reduce uncertainties in the results.

Where a country has estimated its fugitive emissions from part or all of its oil and natural gas system based on a roll-up of estimates reported by individual oil and gas companies, it is *good practice* to document the steps taken to ensure that these results are complete, transparent and consistent across the time series. Corrections made to account for companies or facilities that did not report, and measures taken to avoid missed or double counting (particularly where ownership changes have occurred) and to assess uncertainties should be highlighted.

Where Tier 2 or Tier 3 approaches are used to calculate a subset of emissions (e.g. flaring), care should be taken to ensure that all remaining emissions (e.g. venting and fugitives) are accounted (e.g. using disaggregated Tier 1 factors in Appendix 4A.2).

4.2.2.6 DEVELOPING CONSISTENT TIME SERIES

UPDATED TO REFLECT CHANGING PRACTICES AND TECHNOLOGIES OVER TIME

Ideally, emission estimates will be prepared for the base year and subsequent years using the same method. The aim is to have emission estimates across the time series reflect true trends in greenhouse gas emissions. Emission or control factors that change over time (e.g., due to changes in source demographics or the penetration of control technologies) should be regularly updated and, each time, only applied to the period for which they are valid. For example, if an emission control device is retrofitted to a source then a new emission factor will apply to that source from then onwards; however, the previously applied emission factor reflecting conditions before the retrofit should still be applied for all previous years in the time series. If an emission factor has been refined through further testing and now reflects a better understanding of the source or source category, then all previous estimates should be updated to reflect the use of the improved factor and be reported in a transparent manner.

Tier 1 emission factors provided in table 4.2.3 to 4.2.13 are technology/practice-specific to the extent possible. A country should assess which technologies and practices are generally in place in the country and apply the corresponding emission factor. As technologies and practices change over time, it is possible that a country will use one EF in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series.

Where some historical data are missing, it should still be possible to use source-specific measurement results combined with back-casting techniques to establish an acceptable relationship between emissions and activity data in the base year. Approaches for doing this will depend on the specific situation, and are discussed in general terms in Volume 1 Chapter 5 of the 2006 Guidelines.

If emission estimates are developed based on a roll-up of individual company estimates, greater effort will be required to maintain time series consistency, particularly where frequent facility ownership changes occur and

different methodologies and emission factors are applied by each new owner without also carrying these changes back through the time series.

4.2.2.7 UNCERTAINTY ASSESSMENT

UPDATED TO REFLECT CHANGING PRACTICES AND TECHNOLOGIES OVER TIME

Sources of error that may occur include the following:

- Measurement errors;
- Extrapolation errors;
- Inherent uncertainties of the selected estimation techniques;
- Missing or incomplete information regarding the source population and activity data;
- Poor understanding of temporal and seasonal variations in the sources;
- Over or under accounting due to confusion or inconsistencies in category divisions and source definitions;
- Misapplication of activity data or emission factors (including due to incomplete information for assigning technology- and practice-specific emission factors);
- Errors in reported activity data;
- Missed accounting of intermediate transfer operations and reprocessing activities (for example, re-treating of slop oil, treating of foreign oil receipts and repeated dehydration of gas streams: in the field, at the plant, and then following storage);
- Differences in the effectiveness of control devices, potential deterioration of their performance over time and missed accounting of control measures.

Guidance regarding the assessment of uncertainties in emission factors and activity data are presented in the subsections below.

4.2.2.7.1 EMISSION FACTOR UNCERTAINTIES

The uncertainty in an emission factor will depend both on the accuracy of the measurements upon which it is based and the degree to which these results reflect the average behaviour of the target source population. Accordingly, emission factors developed based on data measured in one country may have one set of uncertainties when the factors are applied in that country and another set of uncertainties when they are applied similarly in a different country. Thus, while it is difficult to establish one set of uncertainties that will always apply, a set of default values has been provided for the default factors provided in Tables 4.2.3 through 4.2.13. These uncertainties are estimated based on expert judgement and reflect the level of uncertainty that may be expected when the corresponding emission factors are used to develop emission estimates at the national level. Use of the presented factors to estimate emissions from individual facilities or sources would be expected to result in much greater uncertainties.

4.2.2.7.2 ACTIVITY DATA UNCERTAINTIES

The percentages cited in this section are based on expert judgement and aim to approximate the 95 percent confidence interval around the central estimate. Gas compositions are usually accurate to within 5 percent on individual components. Flow rates typically have errors of 3 percent or less for sales volumes and 15 percent or more for other volumes. Production statistics or disposition analyses may not agree between different reporting agencies even though they are based on the same original measurement results (e.g. due to possible differences in terminology and potential errors in summarising these data). These discrepancies may be used as an indication of the uncertainty in the data. Additional uncertainty will exist if there is any inherent bias in the original measurement results (for example, sales meters are often designed to err in favour of the customer, and liquid handling systems will have a negative bias due to evaporation losses). Random metering and accounting errors may be assumed to be negligible when aggregated over the industry.

Where available, counts of major facilities (e.g., gas plants, refineries and transmission compressor stations) may be known with little error (e.g., less than 5 percent). Where errors in these counts occur it is usually due to some uncertainties regarding the number of new facilities built and old facilities decommissioned during the time period.

Counts of well site facilities, minor field installations and gas gathering compressor stations, as well as the type and amount of equipment at each site, will be much less accurately known, if known at all (e.g., at least ± 25 percent uncertainty or more).

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Estimates of emission reductions from individual control actions may be accurate to within a few percent to □25 percent depending on the number of subsystems or sources considered.

4.2.3 Inventory Quality Assurance/Quality Control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Volume 1 Chapter 6 of the *2006 IPCC Guidelines*, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks, as outlined in Volume 1 Chapter 5 of the *2006 IPCC Guidelines*, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1 Chapter 4 of the *2006 IPCC Guidelines*.

In addition to the guidance in Volume 1 Chapter 6 of the *2006 IPCC Guidelines*, specific procedures of relevance to this source category are outlined below.

REVIEW OF DIRECT EMISSION MEASUREMENTS

UPDATED TO REFLECT THE LATEST INFORMATION

If direct measurements are used to develop country-specific emission factors, the inventory compiler should establish whether measurements at the sites were made according to recognised standard methods. If the measurement practices fail this criterion, then the use of these emissions data should be carefully evaluated, estimates reconsidered and qualifications documented. The compiler should also assess key background information in the study, such as, what activities are occurring and what equipment in place (including controls) at the time of measurement and whether the measurements are representative of average conditions for that activity and may be applied as an average factor, or if it should be adjusted for different operating practices, etc. The compiler should confirm that the categorizations (e.g. for equipment and practices) used in the study are the same as used in the inventory, and should make adjustments if not. The national representativeness of the factors should also be assessed. As applicable, the attribution of measured emissions to the specific equipment or broader category should also be assessed.

ACTIVITY DATA CHECK

Several different types of activity data may be required for this source category, depending on which methodological tier is used to estimate the emissions. Where activity data are available from multiple sources (i.e. from national statistics and industry organisations) these data sets should be checked against each other to assess reasonableness. Significant differences in data should be explained and documented. Trends in the main emission drivers and activity data over time should be checked and any anomalies investigated.

EXTERNAL REVIEW AND STAKEHOLDER INVOLVEMENT

Emission inventories for large, complex oil and gas industries may be susceptible to errors due to missed or unaccounted for sources, or due to customization of average emission factors taken from a data source that represents estimates from another country or region with operating characteristics different from those in the country where the emission factor is being applied. To minimise such errors, it is important to obtain active involvement of industry and other technical experts in the preparation and refinement of these inventories. This will be especially important in the selection of appropriate technology- and practice-specific emission factors.

4.2.4 Reporting and Documentation

UPDATED TO REFLECT CHANGING PRACTICES AND TECHNOLOGIES OVER TIME, AND UPDATED DISAGGREGATION BY SEGMENT

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates, as outlined in Volume 1 Chapter 8 of the *2006 Guidelines*.

It may not be practical to include all supporting documentation in the inventory report. However, at a minimum, the inventory report should include summaries of the methods used and references to source data such that the reported emissions estimates are transparent and the steps in their calculation may be retraced. For segments where a technology- or practice-specific Tier 1 emission factor is used, the rationale for selecting that factor and the method for applying the factors over the time series must be clearly documented. It is expected that many countries will use a combination of methodological tiers to evaluate the amount of fugitive greenhouse gas emissions from the different parts of their oil and natural gas systems. The specific choices should reflect the relative importance of the different subcategories and the availability of the data and resources needed to support the corresponding

calculations. Table 4.2.15 is a sample template, with some example data entries, that may be used to conveniently summarize the applied methodologies and sources of emission factors and activity data. Tier 1 EF are inclusive of venting, flaring, and leak emissions. For calculations, compilers may separate their emissions into the separate categories of venting, flaring and leaks if data are available. Emissions reported for each segment should be inclusive of venting, flaring, and leak emissions (i.e., should represent the total emissions for that segment). If a compiler chooses to report disaggregated data on venting and flaring, they may do so as information items.

Since emission factors and estimation procedures are continually being improved and refined, it is possible for changes in reported emissions to occur without any real changes in actual emissions. Accordingly, the basis for any changes in results between inventory recalculations should be clearly discussed and those due strictly to changes in methods and factors should be highlighted.

The issue of confidential business information will vary from region to region depending on the number of firms in the market and the nature of the business. The significance of this issue tends to increase in progressing downstream through the oil and gas industry. A common means to address such issues where they do arise is to aggregate the data using a reputable independent third party.

The above reporting and documentation guidance is applicable to all methodological choices. Where Tier 3 approaches are employed, it is important to ensure that either the applied procedures are detailed in the inventory report or that available references for these procedures are cited since the IPCC Guidelines do not describe a standard Tier 3 approach for the oil and gas sector. There is a wide range in what potentially may be classified as a Tier 3 approach, and correspondingly, in the amount of uncertainty in the results. If available, summary performance and activity indicators should be reported to help put the results in perspective (e.g. total production levels and transportation distances, net imports and exports, and specific energy, carbon and emission intensities). Reported emission results should also include a trend analysis to show changes in emissions, activity data and emission intensities (i.e., average emissions per unit of activity indicator) over time. The expected accuracy of the results should be stated and the areas of greatest uncertainty clearly noted.

The current trend by some government agencies and industry associations is to develop detailed methodology manuals and reporting formats for specific segments and subcategories of the industry. This is perhaps the most practical means of maintaining, documenting and disseminating the subject information. However, all such initiatives must conform to the common framework established in the IPCC Guidelines so that the emission results can be compared across countries.

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TABLE 4.2.16 (ELABORATION) FORMAT FOR SUMMARIZING THE APPLIED METHODOLOGY AND BASIS FOR ESTIMATED EMISSIONS FROM OIL AND NATURAL GAS SYSTEMS SHOWING SAMPLE ENTRIES											
IPCC Code	Category, Sub-category or Segment	Sub-segment (if applicable)	Source Type (all, vent, flare, leak)	Method	Activity Data			Emission Factors			
					Type	Basis	Year	Basis/Reference ⁷			Date Country Specific Values Updated
								CH ₄	CO ₂	N ₂ O	
1.B.2	Oil and Natural Gas										
1.B.2.a	Oil										
1.B.2.a.i	Exploration										
1.B.2.a.ii	Production and Upgrading										
1.B.2.a.iii	Transport										
1.B.2.a.iv	Refining										
1.B.2.a.v	Distribution of oil products										
1.B.2.a.vi	Other										
1.B.2.a.vii	Abandoned Wells										
1.B.2.b	Natural Gas										

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⁷ Include here information on basis for selecting technology/practice-specific factors, as applicable.

TABLE 4.2.16 (ELABORATION) (CONTINUED)											
FORMAT FOR SUMMARIZING THE APPLIED METHODOLOGY AND BASIS FOR ESTIMATED EMISSIONS FROM OIL AND NATURAL GAS SYSTEMS SHOWING SAMPLE ENTRIES											
IPCC Code	Category, Sub-category or Segment	Sub-segment (if applicable)	Source Type (all, vent, flare, leak)	Method	Activity Data			Emission Factors			
					Type	Basis	Year	Basis/Reference			Date Country Specific Values Updated
								CH ₄	CO ₂	N ₂ O	

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1.B.2.b.i	Exploration										
1.B.2.b.ii	Production	Well Servicing	All	Tier 1	Number of Active Wells	National Statistics	2005	D	D	D	---
		Gas Production	Equipment Leaks	Tier 1	Throughput	National Statistics	2005	EFDB	EFDB	EFDB	---
1.B.2.b.iii	Processing	All	Equipment Leaks	Tier 1	Throughput	National Statistics	2005	D	EFDB	EFDB	---
1.B.2.b.iv	Transmission and Storage	Gas Transmission	Equipment Leaks	Tier 2	Number of facilities	Industry Survey	2005	CS	CS	----	2005
1.B.2.b.v	Distribution										
1.B.2.b.vi	Other										
1.B.2.b.vii	Abandoned Wells										
1.B.3	Other emissions from Energy Production										
AP – API Compendium D – IPCC Default Emission Factors CS – Country-Specific Emission Factors EFDB – IPCC Emission Factor Database											

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4.3 FUGITIVE EMISSIONS FROM FUEL TRANSFORMATION

Intentional or unintentional release of greenhouse gases may occur during the extraction, processing and delivery of fossil fuels to the point of final use. These are known as fugitive emissions.

4.3.1 Overview and description of sources

This section is a new guidance. It clarifies how fugitive emissions from fuel transformation should be estimated. Emissions from these fuel transformation activities link to the Energy, IPPU and AFOLU sectors and cross references are provided to the relevant sections in the guidelines. Inventory compilers should ensure all emissions from specific fuel transformation activities are captured in the inventory.

Fugitive emissions from the following fuel transformation activities have been included in this section - charcoal production, coke production, other solid fuels to solid fuels, coal to liquid, gas to liquid, biomass to liquid, biomass to gas, and refineries. The boundaries for all these transformation activities are the respective transformation process boundaries, and fugitive emissions in upstream and downstream supply chains are to be estimated using appropriate methodologies elsewhere in these guidelines, including in other volumes.

TABLE 4.3.1 ESTIMATION AND REPORTING OF FUGITIVE EMISSIONS FROM FUEL TRANSFORMATION				
Fuel transformation	Methods for estimating <u>fugitive emissions</u> from the transformation of this fuel are set out in the following section of the Guidelines	<u>Fugitive emissions</u> from the transformation of this fuel should be reported under the following category	Methods for estimating emissions from the use of this fuel for <u>energy purposes</u> are set out in the following section of the Guidelines	Emissions from the use of this fuel for <u>energy purposes</u> should be reported under the following categories
Charcoal production	4.3.2.1	1B1c	[add reference]	1A (and subcategories)
Coke production	4.3.2.2	1B1c	[add reference]	1A (and subcategories)
Wood pellet production	4.3.2.3 Appendix 4a.2	1B1c	[add reference]	CH ₄ , N ₂ O in 1A (and subcategories) CO ₂ as a memo item “CO ₂ emissions from biomass”
Gasification transformation	4.3.2.4 Appendix 4a.3	1B1c	[add reference]	1A (and subcategories)
Notes: 1B1c Solid Fuel Transformation				

4.3.2 Methodological issues

4.3.2.1 CHARCOAL PRODUCTION

About half the wood extracted worldwide from forests is used to produce energy, mostly for cooking and heating. Some of the wood is used to make charcoal. The share of energy use from harvested wood is as high as 90 percent in Africa and more than 60 percent in Asia. An estimated 17 per cent of wood extracted from forests was converted to charcoal (FAO, 2016a), and most of the remainder was used in the form of fuelwood, producing 2 – 7 percent of global anthropogenic emissions. Charcoal production can be on very small scales (domestic) to larger scales (industrial), is normally poorly regulated with little or no emission control. Emissions are due largely to unsustainable forest management, inefficient charcoal manufacture and woodfuel combustion (FAO, 2017; AFREA, 2011).

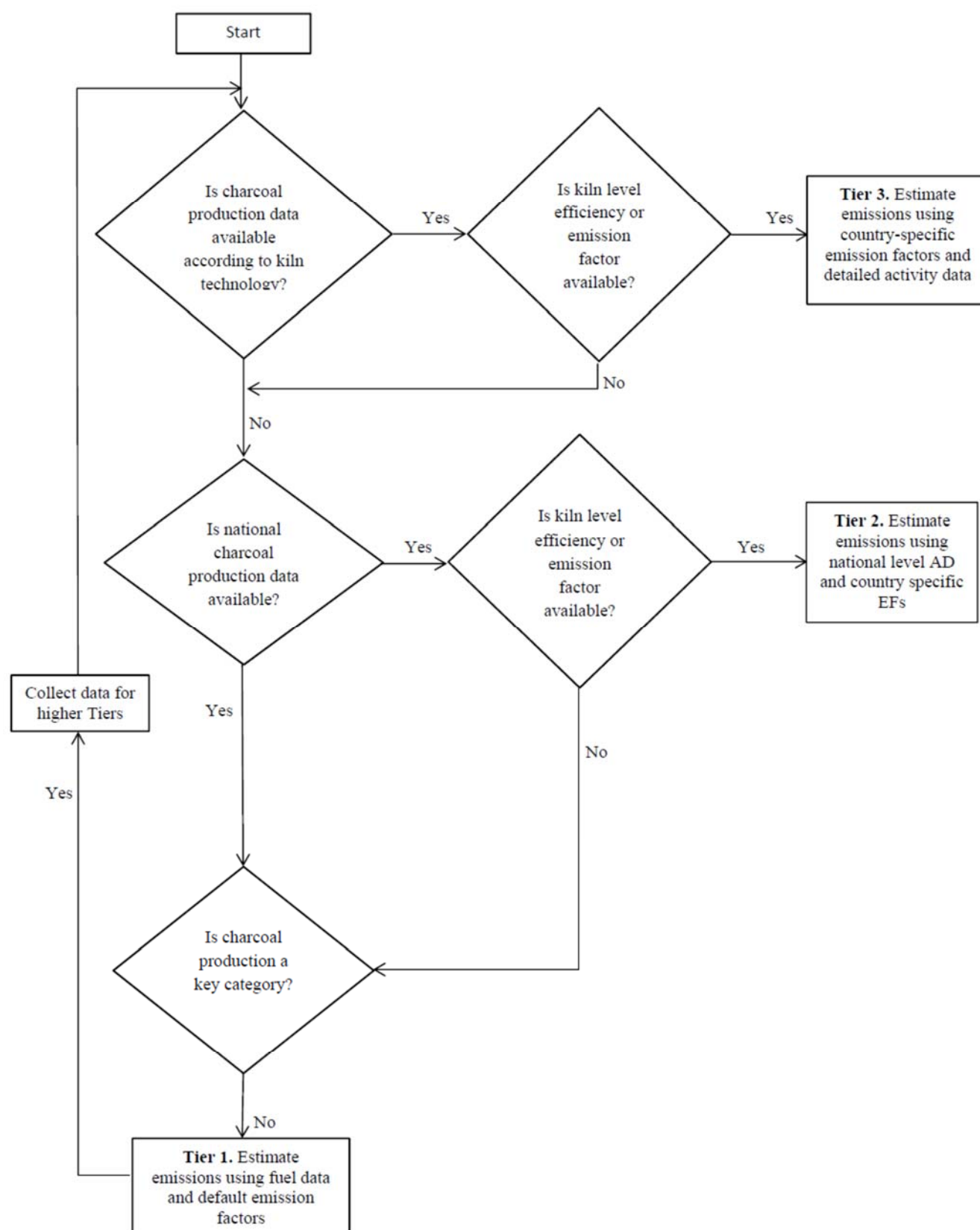
Charcoal produced using sustainably managed resources and improved technologies, however, is a low net emitter of greenhouse gases, thereby helping mitigate climate change while also increasing access to energy and food and providing income-generating opportunities (Iiyama *et al.*, 2014b; Schure, Levang and Wiersum, 2014).

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Charcoal is produced by the carbonization of wood. Carbonization of fuel is the thermal decomposition in the absence of oxygen at a temperature above 300°C. The carbonization of wood produces charcoal, volatile compounds and a range of gases. The gases produced include direct greenhouse gases (CO₂, CH₄ and N₂O), indirect greenhouse gases (CO) and other gases, including H₂. Emissions of biogenic CO₂ from charcoal production are considered under Agriculture, Land Use Change and Forestry (AFOLU). Fugitive emissions of CH₄ and N₂O are highly likely to occur.

CHOICE OF METHODS, DECISION TREES, TIERS

Figure 4.3.1 shows the decision tree for estimating fugitive emissions from charcoal production activities. For countries with kiln-level charcoal production data, or kiln type data, and who have kiln efficiency or emission factor data available, a Tier 3 estimation could be applied. For countries where country level charcoal production data is available, a country specific EF may be estimated and applied in a Tier 2 approach. However, if charcoal production is a *key category*, estimate emissions using higher tiers, and if it is not a *key category* estimate emissions using Tier 1.

2626 **Figure 4.3.1 Decision tree for charcoal production**

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Tier 1

The general form of the equation for estimating emissions for Tier 1 approach, based on charcoal production activity data is given by Equation 4.3.1 below.

$$\text{Emissions}_{GHG, \text{ charcoal produced}} = \text{Charcoal produced} \bullet \text{Emission Factor}_{GHG}$$

Where:

Emissions_{GHG, charcoal produced} = emissions of a given GHG by type of fuel (kg GHG)

Charcoal produced = amount of charcoal produced [units]

Emission Factor_{GHG} = emission factor according to charcoal kiln type, and GHG (kg GHG/unit of charcoal produced)

Tier 1 emission factors are given in Table 4.3.2.

Tier 2 & 3

The Tier 2 and 3 methods uses Equation 4.3.1, but with higher tier or country specific EF. It is *good practice* for inventory compilers to apply an emission factor in Table 4.3.2 suitable to the technologies in use.

CHOICE OF EMISSION FACTOR

Table 4.3.2 provides default Emission factors calculated as median from various studies and the lower limit and upper limits of charcoal production.

TABLE 4.3.2 DEFAULT EMISSION FACTORS FOR CHARCOAL PRODUCTION ACCORDING TO KILN TECHNOLOGY (g GHG / kg of charcoal produced)			
Gas	Default Emission Factor	Lower limit	Upper Limit
CO ₂ ^a	1570	966	2510
CH ₄	40.3	12.7	89.0
N ₂ O	0.08	0.02	0.21
CO	220	106	336
NO _x	0.07	0.03	0.11
Notes: Sources of data Bailis (2009); Taccini (2010), Chidumayo and Gumbo (2013), Müller, Michaelowa & Eschman (2011), Pennise et al. (2001), Smith et al. (1999), UNDP (2013) ^a CO ₂ emissions are reported as Memo item since charcoal production is a biogenic source.			

CHOICE OF ACTIVITY DATA

Preference must be given to sourcing accurate charcoal production data. Charcoal production might be available in national energy balances. The quantities of charcoal produced might be recorded by statistical agencies, and could be estimated from the weight or volume of wood used to make charcoal. But, production may not be solely for domestic purposes, and some charcoal produced might be exported. Total charcoal production can be estimated by measuring the charcoal produced in each kiln countrywide each year. Measurement is done by weighing the bags of charcoal produced at each site. If gravimetric production activity is not available, quantities of charcoal produced can be approximately estimated from the product of the number of charcoal bags filled assuming each weight of each bag is known. Estimates of production made in this way should not be used for an inventory, but could be used to help verify production data from other sources.

UNCERTAINTY ASSESSMENT

The uncertainty associated with charcoal production is high as the use of this fuel is typically not accurately recorded at national level, and, most of the traditional charcoal makers do not measure the quantities of charcoal

produced. Uncertainties associated with the charcoal production data might be available from statistical data. If such data are not available, then expert elicitation and expert judgement can be used. The uncertainties associated with the emission factors are very high. The emission factors depend on the type of kiln and corresponding efficiency. Since most of the charcoal is produced by traditional mound methods, which are not standardized, the emission factors will necessarily be highly uncertain.

TABLE 4.3.3 DEFAULT UNCERTAINTY ASSESSMENT FOR EMISSION FACTORS FROM CHARCOAL PRODUCTION		
Kiln technology	CH ₄	N ₂ O
Low efficiency kiln	Order of magnitude ^a	Order of magnitude ^a
High efficiency kiln	Order of magnitude ^a	Order of magnitude ^a
Mound kiln	Order of magnitude ^a	Order of magnitude ^a
Note: ^a Having an uncertainty range from one-tenth of the mean value to ten times the mean value. Source: Expert judgement		

4.3.2.2 COKE PRODUCTION

To ensure the estimates of total fugitive GHG emissions from coke production are complete, emissions should be estimated from unintentional leakage during the coke production process and from any flaring of coke oven gases. It is noted that inventory compilers may find it difficult to estimate the quantities of GHGs released from unintentional leakage because the activity data necessary may not be available.

FUGITIVE EMISSIONS FROM UNINTENTIONAL LEAKAGE

Coke is produced by the pyrolysis of coal. Coal pyrolysis at high temperature is called carbonisation. The process produces coke, volatile compounds and a range of gases. In the coke production process, the temperature of the flue-gases from under firing is normally 1150 – 1350 °C indirectly heating the coal up to 1 000 – 1 100°C for 14 – 28 hours (JRC, 2013). Coke is the most important reducing agent in hot metal production and removes the oxygen either indirectly by forming carbon dioxide or directly using its inherent carbon content. The gasification of the coke also serves to supply the heat necessary for the reduction process. Coke functions both as a support material and as a matrix through which gas circulates in the stock column.

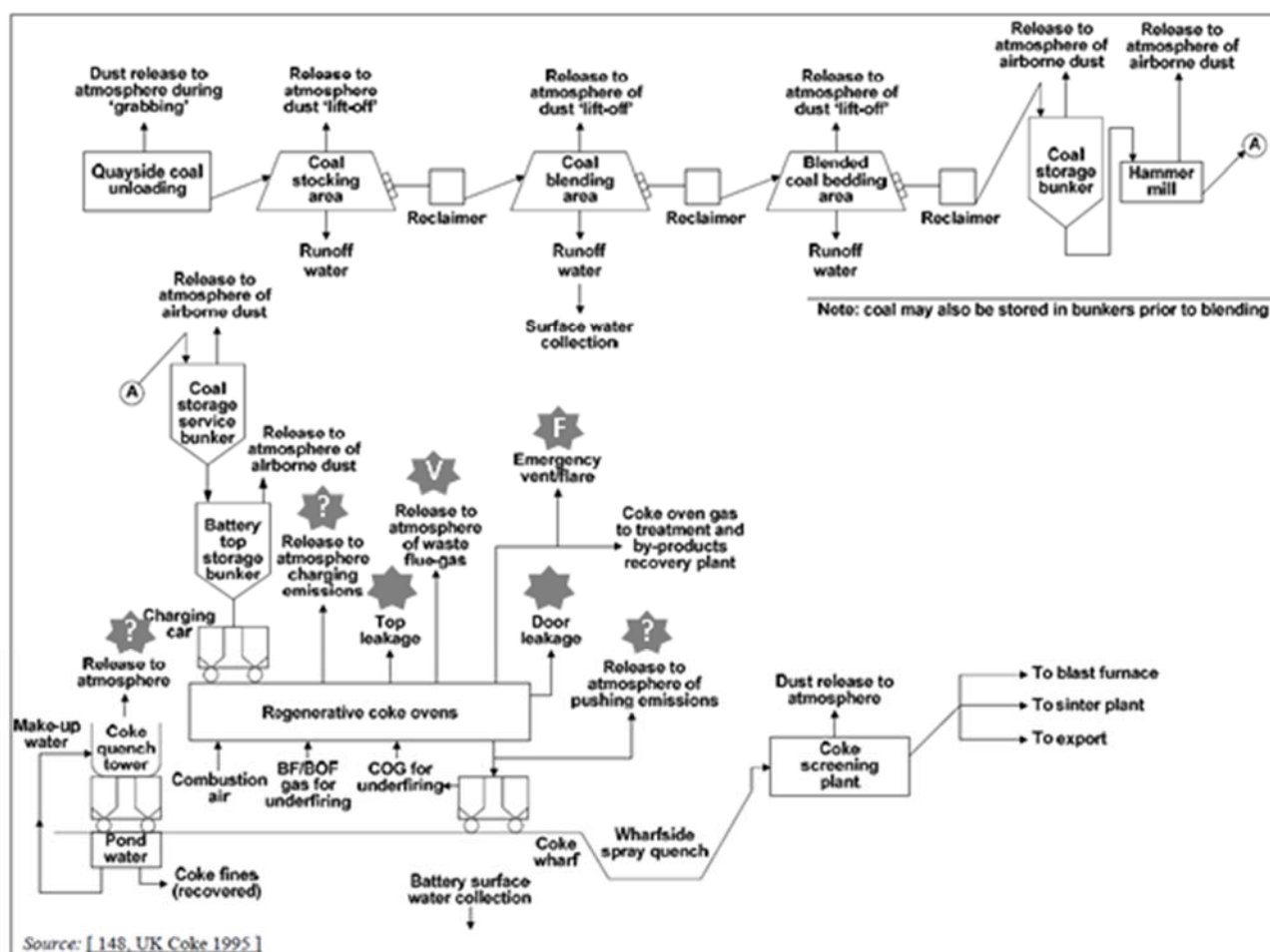
Globally the production of coking coal and associated coke oven gas (COG) is significant. In 2014, 711 173 ktce of coking coal were produced.

Only certain coals, for example coking or bituminous coals, with the right plastic properties, can be converted to coke and, as with ores, several types may be blended to improve blast furnace productivity and extend coke battery life. Other materials which contain carbon can also be used for making coke in small quantities (e.g. petroleum coke, used crushed rubber tyres). Oil or oil residues are added to give a better compaction of the coal.

Since the 1940s, the coke production process has been mechanised and the materials used in the construction of the ovens have been improved without significant design modifications. Horizontal chamber coking is the common coke plant. Batteries may contain up to 70 ovens as large as 14 m long and 6 m high. Because of heat transfer considerations, widths have remained at between 0.3 and 0.6 m. Each oven in the battery holds up to 30 tonnes of coal. Some recently constructed coke oven plants have increased dimensions further. ‘Heat recovery’ coke making gained importance during recent years, although this technique is not applied in Europe to date. Heat recovery coke making needs oven systems which differ clearly in design when comparing with conventional horizontal chamber systems (JRC, 2013).

Figure 4.3.2 shows a typical flow diagram of a coke oven plant showing all sources of emissions.

Figure 4.3.2 Typical flow diagram of a coke oven plant showing emissions sources



Legend:

★ Likely significant source of GHG emissions

★? Possible sources of GHG emissions

★V Venting of GHG emissions

★F Flaring / Venting of GHG emissions

The coke-making process can be subdivided into several stages. Fugitive emissions of varying intensities are possible at each of these stages:

- coal handling and preparation;
- battery operation (coal charging, heating/firing, coking, coke pushing, coke quenching);
- coke handling (discharge, storage, conveyance) and preparation;
- coke oven gas (COG) treatment with recovery and treatment of by-products in the case of a conventional coking plant recovery of the heat of the cooking and treatment of the flue gas in the case of a heat recovery coking plant.

METHODOLOGICAL ISSUES

CHOICE OF METHODS, DECISION TREES, TIERS

There are many potential sources of fugitive emissions from the coking process. Table 4.3.4 provides a summary of likely emissions according to coke production processing stage.

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TABLE 4.3.4 COMMENTARY ON FUGITIVE GREENHOUSE GAS EMISSIONS FROM COKE PRODUCTION ACCORDING TO PROCESSING STAGE						
Coke production processing stage	Summary of activity (operation)	Likelihood of fugitive emissions (Y = Yes; P = possible; U = unlikely)			Source and significance of fugitive emissions	Notes
		CO ₂	CH ₄	N ₂ O		
coal handling and preparation	<ul style="list-style-type: none"> The coke ovens are charged with pulverised coal Stamp charging might be used to compact the coking coal 	N	Y	N	<ul style="list-style-type: none"> CH₄ emissions could be significant, especially from gassy coal 	<ul style="list-style-type: none"> Emissions of CH₄ from gassy coal in storage prior to use in the coking ovens are not considered as part of this methodology These emissions should be considered as part of coal handling and storage under 1B1ai2
heating/firing of the chambers	<ul style="list-style-type: none"> The individual coke oven chambers are separated by heating walls In order to improve energy efficiency, regenerators are located directly under the ovens, exchanging heat from flue-gases with combustion air and/or process gases (COG) 	N	P	N	<ul style="list-style-type: none"> CH₄ emissions could occur, especially from gassy coal Emissions might occur if the heating walls are not completely gas-tight 	<ul style="list-style-type: none"> If the heating walls are not completely gas-tight because of cracks, coke oven gas produced during coking will reach the flue-gas and will cause incomplete combustion resulting in emissions at the stack
coking	<ul style="list-style-type: none"> The complete coking process takes around 14 – 28 hours, depending e.g. on the width of the oven (in case of heating by the side), the density of coal and on the quality of the desired coke (e.g. use in foundries or blast furnaces) 	P	P	P	<ul style="list-style-type: none"> Fugitive emissions could occur through leakage of unburnt COG because of poor sealing in the coke batteries, particularly around the door seals, and, from any flaring of the COG produced N₂O and CO₂ would only be released from flaring of COG The magnitude of the emissions could vary from insignificant to perhaps 5% of the COG produced 	<ul style="list-style-type: none"> <u>Emissions from the fuel used to heat the coke batteries should be reported in the energy sector using the methodologies set out in the stationary combustion chapter</u> Coke yield and COG production and composition depend, to a large extent, on coal composition and coking time

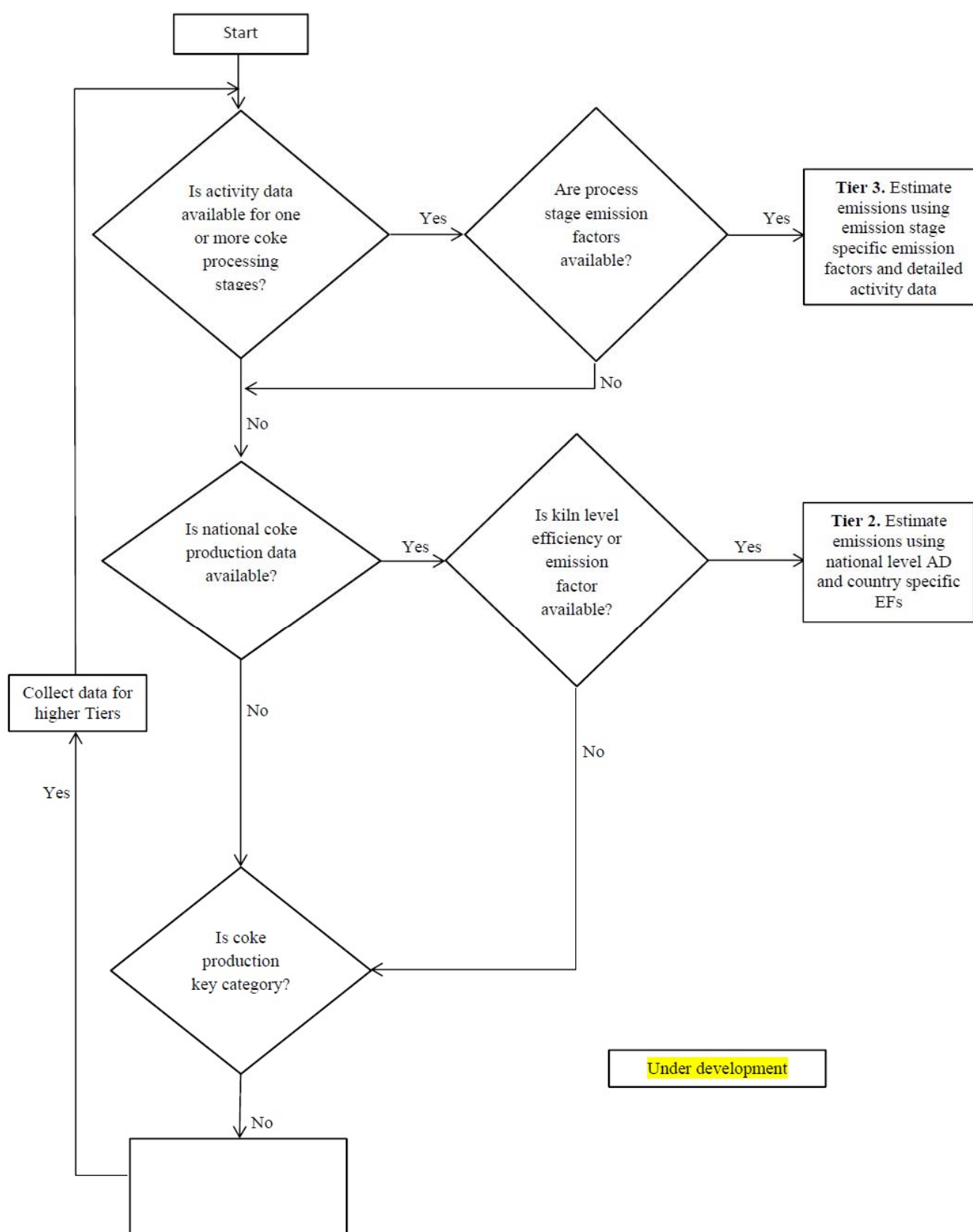
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TABLE 4.3.4
COMMENTARY ON FUGITIVE GREENHOUSE GAS EMISSIONS FROM COKE PRODUCTION ACCORDING TO PROCESSING STAGE

Coke production processing stage	Summary of activity (operation)	Likelihood of fugitive emissions (Y = Yes; P = possible; U = unlikely)			Source and significance of fugitive emissions	Notes
		CO ₂	CH ₄	N ₂ O		
coke pushing	<ul style="list-style-type: none"> Fully-carbonised coke is pushed out of the oven into a container by the ram of the pusher machine usually in less than one minute 	N	P	N	<ul style="list-style-type: none"> Possibility of very small emissions of CH₄ as the coke is pushed out of the batteries from residual COG in the coke batteries 	<ul style="list-style-type: none"> Fugitive emissions from this activity will be very small relative to the other likely fugitive emissions from coke production
coke quenching	<ul style="list-style-type: none"> Wet quenching and dry quenching techniques can be used Wet quenching consumes large volumes of water. The temperature of the coke is reduced from 1 100 to 80 °C to avoid combustion For dry quenching, the quenching car takes the hot coke to a vertical quenching chamber. Inert quenching gas circulates around the chamber, which is isolated from the atmosphere, preventing combustion whilst cooling the coke. The gas is cooled by a heat exchanger in order to recover thermal energy 	N	U	N	<ul style="list-style-type: none"> Possibility of very small emissions of CH₄ from residual COG as the coke is pushed out of the batteries 	<ul style="list-style-type: none"> Fugitive emissions from this activity will be very small relative to the other likely fugitive emissions from coke production

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2717 **Figure 4.3.3 Decision tree for estimating fugitive emissions from coke production process**



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 2719 Fugitive emissions can occur during coking operations from leakages at the battery, for example, because of
 2720 leakage from vessels, oven doors, flanges, or at the by-product plant. Fugitive emissions occur also from the

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ascension pipe and charging hole sealings. The magnitude of these emissions will depend on the coke oven technology and the level of maintenance. The variability in the magnitude of fugitive emissions will be large.

Specific door emissions vary widely depending upon the type of doors, the size of ovens and the quality of maintenance. Maintenance can be a determining factor. Examples of good results with traditional (knife-edged) doors on well-maintained small ovens and poor results with modern flexible sealing doors on poorly maintained large ovens can be found (Eurofer, 2007).

Because of the high expenditure for leakage monitoring, there is very little actual data available for fugitive emissions caused by battery operation.

Tier 1

The general form of the equation for estimating emissions for a Tier 1 approach, based on coke production activity, is given by Equation 4.3.2 below.

$$\text{Emissions}_{GHG} = \text{Activity}_{\text{coke production}} \bullet \text{Emission Factor}_{GHG}$$

Where:

Emissions_{GHG} = emissions of a given GHG by coke production (kg GHG)
 $\text{Activity}_{\text{coke production}}$ = amount of coke produced (tonnes)
 $\text{Emission Factor}_{GHG}$ = emission factor for each GHG (kg GHG/tonne of coke produced)

Tier 3

The more detailed form of the equation for estimating emissions for a Tier 3 approach, based on coke production activity stage and activity at each stage, is given by Equation 4.3.3 below.

$$\text{Emissions}_{GHG} = \text{Activity}_{\text{coke production processing stage}} \bullet \text{Emission Factor}_{GHG}$$

Where:

Emissions_{GHG} = emissions of a given GHG by coke production processing stage (kg)
 $\text{Activity}_{\text{coke production processing stage}}$ = amount of activity for each processing stage (tonnes)
 $\text{Emission Factor}_{GHG}$ = emission factor according to coke production processing stage for each GHG (kg GHG/tonne of coke production processing stage)

In a Tier 3 approach, the inventory compilers could use emission measurement data for one or more of the coke processing stages, or, possibly use a detailed fugitive predictive emission model. Any models should be verified. If measurements of fugitive emissions are used, it is *good practice* for inventory compilers to explain the rationale behind the emission measurement campaign, how measurements were made, and, if the measurements are applicable to individual coke batteries only or can be applied more widely to other batteries in the country also. Any measurement campaigns should focus on the sources in Table 4.3.4 associated with the greatest likelihood of emissions.

Coking coal in storage prior to being used in coke batteries may degas and release CH₄. The guidance in this section does not cover the release of CH₄ from gassy coal. However, inventory compilers should be aware of the possibility of emissions from this source and estimate and report emissions to the guidance in Section 4.1.

CHOICE OF EMISSION FACTOR

Table 4.3.5 provides default emission factors for fugitive emissions from coke production for use with the Tier 1 methodology.

TABLE 4.3.5 DEFAULT EMISSION FACTORS FOR COKE PRODUCTION		
Gas	Emission Factor	Source
CH ₄	0.049 kg / tonne	(Hensmann, Haardt, & Ebert, 2011)
N ₂ O	No factor available	-
Notes: Factor for “hard-coal-coke production (coking plants)” Hensmann, Haardt, & Ebert, 2011. "Emissionsfaktoren zur Eisen- und Stahlindustrie für die Emissionsberichterstattung". BFI 2011 "Emissionsfaktoren zur Eisen- und Stahlindustrie für die Emissionsberichterstattung“, im Auftrag des Umweltbundesamtes, BFI 2011, FKZ 3707 42 301.		

It is *good practice* to try and verify these emissions to ensure that they are realistic in magnitude in comparison with emissions from other categories in the iron steel sector, and the energy sector.

CHOICE OF ACTIVITY DATA

The quantities of coke produced may form the input to methods used to estimate fugitive emissions. Coke production data is normally available in national energy balance data. Plant specific coke production data may also be available.

UNCERTAINTY ASSESSMENT

The quantities of coke produced are likely to be well known. Uncertainty estimates of production may be available from energy balance data, or, from plant operators. Fugitive emissions of CH₄ and N₂O will be highly uncertain, and, order of magnitude uncertainties on emissions are likely and can be assumed as a first approximation.

TABLE 4.3.6 DEFAULT UNCERTAINTY ASSESSMENT FOR EMISSION FACTORS FROM COKE PRODUCTION		
Oven technology	CH ₄	N ₂ O
Overall assessment for all technologies	Order of magnitude ^a	Order of magnitude ^a
Note: ^a Having an uncertainty range from one-tenth of the mean value to ten times the mean value. Source: Expert judgement		

FLARING OF EMISSIONS

Surplus coke oven gas may be flared if no other economic uses have been found for it.

Tier 1

The general form of the equation for estimating emissions for a Tier 1 approach, based on coke production activity, is given by Equation 4.3.4 below.

<p style="text-align: center;">EQUATION 4.3.4</p> <p style="text-align: center;">FUGITIVE GHG EMISSION FROM FLARING OF COKE OVEN GAS</p> <p style="text-align: center;">$Emissions_{GHG} = Activity_{coke\ production} \bullet Emission\ Factor_{GHG}$</p>

Where:

$Emissions_{GHG}$ = emissions of a given GHG by coke production (kg GHG)

$Activity_{coke\ production}$ = amount of coke produced (tonnes)

$Emission\ Factor_{GHG}$ = emission factor according to COG released for each GHG (kg GHG/tonne of coke production)

When estimating the emissions from flaring of coke oven gas, it is important to ensure there is no double counting of estimates of emissions that might have been made as part of the calculations done in the iron and steel sector.

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Choice of emission factor

The Tier 1 emission factors for coke oven gas are given in Table 2.2 (kg of greenhouse gas per TJ on a Net Calorific Basis) in Volume 2: Energy, Chapter 2.

Choice of activity data

The amount and types of COG produced could be obtained from one, or a combination, of the sources in the list below:

- national energy statistics agencies (national energy statistics agencies may collect data on the amount and types of COG produced from individual enterprises that produce fuels);
- reports provided by enterprises to national energy statistics agencies (these reports are most likely to be produced by the operators or owners of large plants);
- reports provided by enterprises to regulatory agencies (for example, reports produced to demonstrate how enterprises are complying with emission control regulations);
- periodic surveys, by statistical agencies of the types and quantities of COG produced by a sample of enterprises.

Uncertainty assessment

Section 2.4.1 in Volume 2: Energy, Chapter 2 explains the uncertainties associated with the emission factors.

Inventory compilers should investigate if there are any estimates of uncertainties associated with the quantities of COG flared. [Further guidance may be needed on the likely magnitude of error associated with the volume of COG flared]

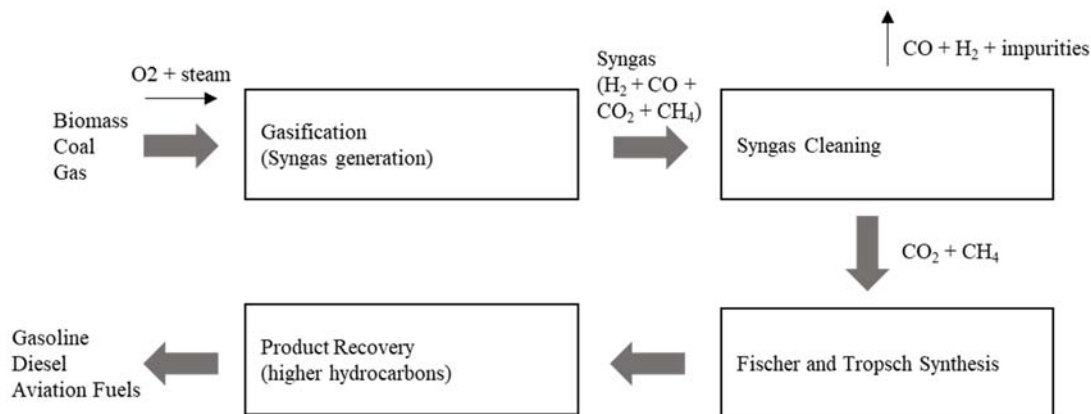
4.3.2.3 BIOMASS TRANSFORMATION PROCESSES

Fugitive emissions are likely from the transformation of biomass into usable forms of energy. The quantities of emissions will be variable, and uncertain. At the time the *2019 Refinement* was created, there was insufficient information available in the scientific literature to select emission factors suitable for estimating emissions and so a methodology is not provided. If countries have developed country specific methods for estimating emissions from biomass transformation process, they may estimate and report emissions. Appendix 4A5 provides a basis for future methodological development to estimate fugitive greenhouse gas emissions from wood pellet production.

4.3.2.4 GASIFICATION TRANSFORMATION PROCESSES

Gasification transformation processes are related to the transformation of biomass, coal or natural gas into syngas, composed by H₂, CO, CO₂ and CH₄, and, then, into a liquid hydrocarbons fuels. These processes are called biomass to gaseous (BtG), biomass to liquid (BtL), coal to liquid (CtL) and gas to liquid (GtL).

The syngas can be used as a fuel to generate electricity through a gas turbine or as a chemical feedstock (IEA Bioenergy, 2006; OCDE/IEA, 2007). The liquids biofuels production is obtained at the Fischer Tropsch process, where the syngas, after cleaned to remove CO₂, CH₄, impurities such as sulphur bearing compounds (in particular H₂S), and heavy metal bearing compounds, is transformed in high-quality fuels like gasoline, diesel and aviation fuels. Figure 4.3.4 shows the process of gasification transformation.

Figure 4.3.4 Gasification transformation process of biomass, coal and gas

BtG and BtL are still emerging technologies, and there are currently very few large-scale plants worldwide. However, considering that they will become more widely adopted, methodologies to estimate the fugitive emissions of these processes are provided in Appendix 4a.3 as indicative methodologies. It is important to highlight, however, that due to the lack of consistent information, these methodologies need to be refined in the future, as the research advances and these technologies mature. CtL and GtL fugitive emissions estimation methodologies are provided below.

COAL TO LIQUIDS

Synthesis gas from CtL is generated by feeding coal into a gasification process. This synthesis gas containing a mixture of CO, H₂, CO₂ and CH₄ is fed into a gas cleaning process where impurities such as sulphur bearing compounds (in particular H₂S), and heavy metal bearing compounds are removed from the synthesis gas. After cleaning, the synthesis gas composition is adjusted in a process called water-gas shift conversion. Here the ratio of H₂ to CO₂ is adjusted to produce a synthesis gas which is optimal for Fischer-Tropsch synthesis. After water-gas shift conversion the modified synthesis gas is fed to the Fischer-Tropsch synthesis process where it reacts to produce liquid hydrocarbons. A significant fraction of CtL plan CO₂ is generated in the gasification process which needs to be separated before the syngas is fed into the FT reactor (Mantripragada and Rubin, 2011). Current production levels mainly from CtL plants are estimated at over 300 000 Barrels Per Day (BPD) with a conservative estimate of 120 million tons of CO₂ equivalent.

GAS TO LIQUIDS

Natural gas is combined with steam and pure oxygen from a cryogenic air separation unit before it is heated and fed into an autothermal reformer (ATR). Syngas, a mixture of H₂ and CO, leaves the ATR and enters the Fischer Tropsch (FT) synthesis reactor, where it is converted to a hydrocarbon wax. The wax exiting the FT reactor is upgraded in the product work-up unit to yield approximately 70% diesel and 30% naphtha liquid products. A steam-methane reforming hydrogen plant is required to provide hydrogen for the product upgrading as well as inlet natural gas pre-treatment. The GtL plant CO₂ is generated from several sources (Heimel & Lowe, 2009):

- Entering with the inlet natural gas (feed gas assumed to contain 1.6 mol% CO₂)
- Forming during syngas generation
- Forming in the FT reactor
- Forming in the hydrogen plant
- Forming in the process heating furnaces

GtL technology in particular as alternative to petroleum based diesel is considered to be one of the most technical options to reduce petroleum consumption in the on-road transportation sector (Hao et al, 2010). The worldwide syngas database produced by the Gasification and Syngas Technologies Council (GSTC) shows that there are more than thirty (30) projects that are either in operation or under development (GSTC, 2014). Hao et al estimated GtL capacity to be 35,000 BPD in the year 2010 and projected an increase in capacity to 1-2 million BPD by 2015 (Hao et al, 2007).

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TABLE 4.3.7 SUMMARY OF GHG EMISSIONS FROM GASIFICATION TRANSFORMATION PROCESSES	
Synthetic fuel production Process	GHGs
CtL	CO ₂ , CH ₄ , N ₂ O
GtL	CO ₂

METHODOLOGICAL ISSUES

The choice of method will depend on the technologies that are operational in countries, [including whether the technologies analysed in this section are *key categories* in the country], and to what extent country and plant-specific information is available or can be gathered.

The most accurate emission estimates and, therefore, the fugitive emissions, can be developed by determining the emissions on a plant-by-plant basis and/or differentiated for each feedstock category (e.g., type of biomass, coal or gas). The methods for estimating CO₂, CH₄ and N₂O fugitive emissions from these technologies vary because of the different factors that influence emission levels. N₂O emissions from coal gasification are negligible and depends on the nitrogen content of the coal.

The general approach to calculate greenhouse gas emissions from those technologies is to obtain the amount of feedstock used and to investigate the related greenhouse gas emission factors, preferably from country-specific information on the carbon content.

To estimate fugitive CO₂ emissions, it will be necessary to:

- Compile data on the amount of feedstock used (e.g. amount of syngas, natural gas input);
- Use default values provided on dry matter content, total carbon content and fossil carbon fraction;
- Use default density at standard temperature and pressure for natural gas to convert the amount of natural gas inputs from volumetric basis to mass basis;
- Carbon mass flows and species composition of each carbon mass flow stream in CtL and GtL plants for tier 3 approach.

CHOICE OF METHODS, DECISION TREES, TIERS

There is limited information about gasification transformation technologies and, therefore, it was considered that fugitive emissions occur only at the gasification stage. The fugitive emissions resulted from the syngas transformation at the Fischer and Tropsch stage was considered negligible, as it is an energy related processes.

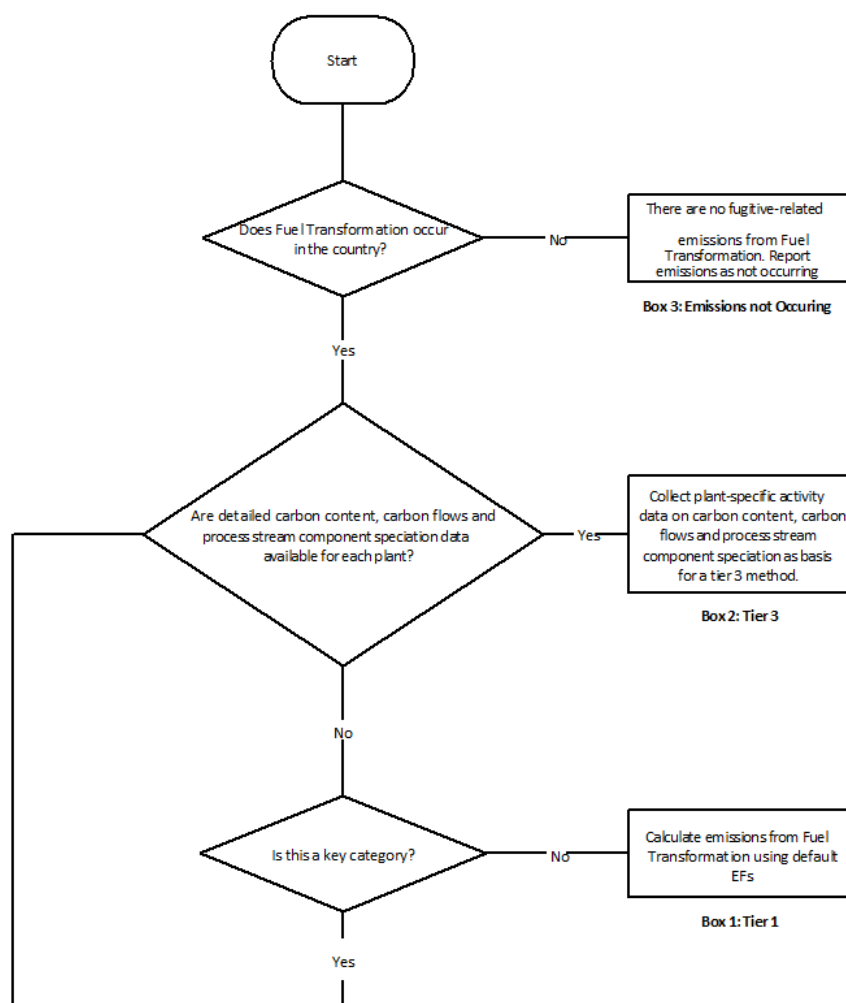
The method for estimating fugitive emissions from CtL and GtL technologies is based on an estimate of the carbon content in the feedstock combusted and converting the product to greenhouse gases emissions.

The activity data are the feedstock inputs into the gasification stage, and the emission factors are based on the carbon content of the feedstock that is of fossil origin.

The choice of method depends on the country specific information available, and is given in the decision tree in Figure 4.3.8.

Figure 4.3.5 Decision tree for estimating emissions from gasification transformation processes

Decision tree for estimation of CO₂, CH₄ and N₂O emissions from Fuel Transformation processes



TIER 1

The Tier 1 method is a simple method that can be used when fugitive emissions from CtL and GtL technologies are not a *key category*.

Fugitive emissions of CO₂, CH₄ and N₂O can be estimated from the amount and type of feedstock (coal or gas) used on these technologies, the total carbon content, the fraction of fossil carbon and the emission factor of fugitive emission. The application of a Tier1 approach is done using Equation 4.3.5 and 4.3.6 presented below.

EQUATION 4.3.5
CO₂ FUGITIVE EMISSIONS FROM [GASIFICATION PROCESSES]

$$CO_2 \text{ Emissions} = \sum (FS_i \cdot CF_i \cdot FCF_i \cdot EF) \cdot 44/12 \cdot 10^{-6}$$

Where:

$CO_2 \text{ Emissions}$ = Direct amount (Gg/yr) of CO₂ emitted at gasification station of CtL and GtL facilities

FS_i = total amount of feedstock of type i (TJ)

CF_i = Fraction of carbon in the feedstock (total carbon content), (fraction)

FCF_i = fraction of fossil carbon in the total carbon, (fraction)

EF = aggregate CO₂ emission factor, kg CO₂/TJ

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2920 44/12 = conversion factor from C to CO₂

2921 10⁻⁶ = conversion factor from kilogram to gigagram

2922 **EQUATION 4.3.6**

2923 **FUGITIVE GHG EMISSIONS FROM [GASIFICATION PROCESSES]**

2924
$$E_{gas\ i} = \sum (FS_j \cdot EF_j) \cdot 10^{-6}$$

2925 Where:

2926 $E_{gas\ i}$ = Direct amount (Gg/yr) of GHG gas i emitted at gasification station of CtL and GtL facilities (CH₄
2927 and N₂O)

2928 FS_j = total amount of feedstock of type j (TJ)

2929 EF_i = aggregate gas i emission factor, kg gas i /Gg or TJ of feedstock j

2930 10⁻⁶ = conversion factor from kilogram to gigagram

2931

2932 **TIER 2**

2933 CtL and GtL plants are versatile and depending on their process unit arrangement downstream, they are able to
2934 produce a wide range of products. Some CtL/GtL plants are able to produce a combination of liquid fuels and
2935 chemicals (e.g. Ammonia (NH₃), Nitric Acid (HNO₃), methanol (CH₃OH), etc.). This in turn affects the rate at
2936 which syngas is produced upstream. The quality of coal used determines the quality of syngas and the effort needed
2937 to treat syngas. Hence, it is *good practice* to develop a Tier 2 emission factor based on plant-specific emission
2938 factors as opposed to country-specific emission factors that are developed by aggregating plant-level emission
2939 factors for a country in question

2940 **TIER 3**

2941 The most appropriate Tier 3 approach is a material balance methodology. This is largely because, the CtL process
2942 in particular is a very versatile process. Depending on the type and volume of downstream products (chemicals or
2943 liquid fuels), the amount of syngas to be processed via the Fischer-Tropsch process can be varied. That in turn,
2944 affects the amount of syngas that needs to be produced upstream. The ultimately affects the amount of Greenhouse
2945 Gas emissions released in the atmosphere. Secondly, the syngas production and treatment processes release a large
2946 volume of flue gas stream that is almost impossible to measure. Hence, a direct measurement methodology is not
2947 ideal for CtL and GtL processes. Preferable a Tier 3 stoichiometric/mass-balance methodology should be followed.

2948 **CHOICE OF EMISSION FACTOR**

2949 **Coal to liquids**

2950 Higman and van der Burgt (2008) presents process-specific CO₂, CH₄ and N₂O emission factors as a function of
2951 syngas production and by process type. It is worth noting that for the CtL process, the bulk volume of greenhouse
2952 gas emissions are released during the production and treatment of syngas. Table 4.3.14 presents emission factors
2953 reported by Higman and van der Burgt. These emission factors have been developed for typical current
2954 international values and ranges of coal qualities (20.700 -27.300 KJ/Kg HHV). Coal Gasification systems
2955 considered are the Air Separation Unit (ASU), Oxygen blown fixed-bed BGL 1000 gasifier, acid gas removal
2956 (Rectisol). Table 4.3.14 also provides CO₂ reduction factors for CtL plants with Carbon Capture and Storage (CCS).

TABLE 4.3.8 EMISSION FACTORS FOR GASIFICATION PROCESSES OF CtL			
System Output	Syngas	Syngas/H ₂	SNG

CO ₂ emissions, kt/PJtotal output	55	55	78
CH ₄ emissions, kt/PJtotal output	0.0061	0.0061	0.0061
N ₂ O emissions, kt/PJtotal output	0 (only marginal emissions depending on the nitrogen content of the coal)	0 (only marginal emissions depending on the nitrogen content of the coal)	0 (only marginal emissions depending on the nitrogen content of the coal)
Reduction of CO ₂ emissions if CCS is applied, %	up to 99%	up to 99%	up to 99%
References and Further Information Higman, van der Burgt: "Gasification", 2nd edition (2008); IEA Clean Coal Centre: "Coal to liquids", Couch (2008); National Energy Technology Laboratory: "Industrial Size Gasification for Syngas, Substitute Natural Gas and Power Production", "Gasification Industry Overview: Addressing the Dash to Gas", Childress (2008); IEA Energy Technology Essentials: "CO ₂ Capture & Storage" (2006)			

Gas to liquids

Jaramillo et al. analysed CO₂ emissions released during syngas production in CtL and GtL plants (Jaramillo et al, 2008). The study by Jaramillo et al (2008) assumes that slightly more diesel is produced than gasoline. This assumption is plausible given that a conventional GtL plant produces 62% Diesel, 44% gasoline and 3% propane. The CO₂ emission factor is therefore derived from the inputs and outputs of a conventional GtL plant by dividing the amount of carbon lost (assuming 100% oxidation) with the volume of natural gas input to produce syngas. CO₂ is the most dominant GHG in the GtL process and therefore, it is a conservative approach to assume that 100% of carbon lost to the atmosphere is CO₂.

TABLE 4.3.9
EMISSION FACTOR FOR GASIFICATION PROCESSES OF GTL

Process	EF CO ₂ (kgCO ₂ /TJ natural gas input)
Gas to liquids	6026

CHOICE OF ACTIVITY DATA

Coal to liquid

The activity data required for a Tiers 1 and 2 are the amounts of syngas produced in terajoules (TJ). Since this data is monitored continuously at individual plant level, it is *good practice* to collect syngas production data from each plant.

For the Tier 3 method, carbon mass flow and species composition data is required to accurately quantify the amount of GHGs in the flue gas streams. Even though the amount of syngas produced is not necessary for a Tier 3 method, it is *good practice* to collect and report these data in comparing the results of the Tier 3 method (material balance) against the Tier 1 method.

Gas to liquid

The activity data required for a Tiers 1 and 2 are the amounts of natural gas inputs into the GTL process in terajoules (TJ). Natural gas may be used upstream of the GtL plant for heat and electricity production during production. Therefore, it is *good practice* to ensure that the amount of natural gas used for electricity and heat during natural gas production is separated from the amount of natural gas used as a feedstock in the GtL plant.

For a Tier 3 method, carbon flows and species composition are required to quantify the amount of carbon in each process stream and process unit inside a GtL plant. This information is monitored continuously during process control and therefore should be readily available from each plant.

UNCERTAINTY ASSESSMENT

Fuel transformation processes

Estimates of fugitive emissions from all fuel transformation processes can be highly uncertain due to lack of information about these technologies. It is highly recommended more R&D on these technologies, especially direct measurement on all stages to confirm which ones present fugitive emissions.

Emission factor uncertainties

Considering the minimal literature and the absence of large scale fuel transformation processes, fugitive emission factors provided in this guideline were estimated based on a very few data, resulting in a high level of uncertainty.

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Activity data uncertainties

Where activity data are obtained from plants, uncertainty estimates can be obtained from producers

4.3.3 Completeness

This section of the GLs is currently not able to provide a set of methods to estimate fugitive emissions from all the possible parts of each of the sources. But it is *good practice* for inventory compliers to ensure completeness and to try and estimate emissions if possible. But resources should be prioritised according to the *key category* analysis results.

Where a country has estimated its fugitive emissions based on an aggregation of estimates reported by individual, it is *good practice* to document the steps taken to ensure that these results are complete, transparent and consistent across the time series. Corrections made to account for companies or facilities that did not report, and measures taken to avoid missed or double counting (particularly where ownership changes have occurred) and to assess uncertainties should be highlighted.

4.3.4 Developing consistent time series

Ideally, emission estimates will be prepared for the base year and subsequent years using the same method. The aim is to have emission estimates across the time series reflect true trends in greenhouse gas emissions. Emission or control factors that change over time (e.g., due to changes in source demographics or the penetration of control technologies) should be regularly updated and, each time, only applied to the period for which they are valid. For, example, if an emission control device is retrofit to a source then a new emission factor will apply to that source from then onwards; however, the previously applied emission factor reflecting conditions before the retrofit should still be applied for all previous years in the time series. If an emission factor has been refined through further testing and now reflects a better understanding of the source or source category, then all previous estimates should be updated to reflect the use of the improved factor and be reported in a transparent manner.

A country should assess which technologies and practices are generally in place in the country and apply the corresponding emission factor. As technologies and practices change over time, it is possible that a country will use one EF in some years and another in other years. A compiler should assess the time frame over which changes took place, and consider linear interpolation or other techniques to incorporate the trend from one emission factor to another over the time series.

Where some historical data are missing, it might still be possible to use source-specific measurement results combined with back-casting techniques to establish an acceptable relationship between emissions and activity data in the base year. Approaches for doing this will depend on the specific situation, and are discussed in general terms in Volume 1 Chapter 5 of the 2006 Guidelines.

If emission estimates are developed based on an aggregation of individual company estimates, greater effort will be required to maintain time series consistency, particularly where frequent facility ownership changes occur and different methodologies and emission factors are applied by each new owner without also carrying these changes back through the time series.

4.3.5 Inventory Quality Assurance/Quality Control (QA/QC)

Specific QA/QC procedures to optimise the quality of estimates of emissions are given in Chapter 6 of Volume 1, General Guidance and Reporting.

4.3.6 Reporting and Documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates, as outlined in Volume 1 Chapter 8 of the 2006 Guidelines.

It may not be practical to include all supporting documentation in the inventory report. However, at a minimum, the inventory report should include summaries of the methods used and references to source data such that the reported emissions estimates are transparent and the steps in their calculation may be retraced. For segments where a technology- or practice-specific Tier 1 emission factor is used, the rationale for selecting that factor and the method for applying the factors over the time series must be clearly documented. It is expected that many countries will use a combination of methodological tiers to evaluate the amount of fugitive greenhouse gas emissions. The

3038 specific choices should reflect the relative importance of the different subcategories and the availability of the data
3039 and resources needed to support the corresponding calculations.

3040 Since emission factors and estimation procedures are continually being improved and refined, it is possible for
3041 changes in reported emissions to occur without any real changes in actual emissions. Accordingly, the basis for
3042 any changes in results between inventory recalculations should be clearly discussed and those due strictly to
3043 changes in methods and factors should be highlighted.

3044 The above reporting and documentation guidance is applicable to all methodological choices. Where Tier 3
3045 approaches are employed, it is important to ensure that either the applied procedures are detailed in the inventory
3046 report or that available references for these procedures are cited since the IPCC Guidelines do not describe a
3047 standard Tier 3 approach. Reported emission results should also include a trend analysis to show changes in
3048 emissions, activity data and emission intensities (i.e., average emissions per unit of activity indicator) over time.
3049 The expected accuracy of the results should be stated and the areas of greatest uncertainty clearly noted.

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Annex 4A.1 Standard Conditions

***NEW: PROVIDES CLARITY ON STANDARD CONDITIONS ***

Standard conditions

It should be noted that IPCC default EFs listed in the table (Table 4.2.3 – 4.2.13) are sensitive to temperature and pressure. Activity data must be consistent with the EFs standard conditions. The EFs are given at the most commonly used standard conditions: 15°C and 101.325 kPa (1 atm). If activity data are derived at reference conditions, which are different from those used by IPCC default EFs, inventory compiler should harmonize activity data with 15°C and 101.325 kPa. Pressure is normally fixed for the most of the standard conditions at the level of 101.325 kPa (1 atm). Thus, in general, probable variations of reference temperature should be considered as a priority.

Along with the physical state, activity data can be split into liquids (oil) and gases (natural gas and associated petroleum gas). Different correction approaches of gases and liquids are required.

Liquids (oil)

Liquids may be referenced at 20°C and 15°C. In order to harmonize oil units referenced at 20°C to IPCC default EFs correction can be made with the use of international standard tables of conversion factors (CFs) and densities, which is based on set of detailed data on oil properties and corresponded to internationally recognized sources as follows:

- ASTM D 1250-8 Standard Guide for Use of the Petroleum Measurement Tables issued by American Society for Testing and Material
- API MPMS 11.1:2004. American Petroleum Institute. Manual of Petroleum Measurement Standards Chapter 11 - Physical Properties Data Section 1 - Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils

As follows from the standard, correction approach is based on the equations listed below (Equations 4A.1.1 to 4A.1.4) (GOST R 8.595-2010):

EQUATION 4A.1.1 CONVERSION OF OIL DENSITY AT 15°C

$$\rho_{15} = \rho_{20} \cdot K_{15}$$

EQUATION 4A.1.2 CONVERSION OF RELATIVE OIL DENSITY AT 15.556°C (60°F)

$$\rho_{60/60} = \rho_{20} \cdot K_{60/60}$$

EQUATION 4A.1.3 CONVERSION OF °API DENSITY

$$\rho_{API} = \rho_{20} \cdot K_{API}$$

EQUATION 4A.1.4 CONVERSION OF OIL VOLUME

$$V_{bbl} = M \cdot K_{bbl}$$

Where:

ρ_{15} = oil density at 20°C, kg/m³;

ρ_{20} = oil density at 15°C, kg/m³;

K_{15} = oil density at 20°C to oil density at 15°C conversion factor;

3096 $\rho_{60/60}$ = relative oil density at 60°F (15.556°C);

3097 ρ_{API} = API oil density, °API;

3098 $K_{60/60}$ = oil density at 20°C to relative oil density at 60°F conversion factor 10³(kg/m³);

3099 K_{API} = oil density at 20°C to relative oil API density conversion factor, °API/(kg/m³);

3100 M = oil mass, t;

3101 K_{bbl} = oil mass (t) to oil volume (bbl) conversion factor bbl/t.

3102 Uncertainties of correction approach are less than 0.01kg/m or 0.01°API, less than 0.01% of oil volume.

3103

3104 ***Gaseous (natural gas and APG)***

3105 Since for the most cases the pressure fixed at the 101.325 kPa (1 atm), the temperature correction can be performed
3106 as follows (equation 4A.1.5).

EQUATION 4A.1.5 CONVERSION OF GAS VOLUME

$$V_{st} = V_g \cdot CF_t$$

3110 Where:

3111 V_{st} = gas volume at the required reference conditions, m³;

3112 V_g = gas volume at the given reference conditions, m³;

3113 CF_t =conversion factor, dimensionless.

3114 According to the equation, initial gas volume should be multiplied by the conversion factor to obtain the gas
3115 volume at the required temperature. The factors are derived by means of ideal gas equation at the pressure fixed
3116 at the level of 101.325 kPa (1 atm). The conversion factors are shown at the table 4A.1.1.

TABLE 4A.1.1 RECALCULATION OF GAS VOLUMES TO THE REQUIRED TEMPERATURE CONVERSION FACTORS (CFT)	
To From	15°C
0°C	1.055
20°C	0.983

3117

3118 The difference between ideal and real volumes of APG and natural gas is within 0.55%. Such difference expresses
3119 uncertainty of the correction.

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Annex 4A.2 Disaggregation of Tier 1 factors presented in Section 4.2.2.3

***NEW: PROVIDES METHOD AND VALUES TO DISAGGREGATE THE AGGREGATE EFS PRESENTED IN 4.2 ***

This Annex presents the percent of emissions that are leaked, vented, and flared in the data sets used for the Tier 1 emission factors. To disaggregate the aggregate Tier 1 EF in the *2019 Refinements*, apply the % below to the corresponding aggregated value presented in Section 4.2. The disaggregation is presented for factors which included disaggregation in the *2006 IPCC Guidelines*.

Box 4A.2.1

EXAMPLE OF CALCULATION OF DISAGGREGATED EMISSION ESTIMATES FOR OIL PRODUCTION

Oil production in Country A occurs entirely onshore. The compiler has assessed available data on technologies and practices and determined that most activities are occurring with higher-emitting technologies and practices, and that the best available activity data is active oil well counts. In year 2017, country A had 100,000 active oil wells. Table below demonstrates how Country A would use a Tier 1 approach to calculate total emissions for oil production in 2017, and disaggregated emissions for oil production in 2017.

EXAMPLE CALCULATION OF DISAGGREGATED EMISSION ESTIMATE FOR OIL PRODUCTION FOR COUNTRY A				
	CH ₄	CO ₂	NM VOC	N ₂ O
Calculation of Total Emissions				
EFs (tonnes per well) (from Table 4.2.4)	2.35	8.47	1.01	1.27E-04
Number of wells	100,000			
Total tonnes of gas	234,637	847,302	100,894	13
Disaggregation fraction (from Table 4A.2.2)				
Leak	0.07	0	0.07	0
Vents	0.83	0.03	0.83	0.03
Flare	0.1	0.97	0.1	0.97
Disaggregated EF (in tonnes per well)				
Leak	0.16	-	0.07	-
Vents	1.95	0.25	0.84	0.00
Flare	0.23	8.22	0.10	0.00
Disaggregated emission estimate, in tonnes				
Leak	16,425	-	7,063	-
Vents	194,749	25,419	83,742	0
Flare	23,464	821,883	10,089	12

TABLE 4A.2.1 DISAGGREGATION OF TIER 1 EMISSION FACTORS FOR OIL PRODUCTION SEGMENT, 1.B.2.A.II							
Category	Sub-category	Emission source	CH ₄	CO ₂	NMVOC	N ₂ O	Application

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Onshore Production	Most activities occurring with higher- emitting technologies and practices	Leaks	7%	0%	7%	0%	Apply percentages to applicable EF (EF based on either onshore oil production, or active oil well)
		Vents	83%	3%	83%	3%	
		Flares	10%	97%	10%	97%	
Onshore Production	Most activities occurring with lower-emitting technologies and practices	Leaks	9%	1%	9%	1%	Apply percentages to applicable EF (EF based on either onshore oil production, or active oil well)
		Vents	78%	0%	78%	0%	
		Flares	13%	99%	13%	99%	
Offshore Oil Production	All	Leaks	33%	-	33%	-	Apply percentages to applicable EF (EF based on offshore gas production)
		Vents	0%	99%	0%	99%	
		Flare	67%	1%	67%	1%	
Oil Sands Mining and Ore Processing	All	Leaks ^a	2.3%	0.3%	20.9%	3%	Apply percentages to applicable EF (EF based on crude bitumen production from surface mining)
		Tailings Ponds	91.2%	46.9%	45.9%	-	
		Exposed Mine Surface	6.3%	30.4%	33.2%	-	
		Vents	0%	3%	-	-	
		Flare	0.3%	19.4%	0.1%	97%	
Oil Sands Upgrading	All	Leaks	8%	0%	39%	17%	Apply percentages to applicable EF (EF based on synthetic crude oil production)
		Vents	82%	82%	53%	-	

		Flare	11%	18%	8%	83%	
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TABLE 4A.2.2 DISAGGREGATION OF TIER 1 EMISSION FACTORS FOR OIL REFINING, 1.B.2.A.IV							
Category	Sub-category	Emission source	CH ₄	CO ₂	NMVOC	N ₂ O	Application
Oil Refining	All	Leaks	99%	55%	ND	ND	Apply percentages to applicable EF (EF based on thousand cubic meters oil refined)
		Flares	1%	45%	ND	ND	

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TABLE 4A.2.3 DISAGGREGATION OF TIER 1 EMISSION FACTORS FOR GAS PRODUCTION, 1.B.2.B.II							
Category	Sub-category	Emission source	CH ₄	CO ₂	NMVOC	N ₂ O	Application
Onshore production	Most activities occurring with higher- emitting technologies and practices	Leaks	11%	4%	11%	4%	Apply percentages to applicable EF (EF based on either gas production or gas wells)
		Vents	89%	31%	89%	31%	
		Flare	0	65%	0	65%	
Onshore Production	Most activities occurring with lower-emitting technologies and practices	Leaks	15%	2%	15%	2%	Apply percentages to applicable EF (EF based on either gas production or gas wells)
		Vents	84%	6%	84%	6%	
		Flare	-	92%	-	92%	
Onshore Production – Coal Bed Methane	All	Leaks	53	0	53	0	Apply percentages to applicable EF (EF based on coal bed methane production)
		Vents	44	3	44	3	
		Flare	3	97	3	97	
Offshore Gas production	All	Leaks	33%	-	33%	-	Apply percentages to EF (EF based on offshore gas production)
		Vents	0%	99%	0%	99%	
		Flare	67%	1%	67%	1%	

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TABLE 4A.2.4 DISAGGREGATION OF TIER 1 EMISSION FACTORS FOR GAS PROCESSING SEGMENT, 1.B.2.B.III							
Category	Sub-category	Emission source	CH ₄	CO ₂	NMVOC	N ₂ O	Application
Gas Processing	Without LDAR, limited use of dry seal compressors	Leaks	4%	0%	4%	0%	Apply percentages to applicable EF (EF based on either gas processed or gas produced)
		Vents	91%	1%	91%	1%	
		Flare	5%	99%	5%	99%	
Gas Processing	With LDAR, around 50% or more of centrifugal compressors are dry seal	Leaks	5%	0%	5%	0%	Apply percentages to applicable EF (EF based on either gas processed or gas produced)
		Vents	95%	1%	95%	1%	
		Flare	5%	99%	5%	99%	
Gas processing	Acid Gas Removal	Vents	100%	100%	NA	NA	Apply percentages to applicable EF (EF based on either gas processed or gas produced)

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TABLE 4A.2.5 DISAGGREGATION OF TIER 1 EMISSION FACTORS FOR GAS TRANSMISSION SEGMENT, 1.B.2.B.IV							
Category	Sub-category	Emission source	CH ₄	CO ₂	NM VOC	N ₂ O	Application
Gas Transmission	Most activities occurring with higher-emitting technologies and practices	Leaks	57%	25%	57%	NA	Apply percentages to applicable EF (EF based on either gas consumption or kilometre pipeline)
		Vents	43%	14%	43%	NA	
		Flare	-	61%	-	NA	
Gas Transmission	Most activities occurring with lower-emitting technologies and practices	Leaks	46%	14%	46%	NA	Apply percentages to applicable EF (EF based on either gas consumption or kilometre pipeline)
		Vents	54%	11%	54%	NA	
		Flare	-	74%	-	NA	

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Annex 4A.3 Definition of terminologies used in Section 4.2

The location of this contents may be changed in the final draft.

abandoned well: a well no-longer in production or being actively explored; such wells may be unplugged or plugged. Wells plugged according to regulations and abandoned are also known as decommissioned wells. Wells that are not regularly inspected or repaired and remain unplugged are abandoned but not decommissioned.

acid gas: gas that, when mixed with water, forms an acidic solution (e.g. hydrogen sulphide (H₂S) and carbon dioxide (CO₂) - both obtained after sweetening sour gas); see also *sour gas*.

API: the American Petroleum Institute, the primary trade association representing the oil and natural gas industry in the United States.

API gravity: gravity scale developed by the American Petroleum Institute that expresses the relative density of petroleum liquids as API degrees; most values fall between 10 and 70 degrees API gravity, and the lower the API gravity, the higher the density of a hydrocarbon.

appliance: *see gas appliance*.

asphalt: solid or nearly solid bitumen with impurities (nitrogen, oxygen, sulphur) that can melt upon heating; forms when light components or volatiles of petroleum have been removed or evaporated; see also *bitumen*.

associated petroleum gas (APG): gas produced along with oil.

bitumen: typically solid hydrocarbon with high density (API < 10 degrees; e.g. asphalt); see also *asphalt*.

blow-down: vented condensate and gas produced simultaneously at the outset of production or when re-starting a well that has been shut down for a period of time

blow out: when well pressure exceeds the wellhead valves' ability to control it and oil and gas are released at the surface; uncontrolled, possibly catastrophic, flow of reservoir fluids into wellbore that may consist of salt water, oil, gas, or a mixture thereof.

bore hole: the hole drilled by the drill bit; the wellbore including open hole or uncased portion of the well.

cap rock: relatively impermeable rock (e.g. shale, anhydrite, salt) that forms a seal above a reservoir rock and prevents fluids from migrating out of the reservoir.

carbon capture and storage (CCS): the process of trapping carbon dioxide (CO₂) and storing it in a way that it is unable to enter the atmosphere.

CO₂ injection: an enhanced oil recovery (EOR) method whereby CO₂ gas is injected into a reservoir to reduce viscosity and increase production.

carbon intensity: average emission rate of carbon dioxide (CO₂) from a source per unit of activity (e.g. g CO₂ per MJ of energy produced).

casing: cement pipe lowered down a borehole meant to prevent fluids from escaping and/or the borehole from collapsing.

casing head: the adapter between the first casing and the wellhead.

category: a subdivision of a sub-sector. For example, a sub-sector of the Energy sector is 1 B Fugitive Emissions from Fuels. Categories under the 1 B sub-sector include 1 B 1 Fugitive emissions from Solid Fuels, 1 B 2 Fugitive emissions from Oil and Natural Gas Systems and 1 B 3 Fugitive emissions from Fuel transformation.

centrifugal compressor: centrifugal compressors are widely used in production and transmission of natural gas. Seals on the rotating shafts prevent the high-pressure natural gas from escaping the compressor casing. Traditionally, these seals, termed "wet" seals, used high pressure oil as a barrier against escaping gas. An

alternative to the traditional wet (oil) seal system is the mechanical dry seal system. This seal system does not use any circulating seal oil. Dry seals operate mechanically under the opposing force created by hydrodynamic grooves and static pressure. Replacing “wet” (oil) seals with dry seals significantly reduces operating costs and methane emissions (EPA, 2016).

chemical flooding: a type of enhanced oil recovery (EOR) that utilizes alkaline or micellar-polymer flooding.

coal bed methane (CBM): natural gas (methane/CH₄, mainly) generated during coal formation and absorbed in coal. Originally extracted as a safety measure to reduce explosion hazards in mines, today CBM is captured and used as a source of energy. For deeper coal formations, hydraulic fracturing may be needed to release the natural gas (<https://www.epa.gov/uog/process-unconventional-natural-gas-production>).

cold production: non-thermal primary methods of heavy oil production.

completion: process of initiating flow of petroleum or natural gas from a newly drilled well prior to production (a) For *conventional well completion* a reservoir is connected to the wellbore during this process, allowing the flowback of drilling and reservoir fluids (gas, oil, water, mud, etc.) to the surface. While there is flowback, a period known also as well clean-up, there may be flaring or venting of produced gas from the reservoir. (b) For *unconventional well completions*, if hydraulic fracturing is employed, there may be a higher rate of flowback of water, fracking fluids, reservoir gas and fracturing proppant (e.g. sand) that can release greater amounts of methane and hydrocarbons to the atmosphere when compared to *conventional well completions*. (c) In a *green completion* or *reduced emissions completion* (REC), produced gas following hydraulic fracturing is captured, offsetting the loss of methane and other hydrocarbons during flowback from the well completion.

compressor: a device that raises pressure of air or natural gas so the gas can flow into pipelines or other facilities; see also *centrifugal compressor*.

compressor station or plant: facility with many compressors, auxiliary treatment equipment, and pipeline installations to pump natural gas under pressure over long distances.

condensate: gaseous hydrocarbons under reservoir conditions (i.e. temperature, pressure) that become liquid at the surface; includes a mixture of pentanes and higher hydrocarbons.

conservation efficiency (CE): a factor that expresses the amount of produced gas and vapour captured and used for fuel, produced into gas gathering systems, or re-injected (1.0 = all gas is conserved, utilized or re-injected; 0 = gas is vented or flared).

conventional oil: oil produced from a conventional reservoir

conventional reservoir: a reservoir where buoyant forces maintain hydrocarbons beneath a sealing cap stone and whose properties usually allow oil or natural gas to flow readily into well bores; this is distinct from shale or unconventional reservoirs, where gas may be distributed throughout the reservoir at basin scale and where additional buoyant forces or the influence of a water column is not significant.

crude oil: liquid petroleum as it arises from the ground, distinguished from refined oils that are manufactured from it.

cyclic steam stimulation (CSS): a method of *in situ* oil sand extraction that uses steam to heat the reservoir, allowing bitumen to flow into a vertical or horizontal wellbore; see also *steam-assisted gravity drainage (SAGD)*.

decommissioned well: an abandoned well no longer in production that has been isolated according to current regulatory requirements and best practices (e.g. cut-off, sealed, and possibly buried); such wells may still deteriorate over time, and may require inspection and repair when necessary, though the regulatory requirements to do so may vary considerably.

deep-cut extraction plant: gas processing plants located on gas transmission systems which are used to recover residual ethane and heavier hydrocarbons present in the natural gas.

directional drilling: the intentional deviation of a well bore from the path it would have naturally taken by using specialized, steerable drilling equipment; commonly used in shale reservoirs to allow producers to place the borehole in contact with the most productive reservoir rock.

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directional well: a well bore that uses special tools and/or techniques to make sure that its path hits a particular target that is usually located away from (as opposed to directly under) the surface location of the well.

distribution: for oil systems, the segment of the system that includes the transport and distribution of refined products, including bulk and retail facilities; for natural gas systems, this segment includes high-pressure gas pipelines that transfer natural gas to the “city gate” and then to end users through underground main and service pipelines, distribution of town gas, and short term surface storage.

dry hole: an exploratory well where no hydrocarbons are found; a non-productive well.

dry gas: natural gas that does not require any hydrocarbon dew-point control to meet sales gas specifications (may require treating to meet water and acid gas (H₂S and CO₂) content); usually produced from shallow (< 1000 m deep) gas wells.

emission control device: a device used to regulate the amount of gasses or air pollutants emitted from a source.

enhanced coal bed methane (ECBM): increased methane (CH₄) recovery produced by the injection of CO₂ into coal seams.

enhanced gas recovery (EGR): increased recovery of natural gas by injection of inert gases (e.g. N₂, CO₂) to increase well pressure.

enhanced oil recovery (EOR): recovery of oil from a reservoir by means other than using the natural reservoir pressure; can begin after a secondary recovery process or at any time during the productive life of an oil reservoir; an oil recovery enhancement method that uses sophisticated techniques that restores formation pressure and improves oil displacement or fluid flow in a reservoir; there are three major types: chemical flooding (alkaline flooding or micellar-polymer flooding), miscible displacement (CO₂ injection or hydrocarbon injection) and thermal recovery (steam flood or *in situ* combustion).

exploration: the part of oil and natural gas systems that includes well drilling, stem testing, and well completion; the process of trying to find accumulations of oil and natural gas under the surface of the Earth.

exploration well: a well drilled in an unproven area in an attempt to locate oil and natural gas.

flaring: all burning of waste natural gas and hydrocarbon liquids by flares or incinerators as a disposal option rather than for the production of useful heat or energy.

flaring destruction efficiency (FE): the fraction of gas that leaves the flare partially or fully burned.

flow-back: gas, crude oil and water (including water injected during hydraulic fracturing) that are produced from a well until the flow of gas and liquid hydrocarbon is steady; occurs after a treatment or in preparation for returning a well to production.

formation carbon dioxide: CO₂ present in the produced oil and gas when it leaves the reservoir.

fuel: any substance burned as a source of energy for heat or electricity.

fuel combustion: the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus.

fugitive emissions (oil and natural gas): the intentional or unintentional release of greenhouse gases that occur during the extraction, processing and delivery of fossil fuels to the point of final use; this excludes greenhouse gas emissions from fuel combustion. Encompasses venting, flaring, and leaks.

gas appliances: end of pipe equipment such as home heating equipment, water heaters, saunas, stoves, and barbecues that use natural gas.

gathering system: the network of flow lines and process facilities that transport and control the flow of oil or gas from wells to a main storage facility, processing plant, or shipping point (includes pumps, headers, separators, emulsion treaters, tanks, regulators, compressors, dehydrators, valves).

gas injection: the process of pumping associated gas into a reservoir for conservation or to maintain reservoir pressure.

gas-to-oil ratio (GOR): volume of gas at atmospheric pressure produced per unit of oil produced.

gas well: a well with natural gas as the primary product, but on that can also produce condensate (natural gas liquids like propane and butane) and water.

gross calorific value (GCV): conversion factor to convert a fuel quantity between natural units (e.g. mass or volume) and energy units (energy content), in this case gross energy content (IEA; <https://www.iea.org/media/training/alumni/CheatSheet.pdf>).

heater treater: a three-phase separator that separates crude oil, water, and associated gas from the output of a well.

heavy crude: a low API (< 20 degrees)/high density hydrocarbon.

horizontal drilling: a subset of directional drilling where the departure of well bore from vertical exceeds ~ 80 degrees.

hydraulic fracturing: a method of enhanced oil or gas recovery in which fluids are pumped into a rock formation at very high pressures in order to fracture the rock and stimulate the flow of natural gas or oil, increasing the volumes that can be recovered. Wells may be drilled vertically hundreds to thousands of feet below the surface and may include horizontal or directional sections extending thousands of feet away from the well.

hydrocarbon: strictly defined as molecules containing only hydrogen and carbon, but the term is used more broadly to include any molecules in petroleum which also contain S, N, or O. Hydrocarbons may exist as a solid, liquid, or gas and are generally used to refer to oil, gas, and condensate.

hydrogen sulphide (H₂S): a poisonous gas present in some subsurface formations.

injection well: a well used to pump water or gas into a reservoir.

in situ combustion: a method of thermal recovery where fire, generated inside a reservoir by injecting oxygen/air, burns heavy hydrocarbons and vaporizes lighter hydrocarbons, pushing out hot combustion gases, steam and oil water while also reducing oil viscosity.

leak: unintentional (i.e., not vented or flared) emissions from equipment components such as valves, connectors, open ended lines, and flanges; can occur in all segments of oil and natural gas systems.

leak detection and repair (LDAR): determination of a leak in a pipeline or piece of equipment using various detection methods followed by repair.

light crude: a high API/low density crude (API > 40 degrees).

light hydrocarbons: low molecular weight hydrocarbons (e.g. methane, ethane, butane)

liquid hydrocarbons: light liquid compounds extracted from gas flow stream (e.g. propane, butane, pentane)

liquids unloading: see unloading

liquefied natural gas (LNG): oilfield or naturally occurring gas (mostly methane and ethane), liquefied at cryogenic temperatures for transportation.

liquid petroleum gas (LPG): a light hydrocarbon that is gaseous at atmospheric temperature and pressure and which is held in a liquid state (by pressure) in order to ease transport and handling; consists of either propane, butane, or mixtures of the two.

lubricants: hydrocarbons produced from distillate or residue that are mainly used to reduce friction between bearing surfaces; includes all finished grades of lubricating oil, from spindle oil to cylinder oil, and those used in greases, including motor oils and all grades of lubricating oil base stocks.

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million barrels of oil equivalent (MBOE): a unit of energy based on the energy release by burning one million barrels (one barrel is 42 US gallons or 158.9873 L) of crude oil.

meter and regulator stations: points of transfer where pipeline companies measure gas quality and volumetric flow, and reduce the pressure of pipeline gas to feed natural gas distribution systems.

methane (CH₄): the lightest and most abundant hydrocarbon gas and main component of natural gas.

miscible displacement: a type of enhanced oil recovery (EOR) that uses CO₂ injection or hydrocarbon injection.

natural gas: a gas that occurs naturally and often in association with crude petroleum; a mixture of hydrocarbon gases that is highly compressible and expansible (consists primarily of methane, but also ethane, propane, butane, and pentane; impurities such as CO₂, He, N, and H₂S may also be present).

natural gas liquids (NGLs): liquid hydrocarbon constituents of natural gas whose products include polyethylene, polypropylene, and liquified petroleum gas (LPG).

net calorific value (NCV): conversion factor to convert a fuel quantity between natural units (e.g. mass or volume) and energy units (energy content), in this case net energy content (IEA; <https://www.iea.org/media/training/alumni/CheatSheet.pdf>)

non-methane volatile organic compounds (NMVOC): a class of emissions which includes a wide range of specific organic chemical substances which are precursors for the formation of ozone, a greenhouse gas and air pollutant in the troposphere (lower atmosphere).

off-gas: the exhaust gas from a chemical process (combustion or non-combustion). The off gas may be vented to the atmosphere, burned for energy recovery or flared (without energy recovery), or used as a feedstock for another chemical process.

oil: a mixture of liquid hydrocarbons of different molecular weights.

oil sand: are a type of unconventional petroleum deposit made of up a mixture of sand, clay, and water, saturated with a highly viscous form of petroleum called crude bitumen. In the context of Canadian oil sands, the API is < 10 degrees, and *in situ* recovery and mining methods are used to extract the resource.

oil shale: a sedimentary rock containing organic matter in the form of kerogen, a waxy hydrocarbon-rich material regarded as a precursor to petroleum. Oil shale may be burned directly or processed by, for example, heating to extract shale oil (UN IRES report, 2018).

oil well: a producing well that has oil as its primary product; such a well always produces some associated gas and frequently water as well.

permeability: the property of a geologic formation that quantifies the flow of fluid through pore spaces and into the well bore.

petroleum: a generic term for hydrocarbons that includes crude oil, natural gas liquids, natural gas, and their products; a complex mixture of naturally occurring hydrocarbon compounds found in rock which range from solid to gas, but usually refers to liquid crude oil. Impurities such as sulphur, oxygen and nitrogen are common and there is considerable variation in colour, gravity, odour, sulphur content and viscosity in petroleum from different areas.

pipeline: a tube or system of tubes used to transport crude oil and natural gas from the field or gathering system to the refinery.

pipeline capacity: the volume of gas or oil needed to maintain a full pipeline expressed in barrels per foot (bbl/ft).

pipeline gas: gas that is sufficiently dry that it will not precipitate out natural gas liquids (NGLs) at pressure and that has enough pressure to enter high-pressure gas pipelines.

pipeline oil: oil whose water, sediment and emulsion content is low enough for pipeline shipment.

plug and abandon: to prepare a well bore to be closed permanently (shut in and permanently isolated) for various reasons (e.g. after it is determined that there are insufficient hydrocarbons to complete an exploratory well, after

production operations have drained a reservoir, geological reasons, regulatory reasons). Regulatory requirements usually dictate how this occurs (most require cement plugs to be placed in the well born with inflow or integrity tests made at each stage to confirm hydraulic isolation).

pore gas: interstitial gas stored in the pore space of reservoir rock.

porosity: the percent of void in a porous rock compared to solid.

pneumatic controllers/devices: chemical injection pumps, starter motors on compressor engines, instrument control loops, liquid level controllers, pressure regulators, and valve controllers that use pressurized natural gas or compressed air as the supply medium.

primary fuels: fuels extracted directly from natural resources; examples include crude oil, natural gas, coals, etc.

processing: the segment of natural gas systems where natural gas liquids (NGLs) and other constituents (e.g. sulphur) from raw gas are removed to prepare “pipeline quality” gas.

production: the segment of Oil Systems that includes the process of recovering oil from the wellhead or at the oil sands/oil shale mine to delivery at the start of the oil transmission system; also included in this segment are any on-site upgrading activities. For Natural Gas systems this segment includes recovering gas from the wellhead and delivery of that gas to either the inlet of a gas processing facility or a tie-in point of a gas transmission system; also included in this section is gathering and boosting stations.

reciprocating compressor: a compressor that uses pistons driven by a crankshaft to deliver gases at high pressure.

refining: the segment of Oil Systems where refineries process crude oils, natural gas liquids (NGLs) and synthetic crude oils into final products (e.g. primary fuels and lubricants).

reservoir: an underground formation where oil and gas has accumulated; consists of porous rock that holds oil and gas and a cap rock that prevents its escape.

secondary recovery: the recovery of oil or gas by artificially maintaining or enhancing reservoir pressure by injection gas, water or other substances into the reservoir rock.

sector: greenhouse gas emission and removal estimates are divided into main sectors (Energy, Industrial Process and Product Use (IPPU), Agriculture Forestry and Other Land Use (AFOLU), Waste and Other), which are groupings of related processes, sources and sinks.

segment: a sub-division of the Fugitive Emissions from Oil Systems (1 B 2 a) and Fugitive Emissions from Natural Gas Systems (1 B 2 b) sub-categories that refers to the type of activity within the system. For example, 1 B 2 b iii 1 Exploration and 1 B 2 b iii 2 Production are segments of 1 B 2 b.

shale: a fine grained impervious sedimentary rock of clays and other minerals (including high percentage of quartz).

shale gas: natural gas produced from low-permeability deep shale formations; shale that is thermally mature enough and has sufficient natural gas content to produce economic quantities of natural gas.

shale oil: see *oil shale*.

shut in well: a well capable of producing but is not currently due to numerous reasons.

sour: oil or gas contaminated with sulphur or sulphur compounds (especially hydrogen sulphide).

sour gas: natural gas that must be treated to satisfy sales gas restrictions on H₂S content; see also *sweet gas*.

sour crude: crude oil with high sulphur content.

standard temperature and pressure (STP): 15 degrees Celsius and 101.325 kPa (1 atm) atmospheric pressure.

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steam assisted gravity drainage (SAGD): a method of *in situ* oil sand extraction that uses steam to heat the reservoir, allowing bitumen to flow into a vertical or horizontal wellbore; see also *cyclic steam stimulation (CSS)*.

storage: natural gas kept temporarily on long-term in above ground tanks or below-ground formations. Crude oils or refined products stored in above ground tanks.

sub-category: a division of a category. For example, subcategories of 1 B 2 (Fugitive Emissions from Oil and Natural Gas Systems) include 1 B 2 a Fugitive Emissions from Oil Systems and 1 B 2 b Fugitive Emissions from Natural Gas Systems. Subcategories can be further divided into *segments*.

sub-sector: a division of a sector. For the Energy sector, sub-sectors include 1 A Fuel Combustion Activities and 1 B Fugitive Emissions from Fuels, for example.

sub-segment: a division of a segment of Oil or Natural Gas Systems by technology or practice.

sweet: lacking appreciable amounts of sulphur or sulphur compounds.

sweet crude oil: oil with small amounts of H₂S and/or CO₂.

sweet gas: natural gas that does not contain any appreciable amount of H₂S (i.e. does not require treatment to meet requirements for H₂S content).

sweetening: the process that removes hydrogen sulphide or carbon dioxide from a gas stream.

synthetic crude oil (SCO): output from a bitumen or extra heavy oil upgrader, usually in connection with oil sand production or output from oil shale pyrolysis.

synthetic natural gas (SNG): gas obtained from heating coal or refining heavy hydrocarbons.

tar sand: a sand body containing heavy hydrocarbon residues (e.g. tar or asphalt) or degraded oil that has lost its volatile components; hydrocarbons can be liberated by heating and other processes at typically high cost. Also known as oil sands.

thermal recovery: a type of enhanced oil recovery (EOR) that uses stream flood or *in situ* combustion; a process that introduces heat into a reservoir to produce viscous, thick oils (i.e. API < 20 degrees; oils that cannot flow unless heated to reduce viscosity and allow flow toward producing well); encompasses hot fluid injection (steam injection, stream flood or cyclic steam injection), hot water flooding, and *in situ* combustion processes

tight gas: gas produced from a relatively impermeable reservoir rock that is generally difficult to produce without stimulation operations; generally used for reservoirs other than shale that fit this description.

town gas: a manufactured gaseous fuel produced for sale to commercial and residential consumers. Coal gas contains hydrogen (around 50%), carbon monoxide (around 10%), methane (around 35%) and volatile hydrocarbons (around 5%) together with carbon dioxide and nitrogen (each less than 1%); also called coal gas.

transmission: pipeline transportation of pipeline quality gas.

transmission compressor station: stations placed within natural gas transmission systems to help maintain the pressure of the gas within a pipeline as it flows from the natural gas field to market.

transport: the segment of Oil Systems that is related to the transport of marketable crude (conventional, heavy, and synthetic crude oil and bitumen) to upgraders and refineries by pipeline, marine tankers, tank trucks, and rail cars.

unconventional resource or reservoir: a term for oil and natural gas that is produced by means that do not meet the criteria for conventional production; presently, used in reference to oil and gas resources whose porosity, permeability fluid trapping mechanism, or other characteristics differ from conventional sandstone and carbonate reservoirs (examples include coal bed methane, gas hydrates, shale gas, fractured reservoirs, tight gas, oil sands).

underground gas storage: gas that is being stored in salt domes, salt layers, or depleted oil and gas fields.

unload: to initiate flow from a reservoir by removing the column of kill fluid from the well bore.

upgrader: a refinery unit that improves or upgrades heavy oil to produce higher-quality hydrocarbon liquids or upgraded synthetic crude.

venting: emissions from venting of associated gas and waste gas/vapour streams and oil and natural gas facilities; this includes all engineered or intentional discharges of waste gas streams and process by-products to the atmosphere, including emergency discharges, and the release may be continuous or intermittent.

vapour recovery unit (VRU): a system used to recover vapours formed inside sealed crude oil or condensate tanks; consists of a switch that detects pressure variations within a tank and turns a compressor on and off. The compressor sucks vapours through a scrubber that catches liquids and vapours for return to tanks or pipelines.

water flooding: a secondary oil recovery method where water is injected into a reservoir formation to displace residual oil into adjacent production wells.

well blow-out: *see blowout.*

well bore: a drilled hole or borehole, including the open hole or uncased portion of the well.

well completion: *see completion.*

well head: the system of spools, valves and assorted adapters that provide pressure control of a production well.

well integrity: the zonal isolation of liquids and gases.

well servicing: maintenance procedures performed on oil and gas wells after they have been completed and production has begun; these procedures maintain or enhance well productivity.

well testing: a series of activities and tests designed to understand and characterize the characteristics of underground reservoirs where hydrocarbons are trapped.

wet gas: natural gas containing significant heavier hydrocarbons (propane, butane and other NGLs) and that is < 85% methane.

wet oil: oil containing basic sediment and water.

workover: repair or stimulation of an existing production well for the purpose of restoring, prolonging or enhancing the production of hydrocarbons.

Appendix 4a.1 Fugitive emissions from mining, processing, storage and transportation of coal: Basis for Future Methodological Development

Based on the current state of research and data availability, a methodology for estimating emissions from abandoned surface mining has not yet been able to be developed. However, general methodological issues are mentioned below for countries to consider as a basis for future methodological development.

Appendix 4a.1.1 Abandoned Surface Mines

Closed, or abandoned, surface coal mines may continue to be a source of greenhouse gas emissions for some time after the mines have been closed or decommissioned. For the purpose of the emissions inventory compilation, a first critical step is to ensure that each mine is classified in one and only one inventory database (e.g., active or abandoned).

It is also important to consider sub-sector allocation issues - to separate any emissions from abandoned surface mines from those of uncontrolled combustion and burning of coal deposits, to avoid double counting. CO₂ emissions can arise from both low-temperature oxidation of exposed coal-bearing rocks and uncontrolled combustion. The CO₂ emissions from uncontrolled combustion should be reported under *1.B.1.b Uncontrolled Combustion, and Burning Coal Dumps*.

Countries considering activity data for estimating emissions from abandoned surface mines may take into account factors such as the surface area of exposure coal, the degree of flooding and the extent and type of mine rehabilitation that has taken place.

For CO₂ and CH₄ emission factors, consideration may be given to the type of coal mined, eg bituminous, subbituminous, lignite etc., mine site management practices and how the emission factors are likely to change over time since mine closure.

In general, more work needs to take place in order to build a basis for robust and representative Tier 1 methodology development. This is particularly the case for developing appropriate emission factors, as well as understanding the variability and uncertainty associated with emissions from this source.

Appendix 4a.2 Fugitive Greenhouse Gas Emissions from Wood Pellet production: Basis for Future Methodological Development

This Appendix provides a basis for future methodological development rather than complete guidance.

BACKGROUND

Biomass is the fourth largest source of energy worldwide and provides basic energy requirements for cooking and heating of rural households in developing countries. Biomass densification has aroused a great deal of interest in recent years as a technique to enhance the use of residues as energy source. The densified biomass produced is mostly in the form of briquettes in developing countries and in the form of pellets in developed countries.

Wood Pellets

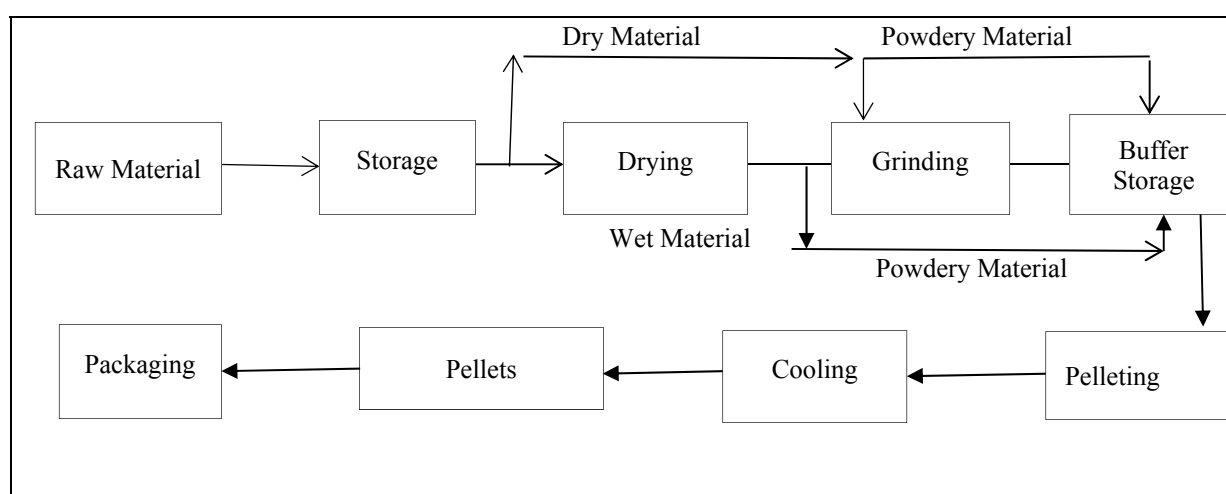
Wood pellets are a type of wood fuel, usually produced as a by-product of sawmilling and other wood transformation activities. Wood pellets are normally produced by compressing dry wood materials to a desired size. First, raw wood materials are passed through a hammer mill and dryer to achieve consistent moisture content. Then, the dry wood particles are fed to a press. In the press they are squeezed through a die having holes of the required size. The high pressure causes the temperature of the wood to increase greatly, causing the lignin to plasticize slightly and form a natural 'glue' that holds the pellet together. The pellets are usually 6 to 8 mm in diameter and 2 cm in length.

According to Global Bioenergy Statistics 2017 (WBA, 2018), 28 million tonnes of pellets are produced annually. Pellets are thus contributing substantially to global bioenergy trade. Pelleting technology is also considered as a mature technology. From environmental context, it is well documented that all biomass gradually decomposes over time, both chemically and biologically, slowly releasing toxic and oxygen-depleting gases such as CO, CO₂ and CH₄ (Kuang et al, 2008). Limited studies (Svedberg et al., 2004) have reported the composition of the off-gas emissions from stored wood pellets. However, CO, CO₂, CH₄ and non-methane organic compounds are commonly identified in the off-gases from biomass (Johansson et al., 2004).

Emissions to air may occur during the wood pellet manufacturing process from sources such as dryers, coolers, pelletizers, hammer mills, and conveyors. Fugitive emissions are also released during the handling, storage and transportation of the materials. Fugitive emissions are unintentional or incidental releases. The significance of fugitive emissions at wood pellet manufacturing facilities may vary depending on the type of raw material, method of transportation and specific process used in the production of the wood pellets. Major sources of these emissions include raw material handling, raw material storage piles, conveyor transfer points, yard dust, haul road dust and engine exhaust (British Columbia, Ministry of Environment, 2011).

The process of wood pellet production follows various distinct stages which include: receipt of the raw material, storage, drying, grinding, pelleting, cooling and packaging as illustrated in Figure 4a.2.1.

Figure 4a.2.1 Flow diagram of wood pellet production process

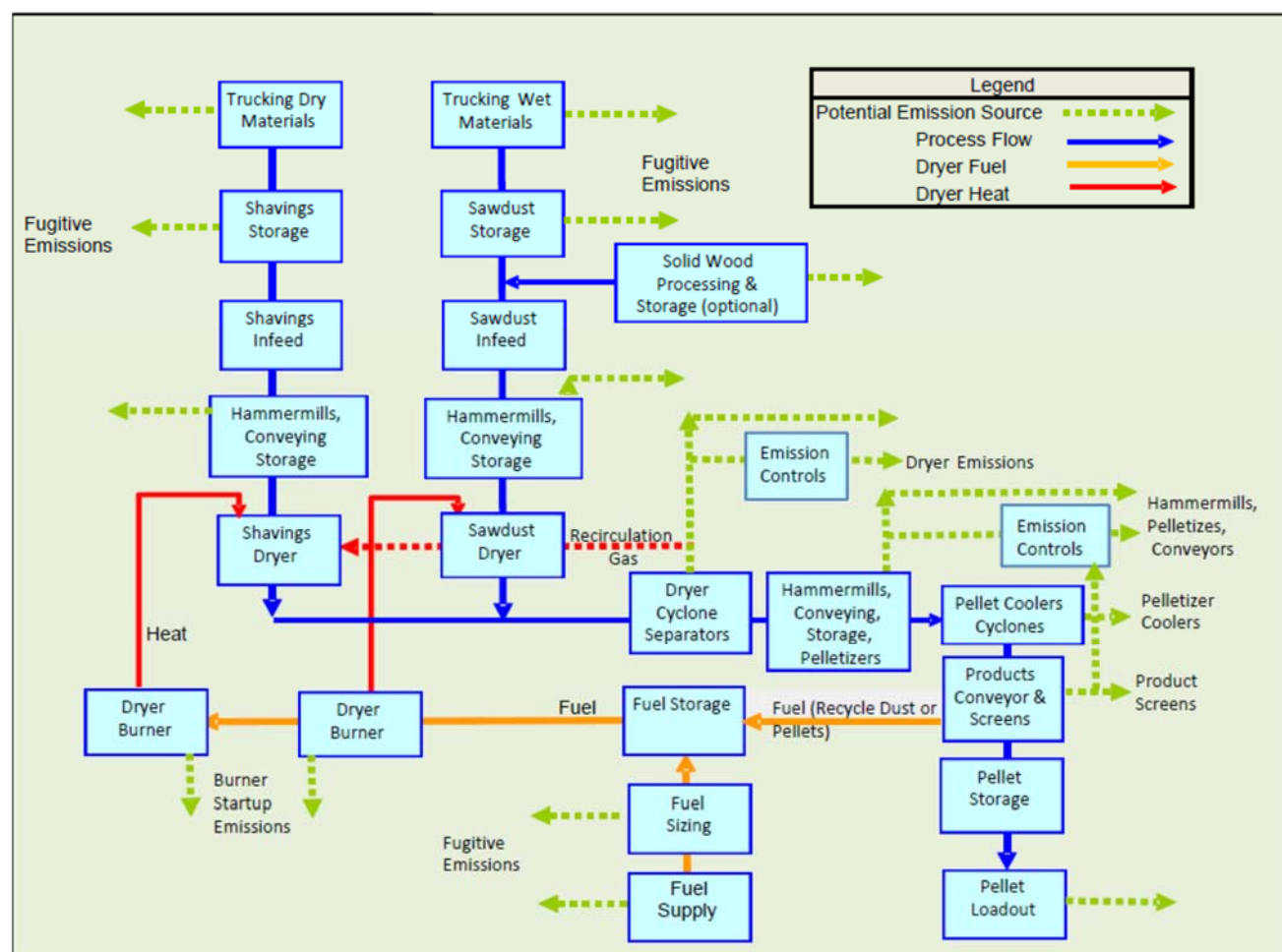


Note: Source: Adapted from Grover and Mishra, 1996, Olsson, 2002

Fugitive Emissions from Pellet Production

The fugitive emissions arising during the pellet manufacture would be classified under category 1B1c of the 2006 IPCC Guidelines, as they are part of emissions from solid fuel transformation. The possible sources of fugitive emissions from pellet production are indicated in Figure 4a.2.2. Inventory compilers need consider including only emissions arising within the pellet mill, namely from the receipt of the raw materials to the storage of pellets prior to transportation to end user.

Figure 4a.2.2 Emissions Diagram for a Typical Pellet Plant (Two Dryers)



Source: British Columbia, Ministry of Energy, 2011

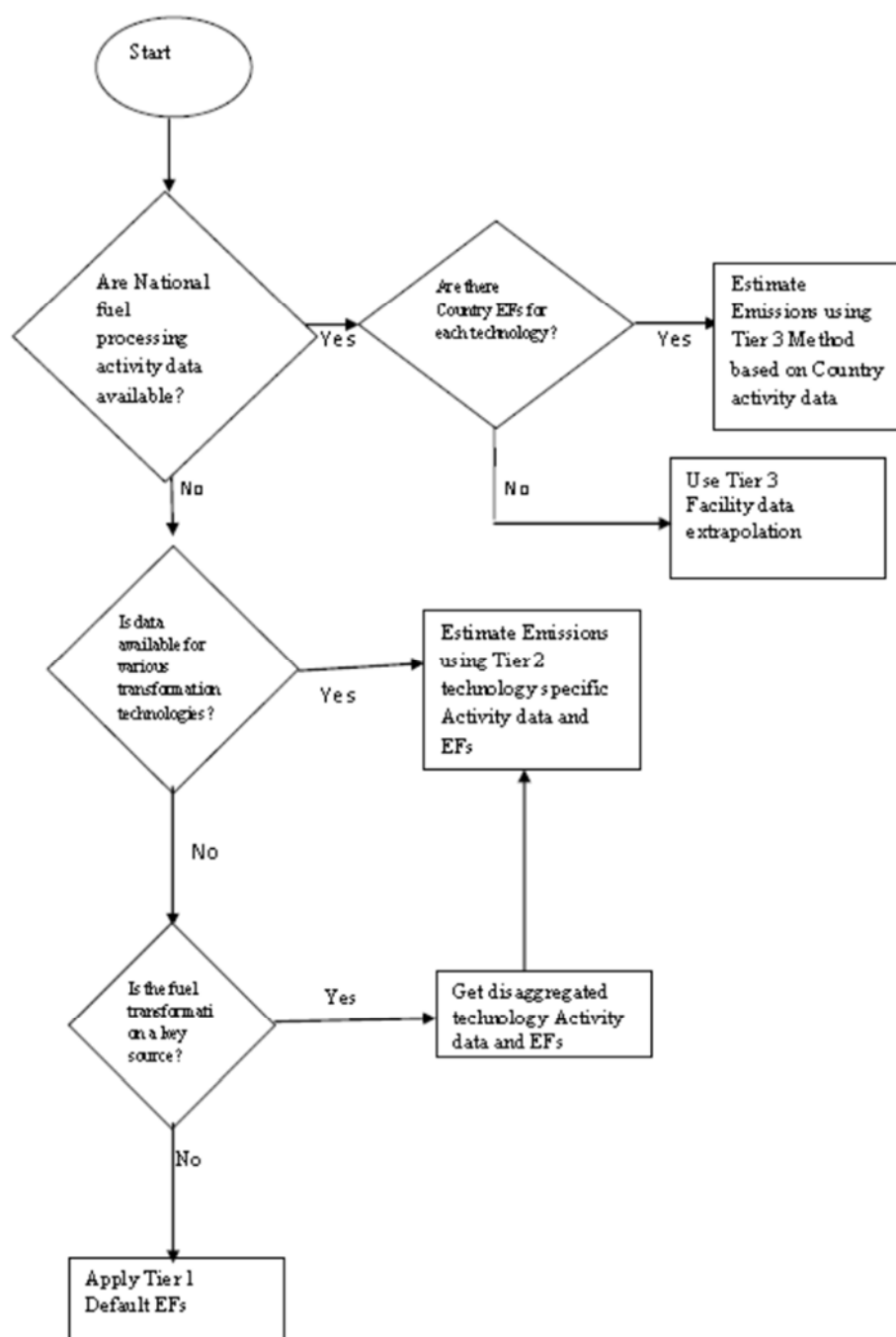
METHODOLOGICAL ISSUES

Fugitive emissions of CO₂ should not be estimated or reported from this source.

The choice of the method for estimating the fugitive emission depends on the nature and level of disaggregation of activity data and emission factors available in the country. Where there is no country or technology specific data, a Tier 1 method could be developed to estimate emissions using default emission factors. In the case where country specific emission factors are available but the activity data are not disaggregated by each transformation technology, a Tier 2 method could be developed. Finally, where technology specific data and emission factors are available, a Tier 3 method could be used. A proposed decision tree for estimating emissions from solid biomass fuel transformation is given in Figure 4a.2.3.

Figure 4a.2.3 Proposed decision tree for estimating fugitive emissions from solid biomass fuel transformation

Decision Tree for Solid to Solid Fuel Transformation



CHOICE OF EMISSION FACTOR

The fugitive emissions from the pellet manufacture are confined to the milling plant but exclude the process energy used for the compaction process. The available literature reviewed at the time of writing (Sjølie and Birger, 2011; Agar et al, 2015; Murphy et al, 2015, Magelli et al, 2009; and Wang et al, 2017) provided emission factors for pellet production largely based on lifecycle analysis. No suitable emission factors suitable for use in national GHG inventories were found to allow the estimation of the fugitive emissions arising at pellet production operations.

Choice of activity data

The activity data required to enable for the estimation of fugitive emissions arising during the manufacture of pellets from solid biomass materials. These include the:

- Quantity of solid biomass input materials including biomass waste and cut wood, available for pelleting;
- Quantity of the pellet and duration of storage prior to being transported to final end-use points.

References

- Agar D, J. Gil, D. Sanchez, I. Echeverria and M. Wihersaariet, (2015). Torrefied versus conventional pellet production – A comparative study on energy and emission balance based on pilot-plant data and EU sustainability criteria. *Applied Energy* **138**: 621–630.
- British Columbia, Ministry of Environment, 2011. Wood Pellet Manufacturing Facilities. Fact sheet Air Emissions.
- Grover, P. D and S.K. Mishra (1996). Fundamentals of Briquetting technology - Biomass Briquetting: Technology and Practices. FAO, Regional Wood Energy Development Programme In Asia GCP/RAS/154/NET).
- Johansson LS, Leckner B, Gustavsson L et al. (2004) Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. *Atmos Environ*; 38:4183–95.
- Kuang XY, Shankar TJ, Bi XT, Sokhansanj S, Lim C, Melin S. (2008) Characterization and kinetics study of off-gas emissions from stored wood pellets. *Ann Occup Hyg* **52**:675–83.
- Magelli F, Boucher K, Bi HT, Melin S, Bonoli A (2009) An environmental impact assessment of exported wood pellets from Canada to Europe. *Biomass Bioenerg* **33**(3):434–441.
- Murphy Fionnuala, Ger Devlinb and Kevin McDonnell, 2015. Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry. *Journal of Cleaner Production*, January 2015.
- Olsson, M.(2002). Wood pellets as low-emitting residential biofuel. Department of Chemical Environmental Science, Chalmers University Of Technology. Göteborg, Sweden
- Sjølie Hanne K., and Birger Solber, 2011. Greenhouse gas emission impacts of use of Norwegian wood pellets: a sensitivity analysis. Norwegian University of Life Sciences, Norway. *Environmental Science & Policy* 14 (2011) 1028 – 1040.
- Svedberg U, Samuelsson J, Melin S., 2008. Hazardous off-gassing of carbon monoxide and oxygen depletion during ocean transportation of wood pellets. *Ann Occup Hyg*; 52: 259–66.
- World Bioenergy Association, 2018. WBA Global Bioenergy Statistics 2017 (4th Edition). Bharadwaj Kummamuru et al. (eds).
- Wang C, Lixiao Zhang, Mingyue Pang and Yan Hao, 2017. A life-cycle comparison of the energy, environmental and economic impacts of coal versus wood pellets for generating heat in China. *Energy* 120 (2017) 374e384. Elsevier, 2016.

Appendix 4a.3 Fugitive Emissions from Biomass to Liquid and Biomass to Gas: Basis for Future Methodological Development

This Appendix provides a basis for future methodological development rather than complete guidance.

Biomass to gaseous (BtG) and biomass to liquid (BtL) gasification transformation processes are processes that use as feedstock woody biomass, agricultural and forest residues and waste biomass (sorted municipal and commercial waste), for example. Therefore, these feedstocks used in these processes does not have any carbon of fossil origin, except from Municipal Solid Waste (MSW) that might present some kind of carbon of fossil origin. The CO₂ fugitive emissions from the biomass and the biomass part of MSW are biogenic emissions and should be estimated for inclusion as an information item in the Energy Sector, as those feedstocks are combusted for energy purposes. The CO₂ estimated should not be included in national totals.

Currently, most BtG and BtL plants are either on demonstration or pilot scales and, hence, there is minimal literature describing research into the emissions from these processes (IEA Bioenergy, 2006; OCDE/IEA, 2007; AIL, S.S.; DASAPPA, S., 2016; NETL/DOE, 2016).

METHODOLOGICAL ISSUES

The choice of method will depend on the technologies that are operational in countries, [including whether the technologies analysed in this section are *key categories* in the country], and to what extent country and plant-specific information is available or can be gathered.

The most accurate emission estimates and, therefore, the fugitive emissions, can be developed by determining the emissions on a plant-by-plant basis and/or differentiated for each feedstock category (e.g., wood biomass, agricultural and forest residues and MSW). The methods for estimating CO₂, CH₄ and N₂O fugitive emissions from these technologies vary because of the different factors that influence emission levels.

The general approach to calculate greenhouse gas emissions from those technologies is to obtain the amount of feedstock used and to investigate the related greenhouse gas emission factors, preferably from country-specific information on the carbon content.

To estimate fugitive CO₂ emissions, it will be necessary to:

- Identify types of biomass used as feedstock (wood, agriculture and forest residue or waste biomass (sorted municipal and/or commercial waste));
- Compile data on the amount of feedstock used;
- Use default values provided on dry matter content, total carbon content and fossil carbon fraction.

CHOICE OF METHODS, DECISION TREES, TIERS

As BtG and BtL are still emerging technologies, and there are currently very few large scale plants worldwide and methodologies to calculate Tier 2 and Tier 3 are not provided. Inventory compilers could choose to use higher Tier methods to estimate emissions, but they need to transparently document the approaches used and state how their methods accurately and completely estimate emissions.

The choice of method depends on the country specific information available, and is given in the decision tree in Figure 4.3.8, in the subsection 4.3.2.4 Gasification Transformation Processes.

TIER 1

The Tier 1 method is a simple method that can be used when fugitive emissions from BtG and BtL technologies are not a *key category*.

Biomass

Fugitive emissions of CO₂ can be estimated from the amount of biomass (wet weight) (such as wood and agriculture and forest residues) taking into account the dry matter content, the total carbon content, and the emission factor of fugitive emission. The application of a Tier1 approach is done using Equation 4a.3.1.

$$\text{CO}_2 \text{ Emissions} = \sum (\text{FSi} \cdot \text{CF}_i \cdot \text{EF}_i) \cdot 44/12 \cdot 10^{-6}$$

Where:

Second-order Draft

3806 CO_2 emissions = Direct amount (Gg/yr) of CO_2 emitted at gasification station of BtL and BtG

3807 FS_i = total amount of feedstock of type i (wet weight) (Gg/yr)

3808 CF_i = Fraction of carbon in the feedstock (total carbon content), (fraction)

3809 EF_i = aggregate gas i emission factor, kg gas i /Gg or TJ of feedstock j

3810 $44/12$ = conversion factor from C to CO_2

3811 10^{-6} = conversion factor from kilogram to gigagram

3812

3813 The calculation of CH_4 emissions is based on the amount of biomass (wet weight) (such as wood and agriculture
3814 and forest residues) used on BtL and BtG plants and the related emission factors as show in Equation 4a.3.2.

3815 N_2O emissions from the combustion of biomass at gasification station of BtL or BtG facilities can be considered
3816 negligible.

3817

3818

3819

$$\text{CH}_4 \text{ Emissions} = \sum (\text{FS}_j \cdot \text{EF}_j) \cdot 10^{-6}$$

3820 Where:

3821 CH_4 Emissions = CH_4 emissions in inventory year (Gg/yr) emitted at gasification station of BtL or BtG
3822 facilities

3823 FS_j = total amount of feedstock of type j (Gg/yr)

3824 EF_i = aggregate gas i emission factor, kg gas i /Gg

3825 10^{-6} = conversion factor from kilogram to gigagram

3826 Municipal Solid Waste

3827 If Municipal Solid Waste (MSW) is the feedstock used in BtL or BtG plants, it is *good practice* to calculate the
3828 fugitive emissions based on waste types/material (such as paper, wood, plastics). Emissions CO_2 can be estimated
3829 from the amount of feedstock (wet weight) taking into account the dry matter content, the total carbon content, the
3830 fraction of fossil carbon and the emission factor of fugitive emission as shown in equation 4a.3.3, adapted from
3831 equation 5.2 in the Waste Volume.

3832 Default data on characteristic parameters (such as dry matter content, carbon content and fossil carbon fraction)
3833 for municipal are provided in Table 5.2 in chapter 5 and Tables 2.3 to 2.6 in Section 2.3 in Chapter 2 of Waste
3834 Volume.

3835

3836

3837

$$\text{CO}_2 \text{ Emissions} = \text{FS}_i \cdot \sum (\text{WF}_j \cdot \text{dm}_j \cdot \text{CF}_i \cdot \text{FCF}_i \cdot \text{EF}_i) \cdot 44/12 \cdot 10^{-6}$$

3838 Where:

3839 CO_2 Emissions = CO_2 emissions in inventory year (Gg/yr) emitted at gasification station of BtL and BtG

3840 FS_i = total amount of solid waste of type i (wet weight) (Gg/yr)

3841 WF_j = fraction of waste type/material of component j of the MSW (wet weight)

3842 dm_j = dry matter content in the component j of the MSW gasified, (fraction)

3843 CF_j = fraction of carbon in the dry matter (i.e., carbon content) of component j

3844 FCF_i = fraction of fossil carbon in the total carbon, (fraction)

3845 EF_i = aggregate gas i emission factor, kg gas i /Gg of feedstock j

3846 $44/12$ = conversion factor from C to CO_2

3847 10^{-6} = conversion factor from kilogram to gigagram

3848

If data by waste type/material are not available, the default values for waste composition given in Section 2.3 Waste composition, of Waste Volume, could be used.

The calculation of CH₄ and N₂O emissions are based on the amount of waste (wet weight) used on BtL and BtG plants and the related emission factors as show in Equation 4a.3.4.

EQUATION 4A.3.4
FUGITIVE GHG EMISSIONS ESTIMATE BASED ON WASTE COMPOSITION

$$E_{\text{gas } i} = \sum (FS_j \cdot EF_j) \cdot 10^{-6}$$

$E_{\text{gas } i}$ = Direct amount (Gg/yr) of GHG gas i emitted at gasification station of BtG and BtL facilities (CH₄ and N₂O)

FS_j = total amount of solid waste of type j (wet weight) (Gg/yr)

EF_i = aggregate gas i emission factor, kg gas i /Gg of feedstock j

CHOICE OF EMISSION FACTOR

Biomass

The emission factor of gasification process of BtG and BtL are provided based on carbon content of biomass used in a selection of plants and the composition of its syngas, as analysed by Asadullah (2014), considering 1% of fugitive emissions are release in the gasification stage (Table 4a.3.1). It was also considered that all the biomass is burned, in another way, that there is no char formation. Asadullah (2014) provides information on gas composition (H₂, CO, CH₄, CO₂, N₂) (volume %) of 15 biomass gasification plants that use as feedstocks wood chip, eucalyptus wood, sawdust, sunflower seed pellet, corncob, olive kernel, wood, rice husk, poplar chips, and seed corn.

TABLE 4A.3.1
EMISSION FACTORS FOR GASIFICATION PROCESSES OF BTG AND BTL

	EF CO ₂ (kg CO ₂ /ton C)	EF CH ₄ (kgCH ₄ /ton C)	EF N ₂ O (kg N ₂ O/ton C)
Biomass	4	0.6	n.d.
n.d. – Not Determined Source: estimated based on Asadullah (2014)			

Municipal Solid Waste

There is no available information to estimate emission factor for fugitive emissions from BtG and BtL facilities related to MSW feedstock.

CHOICE OF ACTIVITY DATA

The activity data required to estimate fugitive emissions from BtG and BtL includes the amount of biomass gasified at gasification stage. Countries that use these technologies should have plant-specific data on the amount of biomass gasified.

UNCERTAINTY ASSESSMENT

Biomass to gaseous and biomass to liquid

Estimates of fugitive emissions from BtG and BtL facilities are likely to be highly uncertain due to lack of information about fugitive emissions from these technologies.

Emission factor uncertainties

There is minimal literature and an absence of large scale BtG and BtL facilities. The fugitive emission factors provided in this guideline were estimated based on very few data and uncertainties are large.

Activity data uncertainties

Where activity data are obtained from plants, uncertainty estimates can be obtained from producers.

References

SECTION 4.1

- Central Institute of Mining and Fuel Research. (2016) *Investigation on Methane Emission for Classification of Degree of Gassiness of Coal Seams and Associated Gas Hazards at Jamadoba Colliery, 6 & 7 Pits Bhugoria Amalgamated Colliery and Digwadiah Colliery of TATA Steel Limited*, CSIR-CIMFR Project No.: SSP/69/2015-16.
- China State Administration of Coal Mine Safety. (2012) *Compilation of Measurement Data for Classification of Degree of Gassiness of Underground Coal Mines in China 2011* (in Chinese). In: ed. China State Administration of Coal Mine Safety.
- Commonwealth of Australia. (2017) *National Inventory Report 2015 Volume 1*. In: p. 347.
- Czech Republic. (2017) *National Greenhouse Gas Inventory Report of the Czech Republic (reported inventories 1990- 2015)*. In: p. 491.
- GOST. (2015) GOST 30319.1-2015 *Natural gas. Methods of calculation of physical properties. General statements*. In.
- Lloyd, P. J. D. (2008) *Fugitive Emissions from Coal Mines - A report underpinning the national inventory, Prepared for Department of Environment Affairs and Tourism*, Republic of South Africa.
- Ministry of the Environment Japan. (2017) *National Greenhouse Gas Inventory Report of JAPAN*. In: p. 752.
- Moscow Geological Prospecting Institute. (1979) *Gas bearing capacity of coal basins and deposits of USSR. Vol. 1. Coal basins and deposits of European part of USSR*. In: p. 628.
- Moscow Geological Prospecting Institute. (1980) *Gas bearing capacity of coal basins and deposits of USSR. Vol. 3*. In.
- Republic of Kazakhstan. (2017) *National report of the Republic of Kazakhstan on the inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for 1990-2015*. In: p. 393.
- Republic of Slovenia. (2017) *Slovenia's National Inventory Report 2017*. In: p. 353.
- RGE "Kaz NIIK" MOOS RK. (2010) *System of normative documents on environmental protection. Guidance document. Methodical instructions on calculation of greenhouse gas emissions to the atmosphere from open-pit coal mining and treatment enterprises*. In: Astatana.
- Slovak Republic. (2017) *National Greenhouse Gas Inventory Report 1990 – 2015 to the UNFCCC and the Kyoto Protocol*. In: p. 448.
- Yu, S., Zhu, S. & Zhang, J. (2018) *An analysis on fugitive CO₂ emission factors from China underground coal mines*. Energy of China 40(5): 8.

SECTION 4.2

- Alberta Energy Regulator (2017), ST39: Alberta Mineable Oil Sands Plant Statistics. <https://www.aer.ca/data-and-publications/statistical-reports/st39>.
- API MPMS 11.1:2004. American Petroleum Institute. Manual of Petroleum Measurement Standards Chapter 11 - Physical Properties Data Section 1 - Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils (<http://www.api.org/publications-standards-and-statistics/standards/standards-addenda-and-errata/standards-addenda-and-errata/~media/a2af8a6e504e478389b286779472edaf.ashx>)
- ASTM D 1250-8 Standard Guide for Use of the Petroleum Measurement Tables
- Australian Government Clean Energy Regulator. (2017). National Greenhouse and Energy Reporting. <http://www.cleanenergyregulator.gov.au/NGER>
- Australian Government Department of the Environment and Energy. (2017). *National Inventory Report 2015*. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.
- Bender & Langer, Mueller BBM (2012). Determination of Emission Factors and Activity Data in the Area of the IPCC (1996) 1.B.2.b.iii - Fugitive Emissions from Natural Gas Storage. Federal Environmental Agency of Germany, 2012 Funding code (FKZ): 360 16 035; Report no. M96023/01; 38 pages

- 3936 Burgers et al. (2011). *Worldwide development potential for sour gas*. Energy Procedia Volume 4, 2011, Pages
3937 2178-2184. <https://doi.org/10.1016/j.egypro.2011.02.104>.
3938 <http://www.sciencedirect.com/science/article/pii/S1876610211003018?via%3Dihub>.
- 3939 Clearstone Engineering Ltd. (2017). An Inventory of GHG, CAC and Other Priority Emissions by the Canadian
3940 Oil Sands Industry: 2015, prepared for Environment and Climate Change Canada
- 3941 Colorado Oil and Gas Conservation Commission (2017). *Glossary of Oil and Gas Terms*.
3942 https://cogcc.state.co.us/COGIS_Help/glossary.htm
- 3943 Davies, R.J., Almond, S., Ward, R.S., Jackson, R.B., Adams, C., Worrall, F., Herringshaw, L.G., Gluyas, J.G.,
3944 Whitehead, M.A., (2014). Oil and gas wells and their integrity: Implications for shale and unconventional resource
3945 exploitation. Mar. Pet. Geol. 56, 239–254.
- 3946 Environment Agency Austria (2017). *Austria's National Inventory Report 2017*.
3947 http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.ph
3948 p.
- 3949 Gas Research Institute (1996). *Methane Emissions from the Natural Gas Industry*. Prepared by Radian. U.S.
3950 Environmental Protection Agency. April 1996. [https://www.epa.gov/natural-gas-star-program/methane-](https://www.epa.gov/natural-gas-star-program/methane-emissions-natural-gas-industry)
3951 [emissions-natural-gas-industry](https://www.epa.gov/natural-gas-star-program/methane-emissions-natural-gas-industry)
- 3952 German Federal Environment Agency (2017). National Inventory Report for the German Greenhouse Gas
3953 Inventory 1990 – 2015.
3954 http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.ph
3955 p.
- 3956 GOST 8.595-2010. (2012). State system of ensuring the uniformity of measurements. Density and volume of
3957 petroleum. The tables of factors for recalculation of density and mass. 2012 (in Russian).
- 3958 IPCC (1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. [http://www.ipcc-](http://www.ipcc-nggip.iges.or.jp/public/gl/invs4.html)
3959 [nggip.iges.or.jp/public/gl/invs4.html](http://www.ipcc-nggip.iges.or.jp/public/gl/invs4.html)
- 3960 IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National
3961 Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).
3962 Published: IGES, Japan. <https://www.ipcc-nggip.iges.or.jp/public/2006gl/>
- 3963 Kang et al. (2016). *Identification and characterization of high methane-emitting abandoned oil and gas wells*.
3964 Proceedings of the National Academy of Science. vol. 113 no. 48, 13636–13641, doi:
3965 10.1073/pnas.1605913113. <http://www.pnas.org/content/113/48/13636.abstract>
- 3966 King, et a. (2013). Environmental risk arising from well-construction failure- differences between barrier and well
3967 failure, and estimates of failure frequency across common well types, locations, and well age. SPE Prod. Oper.
3968 28 (4), 323–344.
- 3969 Marchese et al. (2015). *Methane Emissions from United States Natural Gas Gathering and Processing*. Environ.
3970 Sci. Technol., 2015, 49 (17), pp 10718–10727. DOI: 10.1021/acs.est.5b02275.
3971 <http://pubs.acs.org/doi/abs/10.1021/acs.est.5b02275>.
- 3972 Radian International (1999). *Methane Emissions from the U.S. Petroleum Industry*. Prepared by Radian
3973 International. U.S. Environmental Protection Agency. February 1999.
3974 <https://www.epa.gov/ghgemissions/radian-1999-methane-emissions-us-petroleum-industry>
- 3975 Schlumberger (2017). *Oilfield Glossary*. <http://www.glossary.oilfield.slb.com/>
- 3976 Townsend-Small et al. (2016). *Emissions of coalbed and natural gas methane from abandoned oil and gas wells*
3977 *in the United States*. Geophys. Res. Lett., 43, 2283–2290, doi:10.1002/2015GL067623.
3978 <http://onlinelibrary.wiley.com/doi/10.1002/2015GL067623/full>
- 3979 U.S. Bureau of Ocean Energy Management (2014). *Year 2011 Gulfwide Emission Inventory Study*. Bureau of
3980 Ocean Energy Management, U.S. Department of Interior. OCS Study BOEM 2014-666.
3981 <http://www.data.boem.gov/PI/PDFImages/ESPIS/5/5440.pdf>
- 3982 U.S. EPA (2015). *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2014: Revisions to Natural Gas*
3983 *and Petroleum Production Emissions*. [https://www.epa.gov/sites/production/files/2016-](https://www.epa.gov/sites/production/files/2016-08/documents/final_revision_to_production_segment_emissions_2016-04-14.pdf)
3984 [08/documents/final_revision_to_production_segment_emissions_2016-04-14.pdf](https://www.epa.gov/sites/production/files/2016-08/documents/final_revision_to_production_segment_emissions_2016-04-14.pdf).
- 3985 U.S. EPA (2017). *Greenhouse Gas Reporting Program*. <https://www.epa.gov/ghgreporting>.
- 3986 U.S. EPA (2017). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015*.
3987 <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.

Second-order Draft

3988 Vielstädte et al. (2015). *Quantification of methane emissions at abandoned gas wells in the Central North Sea*,
 3989 Marine and Petroleum Geology, doi: 10.1016/j.marpetgeo.2015.07.030.
 3990 <http://www.sciencedirect.com/science/article/pii/S0264817215300519>

3991 Zimmerle et al. (2015). *Methane Emissions from the Natural Gas Transmission and Storage System in the United*
 3992 *States*. Environ. Sci. Technol., 2015, 49 (15), pp 9374–9383. DOI: 10.1021/acs.est.5b01669.
 3993 <http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01669>.

3994 **SECTION 4.3**3995 **Coke production**

3996 Hensmann M, Haardt S, Ebert D (October 2012) Emission factors for the iron and steel industry for emissions
 3997 reporting, pp. 1-69. Germany.

3998 JRC (2013). Remus R, Aguado-Monsonet MA, Roudier, S, Sancho, LD (2013) Best Available Techniques (BAT)
 3999 Reference Document for Iron and Steel Production In: Seville, Spain: European Commission, Joint Research
 4000 Centre (JRC).

4001 **Charcoal production**

4002 AFREA (2011). Wood-based biomass energy development for sub-Saharan Africa: Issues and approaches. In: pp.
 4003 1-64. Washington, D.C., USA.

4004 FAO (2016). Forestry for a low-carbon future Integrating forests and wood products in climate change strategies.
 4005 Rome: Food and Agriculture Organization of the United Nations.

4006 FAO (2017). The charcoal transition: greening the charcoal value chain to mitigate climate change and improve
 4007 local livelihoods, ed. JV Dam. Rome: Food and Agriculture Organization of the United Nations.

4008 Basu A, Blodgett C, Müller N, Soezer A (2013) Nationally appropriate mitigation action study on sustainable
 4009 charcoal in Uganda. In: ed. E. Travers, pp. 1-88. New York, USA: United Nations Development Programme
 4010 (UNDP).

4011 Chidumayo EN, Gumbo D (2013) The environmental impacts of charcoal production in tropical ecosystems of the
 4012 world: A synthesis. *Energy for Sustainable Development* 17(2): 86-94.

4013 Iiyama M, N. H., Dobie P, Hagen R, Njenga M, Ndegwa G, Gasper MJ et al. (2014) Opportunities and Challenges
 4014 of Landscape Approaches for Sustainable Charcoal Production and Use. In: CRAF Policy Brief 31, Nairobi,
 4015 Kenya: World Agroforestry Centre.

4016 Taccini MM (2011) Study of the methodologies of the United Nations Framework Council on Climate Changes,
 4017 regarding the assessment of greenhouse gases emissions on the charcoal production. In: pp. 1-87. Piracicaba,
 4018 2010: Escola Superior de Agricultura Luiz de Queiroz.

4019 Nicolas M, Michaelowa A, Eschman M (2011) Proposal for a new standardised baseline for charcoal projects in
 4020 the Clean Development Mechanism. In: pp. 1-86. Zurich, Switzerland.

4021 Pennise DM, Smith KR, Kithinji JP, Rezende ME, Raad TJ, Zhang J, Fan C (2001) Emissions of greenhouse gases
 4022 and other airborne pollutants from charcoal making in Kenya and Brazil. *Journal of Geophysical Research:*
 4023 *Atmospheres* 106(D20): 24143-24155.

4024 R, B. (2009) Modeling climate change mitigation from alternative methods of charcoal production in Kenya.
 4025 *Biomass and Bioenergy* 33(11): 1491-1502.

4026 Schure J, L. P., Wiersum KF. (2014) Producing Woodfuel for Urban Centers in the Democratic Republic of Congo:
 4027 A Path Out of Poverty for Rural Households? *World Development* 64(Supplement 1): S80-S90.

4028 Smith KR, P. D., Khummongkol P, Chaiwong V, Ritgeen K, Zhang J, Panyathanya W, Rasmussen RA, Khalil
 4029 MAK. (1999) Greenhouse Gases from Small-scale Combustion Devices in Developing Countries. Phase III:
 4030 Charcoal-Making Kilns in Thailand. In: pp. 1-70. Office of Research and Development, Washington DC.

4031 **Solid fuel to solid fuel transformation**

4032 Ministry of Environment, British Columbia (2011). Wood Pellet Manufacturing Facilities: Fact sheet Air
 4033 Emissions. In: pp. 1-3. Ministry of Environment, British Columbia.

4034 Agar D, Gil J, Sanchez D, Echeverria I, Wihersaari M (2015) Torrefied versus conventional pellet production – A
 4035 comparative study on energy and emission balance based on pilot-plant data and EU sustainability criteria.
 4036 *Applied Energy* 138(Supplement C): 621-630.

4037 Grover PD, Mishra SK (1996) Biomass Briquetting: Technology and Practices. In: Bangkok, Thailand.

- 4038 Johansson LS, Leckner B, Lennart G, Cooper D, Tullin C, Potter A. (2004) Emission characteristics of modern
4039 and old-type residential boilers fired with wood logs and wood pellets. *Atmospheric Environment* 38(25): 4183-
4040 4195.
- 4041 Kummamuru B (2017) WBA Global Bioenergy Statistics 2017. In: pp. 1-80. Stockholm, Sweden: World
4042 Bioenergy Association.
- 4043 Kuang X, S. T., Bi, Xiaotao T, Sokhansanj S, Jim Lim C, Staffan M. (2008) Characterization and Kinetics Study
4044 of Off-Gas Emissions from Stored Wood Pellets. *Ann Occup Hyg* 52(8): 675-683.
- 4045 Olsson M (2002) Wood pellets as low-emitting residential biofuel. In: Department of Chemical Environmental
4046 Science, pp. 1-70. Göteborg, Sweden Chalmers University Of Technology, Göteborg, Sweden
- 4047 Magelli F, Boucher K, Bi HT, Staffan M, Alessandra B (2009) An environmental impact assessment of exported
4048 wood pellets from Canada to Europe. *Biomass and Bioenergy* 33(3): 434-441.
- 4049 Murphy F, D. G., McDonnell K. (2015) Greenhouse gas and energy based life cycle analysis of products from the
4050 Irish wood processing industry. *Journal of Cleaner Production* 92: 134-141.
- 4051 Sjølie HK, Solber B (2011) Greenhouse gas emission impacts of use of Norwegian wood pellets: a sensitivity
4052 analysis. *Environmental Science & Policy* 14(8): 1028-1040.
- 4053 Svedberg U, Samuelsson J, Melin S (2008) Hazardous off-gassing of carbon monoxide and oxygen depletion
4054 during ocean transportation of wood pellets. *Ann Occup Hyg* 52(4): 259-266.
- 4055 Wang C, Chang Y, Zhang L, Pang M, Hao Y (2017) A life-cycle comparison of the energy, environmental and
4056 economic impacts of coal versus wood pellets for generating heat in China. *Energy* 120: 374-384.
- 4057 **BtL and BtG**
- 4058 NETL/DOE (June 2016). Gasification Plant Databases. In: National Energy Technology Laboratory, DOE.
- 4059 IEA Bioenergy (2006). van der Drift A, Boerrigter H (2006) Synthesis gas from biomass for fuels and chemicals,
4060 pp. 1-31, ECN-C--06-001: IEA Bioenergy.
- 4061 Ail SS, Dasappa S (2016) Biomass to liquid transportation fuel via Fischer Tropsch synthesis – Technology review
4062 and current scenario. *Renewable and Sustainable Energy Reviews* 58(Supplement C): 267-286.
- 4063 Asadullah M (2014) Biomass gasification gas cleaning for downstream applications: A comparative critical review.
4064 *Renewable and Sustainable Energy Reviews* 40: 118-132.
- 4065 Ralph EHS (2007) Bioenergy Project Development and Biomass Supply, pp. 1-66. France.
- 4066 **CTL and GTL**
- 4067 IEA Energy Technology Essentials (2006). CO₂ Capture & Storage, pp. 1-4. IEA Energy Technology Essentials,
4068 OECD/International Energy Agency (IEA).
- 4069 Childress, J. (2008) Gasification Industry Overview: Addressing the “Dash to Gas”. In: Tulsa, Oklahoma, USA:
4070 Gasification Technologies Council, Gasification Workshop.
- 4071 IEA Clean Coal Centre (2008). Couch G (2008) Coal to liquids, ISBN 978-97-9029-451-1, IEA Clean Coal Centre
4072 (CCC)/132, London.
- 4073 Hao X, D. M., Xu YY, Wang YI, Chang J, Li YW (2008) Simulation Analysis of a GTL Process Using Aspen
4074 Plus. *Chemical Engineering & Technology* 31(2): 188-196.
- 4075 Heimel S, Lowe C (2009) Technology comparison of CO₂ capture for a gas-to-liquids plant. *Energy Procedia*
4076 1(1): 4039-4046.
- 4077 Higman C, van der Burgat MJ (2008) Gasification (Second Edition), pp. 1-435. Burlington: Gulf Professional
4078 Publishing.
- 4079 Jaramillo P, Griffin WM, Matthews HS (2008) Comparative Analysis of the Production Costs and Life-Cycle
4080 GHG Emissions of FT Liquid Fuels from Coal and Natural Gas. *Environmental Science & Technology* 42(20):
4081 7559-7565.
- 4082 NETL (2007). Leonard MB, Jay W (2007). Industrial Size Gasification for Syngas, Substitute Natural Gas and
4083 Power Production, pp. 1-921. Research and Development Solutions, LLC, National Energy Technology
4084 Laboratory (NETL).
- 4085 Mantripragada HC, Rubina ES (2009). CO₂ reduction potential of coal-to-liquids (CTL) plants. *Energy Procedia*
4086 1(1): 4331-4338.

4087