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TNO report

TNO 2021 R11314

Update of the Netherlands list of fuels in 2021

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Number of pages	30
Number of appendices	-
Sponsor	Rijksdienst voor Ondernemend Nederland
Project name	Brandstoffenlijst 2021
Project number	060.47478

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1 Introduction

The Netherlands list of fuels consist of a complete set of fuels and their heating value (net calorific value: NCV) and CO_2 emission factors for three years. It is accompanied by a set of factsheets which contain background information on the source of the heating values and CO_2 emission factors.

The Netherlands list of fuels was first composed in 2004 (Vreuls, 2004) and was based on heating values and CO_2 emission factors from the IPCC 1996 Guidelines and from national studies. This list has been updated annually, and the most recent version is from 2021 (Zijlema, 2021).

Table 1 provides an overview of the heating values and emission factors for each fuel in 2019, including a comparison with the IPCC default values (from the IPCC 2006 Guidelines and the IPCC 2019 Refinement). For some fuels, the country specific heating value or CO_2 emission factor are not in the range of the IPCC 2006 Guidelines and the IPCC 2019 Refinements. The carbon content in kg C per kg fuel of some fuels (calculated from the heating value and the CO_2 emission factor) also shows some notable values.
These fuels are:

- Heating values: Bitumen, refinery gas, chemical waste gas, waste
- CO_2 emission factors: Gas-/diesel oil, LPG, gas biomass, wastewater biogas, landfill gas and industrial organic waste gas
- Carbon content: Aviation gasoline, naphtha, petroleum coke, paraffin waxes, white spirit and SBP, other petroleum products, anthracite, lignite and coal tar

Refinery gas, chemical waste gas and LPG are discussed in detail in chapter 2. The other fuels may need further improvement in the future, and are summarised in paragraph 2.5.

Within this study, the heating values and CO_2 emission factors of a selection of fuels have been studied in more detail (literature research). The selected fuels are:

- Biogasoline
- Biodiesel
- LPG
- Waste gases (refinery gas, chemical waste gas, coke oven gas, blast furnace gas, oxy gas, phosphor gas)
- Other bituminous coal

Chapter 2 provides a more detailed overview of the background information (literature, data from Annual Environmental Reports) for each of the selected fuels, while a proposal for improved heating values and CO_2 emission factors is presented in chapter 3.

Table 1: Heating values and CO_2 emission factors for the fuels in the Netherlands of fuels (as presented in Zijlema, 2021), compared to the default net calorific values and CO_2 emission factors from the IPCC 2006 Guidelines and the IPCC 2019 Refinement. The 95% confidence intervals are presented in brackets. Highlighted values are outside the IPCC range.

Fuel name	**Heating value (MJ/unit)**					**CO_2 EF (kg/GJ)**		
English	**Used in NL in 2019**			**IPCC 2006/2019**		**Used in NL in 2019**		**IPCC 2006/2019**
A. Liquid Fossil, Primary Fuels								
Crude oil	42.7	MJ/kg	CS	42.3 (40.1 - 44.8)	MJ/kg	73.3	IPCC	73.3 (71.1 - 75.5)
Orimulsion	27.5	MJ/kg	IPCC	27.5 (27.5 - 28.3)	MJ/kg	77.0	IPCC	77.0 (69.3 - 85.4)
Natural Gas Liquids	44.0	MJ/kg	CS	44.2 (40.9 – 46.9)	MJ/kg	64.2	IPCC	64.2 (58.3 - 70.4)
Fossil fuel additives	44.0	MJ/kg	CS					
Liquid Fossil, Secondary Fuels/ Products								
Gasoline [4)]	43.0	MJ/kg	CS	44.3 (42.5 – 44.8)	MJ/kg	73.0	CS	69.3 (67.5 - 73.0)
Aviation gasoline	44.0	MJ/kg	CS	44.3 (42.5 - 44.8)	MJ/kg	72.0	CS	70.0 (67.5 - 73.0)
Jet Kerosene	43.5	MJ/kg	CS	44.1 (42.0 - 45.0)	MJ/kg	71.5	IPCC	71.5 (69.7 - 74.4)
Other kerosene	43.1	MJ/kg	CS	43.8 (42.4 - 45.2)	MJ/kg	71.9	IPCC	71.9 (70.8 - 73.7)
Shale oil	38.1	MJ/kg	IPCC	38.1 (32.1 - 45.2)	MJ/kg	73.3	IPCC	73.3 (67.8 - 79.2)
Gas/Diesel oil [4)]	43.2	MJ/kg	CS	43.0 (41.4 - 43.3)	MJ/kg	72.5	CS	74.1 (72.6 - 74.8)
Residual Fuel oil	41.0	MJ/kg	CS	40.4 (39.8 - 41.7)	MJ/kg	77.4	IPCC	77.4 (75.5 - 78.8)
Liquefied Petroleum Gas (LPG)	45.2	MJ/kg	CS	47.3 (44.8 - 52.2)	MJ/kg	66.7	CS	63.1 (61.6 - 65.6)
Ethane	45.2	MJ/kg	CS	46.4 (44.9 - 48.8)	MJ/kg	61.6	IPCC	61.6 (56.5 - 68.6)
Naphta	44.0	MJ/kg	CS	44.5 (41.8 - 46.5)	MJ/kg	73.3	IPCC	73.3 (69.3 - 76.3)
Bitumen	41.9	MJ/kg	CS	40.2 (33.5 - 41.2)	MJ/kg	80.7	IPCC	80.7 (73.0 - 89.9)
Lubricants	41.4	MJ/kg	CS	40.2 (33.5 - 42.3)	MJ/kg	73.3	IPCC	73.3 (71.9 - 75.2)
Petroleum Coke	35.2	MJ/kg	CS	32.5 (29.7 - 41.9)	MJ/kg	97.5	IPCC	97.5 (82.9 - 115.0)
Refinery Feedstocks	43.0	MJ/kg	IPCC	43.0 (36.3 - 46.4)	MJ/kg	73.3	IPCC	73.3 (68.9 - 76.6)
Refinery Gas	45.2	MJ/kg	CS	49.5 (47.5 - 50.6)	MJ/kg	67.0	CS	57.6 (48.2 - 69.0)
Chemical Waste Gas	45.2	MJ/kg	CS		MJ/kg	62.4	CS	
Other oil	40.2	MJ/kg	IPCC	40.2 (33.7 - 48.2)	MJ/kg	73.3	IPCC	73.3 (72.2 - 74.4)
Paraffin Waxes	42.7	MJ/kg	CS	40.2 (33.7 - 48.2)	MJ/kg	73.3	IPCC	73.3 (72.2 - 74.4)
White Spirit and SBP	43.6	MJ/kg	CS	40.2 (33.7 - 48.2)	MJ/kg	73.3	IPCC	73.3 (72.2 - 74.4)
Other Petroleum Products	42.7	MJ/kg	CS	40.2 (33.7 - 48.2)	MJ/kg	73.3	IPCC	73.3 (72.2 - 74.4)
B. Solid Fossil, Primary Fuels								
Anthracite	29.3	MJ/kg	CS	26.7 (21.6 - 32.2)	MJ/kg	98.3	IPCC	98.3 (94.6 - 101.0)
Coking Coal	28.6	MJ/kg	CS	28.2 (24.0 - 31.0)	MJ/kg	94.0	CS	94.6 (87.3 - 101.0)
Coking Coal (used in coke oven)	28.6	MJ/kg	CS		MJ/kg	95.4	CS	
Coking Coal (used in blast furnaces)	28.6	MJ/kg	CS		MJ/kg	89.8	CS	
Other Bituminous Coal	25.0	MJ/kg	CS	25.8 (19.9 - 30.5)	MJ/kg	94.7	CS	94.6 (89.5 - 99.7)
Sub-Bituminous Coal	18.9	MJ/kg	IPCC	18.9 (11.5 - 26.0)	MJ/kg	96.1	IPCC	96.1 (92.8 - 100.0)
Lignite	20.0	MJ/kg	CS	11.9 (5.5 - 21.6)	MJ/kg	101.0	IPCC	101.0 (90.9 - 115.0)
Oil Shale	8.9	MJ/kg	IPCC	8.9 (7.1 - 11.1)	MJ/kg	107.0	IPCC	107.0 (90.2 - 125.0)
Peat	9.76	MJ/kg	IPCC	9.76 (7.8 - 12.5)	MJ/kg	106.0	IPCC	106.0 (100.0 - 108.0)
Solid Fossil, Secondary Fuels								
BKB & Patent Fuel	20.7	MJ/kg	IPCC	20.7 (15.1 - 32.0)	MJ/kg	97.5	IPCC	97.5 (87.3 - 109.0)
Coke Oven/Gas Coke	28.5	MJ/kg	CS	28.2 (25.1 - 30.2)	MJ/kg	106.8	CS	107.0 (95.7 - 119.0)
Coke Oven gas [3)]	1.0	MJ/MJ	CS	38.7 (19.6 - 77.0)	MJ/kg	42.8	CS	44.4 (37.3 - 54.1)
Blast Furnace Gas [3)]	1.0	MJ/MJ	CS	2.47 (1.2 - 5.0)	MJ/kg	247.4	CS	260.0 (219.0 - 308.0)
Oxy Gas [3)]	1.0	MJ/MJ	CS	7.06 (3.8 - 15.0)	MJ/kg	191.9	CS	182.0 (145.0 – 202.0)
Phosphor Gas	11.0	MJ/Nm3	CS			143.9	CS	
Coal tar	41.9	MJ/kg	CS	28.0 (14.1 - 55.0)	MJ/kg	80.7	IPCC	80.7 (68.2 - 95.3)
C. Gaseous Fossil Fuels								

Fuel name	**Heating value (MJ/unit)**					**CO_2 EF (kg/GJ)**		
English	**Used in NL in 2019**			**IPCC 2006/2019**		**Used in NL in 2019**		**IPCC 2006/2019**
Natural Gas (dry) 3)	31.65	MJ/Nm3 ae	CS	48.0 (46.5 - 50.4)	MJ/kg	56.6	CS	56.1 (54.3 - 58.3)
Compressed natural gas (CNG)	31.65	MJ/Nm3 ae	CS			56.6	CS	
Liquified natural gas (LNG)	31.65	MJ/Nm3 ae	CS			56.6	CS	
Carbon Monoxide	12.6	MJ/Nm3	CS			155.2	CS	
Methane	35.9	MJ/Nm3	CS			54.9	CS	
Hydrogen	10.8	MJ/Nm3	CS			0.0	CS	
Biomass								
Solid Biomass 1)	15.1	MJ/kg	CS	11.6 (5.9 – 23.0) 15.6 (7.9 – 31.0)	MJ/kg	109.6	IPCC	100.0 (84.7 - 117.0) 112.0 (95.0 - 132.0)
Charcoal	30.0	MJ/kg	CS	29.5 (14.9 - 58.0)	MJ/kg	112.0	IPCC	112.0 (95.0 - 132.0)
Biogasoline	27.0	MJ/kg	CS	27.0 (13.6 - 54.0)	MJ/kg	70.7	CS	70.8 (59.8 - 84.3)
Biodiesels	37.0	MJ/kg	CS	27.0 (13.6 - 54.0)	MJ/kg	76.8	CS	70.8 (59.8 - 84.3)
Other liquid biofuels	36.0	MJ/kg	CS	27.4 (13.8 - 54.0)	MJ/kg	79.6	IPCC	79.6 (67.1 - 95.3)
Gas Biomass 3)	21.8	MJ/Nm3	CS	50.4 (25.4 - 100.0)	MJ/kg	90.8	CS	54.6 (46.2 - 66.0)
Wastewater biogas 3)	23.3	MJ/Nm3	CS	50.4 (25.4 - 100.0)	MJ/kg	84.2	CS	54.6 (46.2 - 66.0)
Landfill gas 3)	19.5	MJ/Nm3	CS	50.4 (25.4 - 100.0)	MJ/kg	100.7	CS	54.6 (46.2 - 66.0)
Industrial organic waste gas 3)	23.3	MJ/Nm3	CS	50.4 (25.4 - 100.0)	MJ/kg	84.2	CS	54.6 (46.2 - 66.0)
D Other fuels								
Waste 2)	9.8	MJ/Kg	CS	10.0 (7.0 – 18.0) 11.6 (6.8 - 18.0)	MJ/Kg	105.0	CS	91.7 (73.3 - 121.0) 100.0 (84.7 - 117.0)

CS = Country-specific. IPCC = IPCC default

1) Solid biomass: The two different values from IPCC 2006/2019 refer to 'Wood/Wood Waste' and to 'Other Primary Solid Biomass'. The current emission factor is from the 1996 IPCC Guidelines.

2) Waste: The Dutch heating value and CO_2 emission factor is valid for the combination of fossil and biogenic waste. The two different values from IPCC 2006/2019 refer to respectively 'Municipal Wastes (non-biomass fraction)' and 'Municipal Wastes (biomass fraction)'

3) Note that the Dutch heating values for coke oven gas, blast furnace gas, oxy gas (in MJ/MJ) and natural gas, gas biomass, wastewater biogas, landfill gas and industrial organic waste gas (in MJ/Nm3) cannot be directly compared to the IPCC default values (in MJ/kg), because of differences in units.

4) Pure fossil gasoline and diesel are rare nowadays, as there is a substantial admixture of biogenic material. Therefore, fossil gasoline and diesel should be interpreted as the fossil fractions in the respective fuels. The composition and properties of these fossil fractions will change with the changing admixture of biogenic material. Hence, it is to be expected that fossil gasoline and diesel characteristics change over time, as reported by Statistics Netherlands, and they are derived from market fuel properties and the known composition of the biogenic part, combined with the reported totals of both.

2 Background information on selected fuels

2.1 Biobased transport fuels

With the Renewable Energy Directive (RED) the use and admixture of biogenic fuels is stimulated. In the last decade there is a steady increase of the fraction of biogenic fuels in transport. Moreover, the variety, types and composition of biobased fuels is changing as a result of experience and innovation. Some biobased fuels, like ethanol and FAME (fatty acid methyl ester), can only be added in limited fractions, up to 10% of the fossil fuel, while other biobased fuels, like HVO (hydrogenated vegetable oil) and bionaphtha, can be used as replacement fuels for fossil fuels. A third group of biobased fuels, like MTBE (methyl-tertio-butyl-ether) and ETBE (ethyl-tertio-butyl-ether), can consist partly of biogenic and partly of fossil stock.

There are three main groups of biobased fuels: alcohols, esters, and synthetic fuels. With all of these variations, biogasoline or biodiesel is a varying mixture of additives and fuels. Within biogenic fuels variations in composition exist, as with most fossil fuels, and they are generally not fully known or reported. For example, the molecular weight and chain lengths of FAME may vary with the processing and the vegetable source. Importantly, also the composition of the fossil fraction may change with the amount and type of biobased additions. The fossil part of petrol in itself does not satisfy the petrol specifications. The biogenic additives necessary to ensure that the petrol meets the petrol specifications changes due to larger share of biobased fuels. Hence, the fossil part and the fossil carbon must be derived from the market fuel analyses, and the known biogenic fraction, which is reported as part of the RED.

In the past, the implicit assumption was that the fossil fraction of transport fuels have the properties of the corresponding fossil transport fuel. Moreover, the characteristics from the past still apply nowadays for these fuels. A second issue with the historic approach is the calculation of the emission factor. The emission factor (in kg CO_2/GJ) was derived from the fractions of the fuels mixed. The carbon content of one fuel maybe higher and the heating value lower, leading to some variation in the carbon fraction and the energy. For example, if one adds 10% water, or hydrogen, to the fuel, the emission factor (in kg CO_2/GJ) should not change for water and decrease substantially for hydrogen, because both have no carbon, and therefore both have an emission factor of 0 kg CO_2/GJ. But the average emission factor (in kg CO_2/GJ) is 10% lower in the simplified average. Details are not captured in the averaging of emission factors itself. In the correct procedure the carbon content (in kg C/kg fuel) and the energy (in MJ/kg fuel) should be averaged separately, before the emission factor (in kg CO_2/GJ) is determined. This requires detailed knowledge of the carbon content of all the fuels, including the biogenic fuels.

In the current fuel list there is no distinction between the different types of biogenic gasoline and diesel, although the variation in the properties of the stock is large. Apart from this large variation, which will lead to a varying average, the different biogenic fuels will have their own aspects, related to the possible mixing ratios and the nature of the fossil fraction.

Within the groups of fuels, there is some variation within boundaries, and most of these variations are linked with the density and volatility of the fuel to satisfy fuel specification. This gives boundaries for the expected properties of fuels for given applications. This chapter explains how different stock for fuel may lead to variation of the characteristics, but that characteristics are bounded by the fuel specification. For example, gasoline will have a higher heating value than diesel given the higher volatility and smaller molecules. But, aromatics fraction and biogenic admixture will lead to variations therein. The table below of different molecules in fuels gives insight in this variation.

Although biofuels are reported separately, in many cases they can only be added in small fractions to fossil fuel, to remain within the specification of respective transport fuels. Most liquid fuels are a mixture of components that in combination satisfy the fuel specification, like density, aromatic content, and combustion properties. Both carbon content and heating value are nor regulated to a result of the fuel requirements.

2.1.1 Background on biobased transport fuel characteristics

There are three main groups of biobased fuels: alcohols (mainly ethanol and methanol), esters (mainly FAME and FAEE), and synthetic fuels (mainly HVO and bionaphtha). The lower heating values (in MJ/kg), vary greatly between biobased oxygenated fuels (like methanol, ethanol, MTBE, ETBE, and FAME) and pure hydrocarbon (like fossil fuels, synthetic, paraffin-like fuels, HVO, and bio-naphtha). Oxygenated fuels have heating values between 27 MJ/kg and 39 MJ/kg. The hydrocarbons span a small range between 42.5 and 44.5 MJ/kg. Moreover, the carbon content varies between $CH_{2.3}$ and $CH_{1.8}$, which leads to carbon fractions in the limited range of 84.5% to 87.0%. A great role in both the variation of heating values and the variation in carbon content is played by the aromatics.

Biogenic hydrocarbons from chemical processing (like HVO and bionaphtha) are generally paraffin like, which in the range of hydrocarbons have the lowest emission factor (kg CO_2/GJ). See Table 2. However, since the carbon thereof is of biogenic nature, the emission factor has little relevance. Instead, paraffin-like biogenic admixture to transport fuels allow for a higher CO_2 emission factor for the fossil fraction, and, in some cases, substantially higher fossil carbon fractions than as based on the assumption that the fossil fraction is identical to similar fossil transport fuel. It is therefore important to deduce the actual amount of fossil carbon from the carbon in the market fuel and the carbon in the biogenic fuels.

For example, taking toluene as the lower energy end of fuels, which has a heating value of 40.6 MJ/kg and a carbon content of 91%. If the fraction of aromatics like toluene in the fuel can vary between 0% and 40% (on the basis of an ideal fuel like octane, with a heating value of 44.6 MJ/kg and a carbon content of 84.2% for octane), the mixture varies between 42.9 and 44.4 MJ/kg in heating value and the highest carbon content is 86.9%. This can been seen as the extreme range in hydrocarbon fuel specifications, which leads to an absolute range in CO_2 emission factor of 69.5 to 74.3 kg CO_2/GJ, since both heating value decreases and carbon content increases with more aromatics.

For diesel the same variation plays a role, but the amount of aromatics is limited to 11% in EN590 fuel specification, yielding a slightly higher heating value and lower carbon content, bringing the heating values and carbon content of both fuels closer together.

The use of oxygenated fuels will lower the heating values. There are no suitable components that can increase the heating value above the 44.5 MJ/kg. The lower the density of the fuel, the higher the heating values for hydrocarbons.

For road transport, the heating values of the fuels are in a narrower bandwidth of about 2%, while, for example, larger ship engines accept a wider range in different liquid fuels with heating values in the total range of 5%. However, gaseous fuels like LPG and CNG, have higher heating values and lower carbon content. The maximal heating value, and the lowest carbon content of hydrocarbons is related to the density of the fuel. Gaseous fuels have the highest heating value and the lowest carbon content and therefore also the lowest emission factor. The smallest hydrocarbon molecule that can reasonable be considered for gasoline is heptane with a density of 680 g/litre and a heating value of 44.7 MJ/kg. As the molecule weight increases, from petrol to kerosine to diesel and to marine fuel, the heating value decreases in the range of roughly 44 MJ/kg to 42 MJ/kg.

The highest heating values are seldom achieved by market fuels. The use of aromatics and larger molecules is very common, suppressing the heating value and increasing the carbon content. Only aviation fuel, kerosine, has a minimal heating value of 42.8 MJ/kg specified. For no other fuel such requirement exists.

Table 2: Properties of a selection of hydrocarbons and alcohols. Higher heating value (HHV), Lower heating value (LHV), carbon content (CC), CO_2 emission factor (EF) and the molecular mass (mole mass).

		molecule	**HHV [MJ/kg]**	**LHV [MJ/kg]**	**CC [kg C/kg fuel]**	**EF [kg CO_2/GJ]**	**mole mass [g]**
Paraffins	methane	C1H4	55.54	50.24	0.750	54.74	16
	ethane	C2H6	51.40	47.16	0.800	62.20	30
	propane	C3H8	50.38	46.53	0.818	64.48	44
	butane	C4H10	49.56	45.90	0.828	66.10	58
	pentane	C5H12	48.68	45.15	0.833	67.68	72
	hexane	C6H14	48.35	44.90	0.837	68.37	86
	heptane	C7H16	48.11	44.72	0.840	68.88	100
	octane	C8H18	47.93	44.58	0.842	69.26	114
	nonane	C9H20	47.79	44.48	0.844	69.56	128
Olefins	ethene	C2H4	50.33	47.30	0.857	66.44	28
	propene	C3H6	48.95	45.92	0.857	68.44	42
	butylene	C4H8	48.49	45.46	0.857	69.13	56
acetylenes	ethyne	C2H2	49.95	48.32	0.923	70.05	26
	propyne	C3H4	48.40	46.28	0.900	71.31	40
naphthenes	cyclopentane	C5H10	46.96	43.93	0.857	71.54	70
	cyclohexane	C6H12	46.61	43.58	0.857	72.11	84
aromatics	benzene	C6H6	41.86	40.23	0.923	84.13	78

	toluene	C7H8	42.47	40.63	0.913	82.40	92
	ethylbenzene	C8H10	43.03	41.03	0.906	80.93	106
Alcohols	methanol	C1H4O	22.69	20.04	0.375	68.61	32
	ethanol	C2H6O	29.69	26.92	0.522	71.05	46
	propanol	C3H8O	33.65	30.82	0.600	71.37	60

2.1.2 Carbon content as key ingredient

As the fuel properties of the fossil component are normally not available separately, they have to be inferred from market fuel properties and the properties of the bio-admixture. In the past it was assumed that the fossil part of market fuel was fossil fuel. Like ethanol was added to normal fossil petrol. This is not the case. The fossil part does not satisfy the fuel specification, before ethanol is added. With higher bio-admixture this discrepancy increases. Therefore it is essential to report also the carbon content of all fuels, so the carbon can be separated properly into biogenic and fossil origin. The biogenic carbon content is not standard reported but should be included to determine the GHG potential of market fuels properly, from the fossil carbon.

Table 3 provides an overview of the carbon content of several biogenic fuels and standard market fuels. FAME, HVO, and bionaphtha are collections of molecules from processing bio-components. FAME is the ester of liquid vegetable oil, close to the properties of diesel, so expected to be similar to the ester of cetane. It may be a somewhat larger molecule, but limited information exists on its actual composition. HVO (“blauwe diesel”) and bionaphtha, for diesel and petrol, respectively, are expected to be mainly paraffins, from cracking, hydrotreated, and pyrolysis. Also here the exact composition is unknown, but likely to be similar to cetane (in the case of diesel) and octane (in the case of petrol) to ensure the fuel specifications are respected. When mixed with fossil fuels, the fossil component is likely to contain more heavier fractions and aromatics with higher carbon content than regular fossil fuel.

Carbon fraction is, given the molecular structure $C_xH_yO_z$:

Carbon Fraction [-] = 12*C/(12*C+H+16*O)

Or, incorporating the normal isotopes abundancies:

Carbon Fraction [-] = 12.011*C/(12.011*C+1.008*H+15.999*O)

The emission factors (in kg CO_2/GJ) are to be inferred from the composition, based on mass fractions, and the carbon fractions (*$Carbon_i$*) and heating values (*LHV_i*) of these components *i*:

$$EF = \frac{44}{12}\frac{\sum Fraction_i * Carbon_i}{\sum Fraction_i * LHV_i}$$

Table 3: The ratio in C, H and O and the carbon fractions of several molecules and standard market fuels, partly from UNECE Regulation 83. FAME, bionaphtha, and HVO are estimates from this study.

		C	**H**	**O**	**Carbon content [%]**
Propane	C3H8	1	2.67	0.000	81.8%
Butane	C4H10	1	2.50	0.000	82.8%
LPG	*LPG*	1	2.53	0.000	82.6%
Diesel B5	*B5*	1	1.86	0.005	86.1%
Diesel B7	*B7*	1	1.86	0.007	85.9%
Gasoline E5	*E5*	1	1.89	0.016	84.8%
Gasoline E10	*E10*	1	1.93	0.033	83.0%
FAME	C18H36O2	1	2.00	0.111	76.1%
HVO	C16H34	1	2.13	0.000	85.0%
DME	C2H6O	1	3.00	0.500	52.2%
bionaphtha	C8H18	1	2.25	0.000	84.2%
MTBE	C5H12O	1	2.40	0.200	68.2%
ETBE	C6H14O	1	2.33	0.167	70.6%

2.1.3 Introduction of reported fuel properties

The NEa (Dutch Emissions Authority) reports on the biofuels, as part of the obligations in the Renewable Energy Directive (RED). The biogasoline and biodiesel are partly based on this information. The Renewable Energy Directive (RED) prescribes the heating values (in MJ/kg and MJ/litre), from which other values, like density, can be derived.

The recent shifts in biofuels, like for example, the shift from bio-ethanol to bionaphtha, observed by the NEa, should be consistent in the fuel list. However, given the restrictive nature of the NEa reporting, special care must be taken that no artefacts in the fuel properties arise. In particular, the fossil part of fuels should be the remainder of the combination of the reported NEa values and the market fuel properties from recent studies.

Combining these NEa reports with statistics from CBS (Statistics Netherlands) of the sale and use of market fuels, allows one to determine the average market fuel, including the biogenic components and the fossil fraction and composition. The fossil fraction does not necessarily have the same composition and properties as traditional fossil fuel. With the new biogenic components like HVO and bionaphtha, which can be added to fuels with high percentages, the fossil fraction is likely to have lower energy content and high carbon content than the common fossil fuel.

2.1.4 Biogasoline

In autumn of 2019 the standard gasoline market fuel in the Netherlands shifted from E5 to E10. The volume fraction of bio-ethanol, C_2H_6O, in this gasoline shifted from 5% to 10%. Therefore, ethanol is a large share of the bio-gasoline. Until recent, ETBE, and to a lesser extent MTBE, was the second largest fraction of biogasoline.

However, only 37% and 22% of ETBE ($C_6H_{14}O$), and MTBE ($C_5H_{12}O$), respectively, counts as biofuel, according to RED. Ethanol, ETBE, and MTBE have substantial lower heating values than fossil gasoline, with 27, 36, and 35 MJ/kg, compared with 43 MJ/kg for fossil fuel (RED). The precise composition of the biogasoline determines the actual heating value and the carbon content.

Recently, bionaphtha, a by-product of HVO production and cracking of vegetable oils, has an increasing contribution in the overall biogasoline in the Netherlands. Bio-naphtha is expected to be mainly light hydrocarbons, with a high heating value, close to 44 MJ/kg (RED) and large carbon fraction, around 84%, based on similarity to octane,C_8H_{18}.

Therefore, biogasoline includes a wide range of fuels, from which ethanol and bio-naphtha are likely the major contributors. Although the heating values and carbon content vary greatly between the components, the emission factors are in a narrow range of 70-72 kg CO_2/GJ.

The country specific values for market fuels, used in the Netherlands, has shown variations and deviations from the generic values, related also to the biogasoline. With the changing composition of the biogenic fraction, it is recommended to continue monitoring the average market fuel properties, in particular the heating value and carbon content, and derive the fossil fraction properties from it.

2.1.5 *Biodiesel*

For many years now, FAME (Fatty Acid Methyl Ester) has been the biogenic component of diesel, i.e., the key biodiesel. Standard diesel, B7, contains 7% FAME, which is also the limit of the fraction of FAME in diesel. It has a lower heating value, at 37 MJ/kg (RED), and a lower carbon content, such that the CO_2 emission factor is only slightly higher than diesel itself. FAME is a collection of molecules. For practical purposes it is assumed that $C_{18}H_{36}O_2$ is the representative molecule, with a 76% carbon fraction.

HVO, hydrotreated vegetable oil, is an increasingly important biodiesel, with similar properties as fossil diesel and synthetic fuel. Therefore, there is little restriction to replace fossil diesel with HVO in almost any mixing ratio. For carbon fraction it is assumed equivalent to cetane, $C_{16}H_{34}$, with a heating value of 44 MJ/kg (RED) and 85% carbon fraction.

2.1.6 *Adaptation of the fuel list to standard biogenic fuels*

Instead of the combined biofuels, i.e., biogasoline and biodiesel, the different components from the RED (Renewable Energy Directive), without a distinction in source the following fuels with fixed properties, unlike the mix of biogasoline and biodiesel, should be distinguished (see Table 4). The heating value and the density are derived from the Renewable Energy Directive (RED). The carbon fractions are from this study. These results deviate slightly from other sources, partly due to the rounding of the numbers in the RED. Methanol may require adaptation of the engine if it is to be added in significant quantities to fossil fuels. It is not necessary limited to gasoline replacement, but can be used, after engine adaptation, in diesel engines too, similar to hydrogen.

Table 4: Characteristics of biofuels with fixed properties: Lower heating value (LHV), density, carbon content (CC), CO_2 emission factor (EF) and the fossil fraction.

Fuel	**LHV [MJ/kg]**	**Density [g/litre]**	**CC [kg C/kg fuel]**	**EF [kg CO_2/GJ]**	**Fossil fraction [%]**
Biogasoline ethanol	27	778	0.522	70.9	0%
Biofuel methanol	20	800	0.375	68.8	0%
Biogasoline MTBE	35	743	0.682	71.4	78%
Biogasoline ETBE	36	771	0.706	71.9	63%
Biogasoline synthetic and treated fuel (mainly bionaphtha)	45	667	0.842	68.6	0%
Biodiesel esters (mainly FAME, but also FAEE)	37	892	0.761	75.4	5.4%
Biodiesel synthetic and treated fuels (mainly HVO)	44	773	0.850	70.8	0%

Table 5: Relative shares of biogasoline fuels and biodiesel fuels, as calculated from reported biofuels in Appendix I of NEa (2020) in physical units (corrected for double counting of biofuels in the NEa report).

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Biogasoline									
Biogasoline ethanol	91.6%	91.5%	94.5%	99.4%	99.7%	99.5%	99.4%	77.3%	82.8%
Biofuel methanol	1.3%	0.7%	1.6%	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%
Biogasoline MTBE	7.1%	7.2%	2.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Biogasoline ETBE	0.0%	0.6%	1.6%	0.2%	0.3%	0.5%	0.6%	11.5%	0.3%
Biogasoline synthetic and treated fuel (mainly bionaphtha)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.2%	16.3%
Biodiesel									
Biodiesel esters (mainly FAME, but also FAEE)	99.8%	98.0%	99.1%	96.4%	98.2%	98.0%	98.9%	97.2%	79.1%
Biodiesel synthetic and treated fuels (mainly HVO)	0.2%	2.0%	0.9%	3.6%	1.8%	2.0%	1.1%	2.8%	20.9%

A weighted average heating value, carbon content and CO_2 emission factor of biogasoline and biodiesel can be calculated from the characteristics from Table 4 and the relative shares as presented in Table 5. The relative shares are calculated from reported biofuels in Appendix I of NEa (2020) in physical units (corrected for double counting of biofuels in the NEa report). The resulting average heating value, carbon content and CO_2 emission factor of biogasoline and biodiesel are presented in Table 6.

Table 6: Average heating value, carbon content and CO_2 emission factor of biogasoline and biodiesel.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Biogasoline									
Heating value (MJ/kg)	27,5	27,6	27,2	27,0	27,0	27,0	27,1	30,1	29,9
Carbon content (kg/kg fuel)	0,531	0,534	0,526	0,523	0,522	0,523	0,523	0,579	0,574
Emission factor (kg CO_2/GJ)	70,9	70,9	70,9	70,9	70,9	70,9	70,9	70,6	70,3
Biodiesel									
Heating value (MJ/kg)	37,0	37,1	37,1	37,3	37,1	37,1	37,1	37,2	38,5
Carbon content (kg/kg fuel)	0,761	0,763	0,762	0,764	0,763	0,763	0,762	0,764	0,780
Emission factor (kg CO_2/GJ)	75,4	75,3	75,4	75,2	75,3	75,3	75,4	75,3	74,3

2.2 LPG

LPG consist of propane and butane or a combination of these two, and it is used for multiple goals, each with different mixtures of propane and butane:

- Road transport
- Petrochemical industry
- Other sectors (construction, agriculture, etc)

The LPG composition for road transport applications differs per country and per season. The share of propane is higher in winter than in summer, because of the lower boiling point of propane. According to the website of Statistics Netherlands (https://www.cbs.nl/nl-nl/onze-diensten/methoden/begrippen/autogas--lpg--), LPG consists of approximately 60% propane and 40% butane in summer and approximately 70% propane and 30% butane in winter. Based on these shares, an average content of 65% propane and 35% butane is expected.

It should be noted that according to the UNECE, the chemical composition of LPG is much closer to butane than propane. The CO_2 emission factor of butane is 2.5% higher than of propane. Also JRC Concawe reported in 2020 a heating value of 46 MJ/kg and a carbon fraction of 82.5 %C (Prussi et al., 2020), suggesting a higher butane fraction than 50% for the annual European average. Winter LPG should, to avoid freezing, have 60% of propane or more, at low temperatures. Summer LPG has few limitations. Based on these shares, an average content of at least 30% propane and maximum 70% butane is expected.

For the other sectors, the mixture can vary much more, or even consist of propane or butane only. The UNECE Regulation 83 has two LPG reference fuels at opposite ends of the full range of market fuels at 30% and 85%. Other components than propane and butane are restricted to less than 2%.

Heating value

The current heating value is from Statistics Netherlands (https://www.cbs.nl/en-gb/onze-diensten/methods/definitions/calorific-value) and is equal to 45.2 MJ/kg, which is in the IPCC Guidelines (2006) range of 44.8 – 52.2 MJ/kg (with an average of 47.3 MJ/kg).

The current heating value is lower than the heating values of propane (46.5 MJ/kg) and butane (45.9 MJ/kg).

Based on the average composition of LPG in the transport sector (65% propane and 35% butane), a heating value of 46.3 MJ/kg could be expected for the transport sector. If the share of butane in LPG would be the maximum of 70%, then an average heating value of 46.1 MJ/kg could be expected for the transport sector.

On the other hand, LPG is also used by companies for mobile and stationary applications. The LPG used in these sectors could consist of propane or butane only (or a blend of these). A small group of companies report the use of LPG in their environmental report, and most often the default heating value of 45.2 MJ/kg is used. Only 1 company reports a deviating heating value of 42.7, but this is probably set equal to the heating value of gas-/diesel oil (and not the result of any measurements).

Based on the heating values of propane and butane, it could be decided to increase the heating value. However, there is an uncertainty in the exact composition of the fuel (both in mobile and in stationary applications), which complicates calculating the exact heating value of LPG. If it is decided that the LPG heating value needs to be improved, then it is necessary to perform measurements on LPG for road transport and for other applications. The composition can be calculated based on vapor pressure measurements (instead of chemical analysis). Table 8 provides an overview of different heating values and CO_2 emission factors for different propane / butane ratios.

<u>CO_2 emission factor</u>

The CO_2 emission factor of LPG is from Olivier (2004) and is based on the average composition of LPG. The carbon content of propane and butane differ by 1%. The current CO_2 emission factor (in kg CO_2 per kg fuel) from Zijlema (2021) is approximately the average of CO_2 emission factors of propane and butane (see Table 7).

Table 7: Carbon content of propane and butane.

		Molecular weight (g/mol)	**Carbon content (kg C/kg)**	**CO_2 emission factor (kg CO_2/kg)**
Propane	C3H8	44.10	0.817	2.994
Butane	C4H10	58.12	0.827	3.029
LPG (Zijlema, 2021)	Mixture C3H8 & C4H10			3.015

The implied CO_2 emission factors reported by a small group of companies in their environmental report varies between 66.6 and 75.1 kg CO_2 per GJ LPG in the environmental reports of 2019, but most companies use the default CO_2 emission factor to calculate and report their emissions. If the implied CO_2 emission factor of 75.1 kg/GJ is excluded, then the emission factors in the environmental reports of 2019 range between 66.6 and 68.1 kg CO_2 per GJ LPG. These small deviations in emission factors are most likely the result of rounding of the reported fuel consumption or the reported emissions. The environmental reports do not provide data with sufficient quality to estimate an improved emission factor.

Since the current CO_2 emission factor in kg per kg LPG is in the range of the CO_2 emission factor of propane and butane, it is advised to maintain the current CO_2 emission factor. However, if it is decided to improve the heating value, then the CO_2 emission factor in kg/GJ also needs to be adjusted.

The heating value and CO_2 emission factor depend on the exact ratio between propane and butane. In Table 8, the heating value and CO_2 emission factor are presented for the ratio presented on the Statistics Netherlands website (0.65/0.35) and the ratio with a maximum of butane (0.30/0.70). For comparison, the heating value and CO_2 emission factor of propane and butane are also included in the table.

Table 8: Heating value and CO_2 emission factor for LPG assuming different propane/butane ratios, compared to the current heating value and CO_2 emission factor in the Netherlands list of fuels.

Propane / butane ratio	**Heating value (MJ/kg)**	**CO_2 emission factor (kg CO_2/kg)**
1.00 / 0.00 (propane only)	46.5	64.3
0.65 / 0.35	46.3	64.9
0.30 / 0.70	46.1	65.5
0.00 / 1.00 (butane only)	45.9	66.0
Current LPG in Zijlema (2021)	45.2	66.7

Conclusion

Since the current heating value of LPG in the Netherlands list of fuels is lower than the heating values of propane and butane, it is expected that the current heating value is an underestimate. Before a new heating value is derived, it is advised to investigate the composition of LPG (which can be calculated from measurements on the vapor pressure of LPG). As the heating value is used by Statistics Netherlands to prepare the energy statistics, a decision to update the LPG heating value needs to be made in agreement with Statistics Netherlands.
If it is decided that the LPG heating value is updated, then the CO_2 emission factor also needs to be updated, which can be calculated from carbon content and heating value.

2.3 Other bituminous coal

Other bituminous coal is a relative soft type of coal containing tar and other bituminous components. This type of coal is used as a fuel for the production of electricity by a four power stations in the Netherlands in 2021.
Bituminous coal can be mixed with other fuels, like different types of biomass or (bio)waste.

Heating value
The current heating value is from Statistics Netherlands and is updated yearly based on company-specific data which is reported monthly to Statistics Netherlands. The heating value for 2019 is equal to 25.0 MJ/kg. This is close to the average heating value of 24.7 MJ/kg reported by coal-fired power plants in their environmental reports in 2019.

A comparison on company-level of the heating value in the energy statistics and in the environmental reports has not been made, but the difference in heating value could be caused by differences in reporting (monthly vs yearly). The heating value in the Netherlands list of fuels is equal to the heating value from Statistics Netherlands in order to be consistent with the energy statistics.

<u>CO_2 emission factor</u>
Statistics Netherlands calculates the CO_2 emissions from coal-fired power plants based on the energy statistics and on the reported CO_2 emissions in ETS reports (Emission Trading Scheme). Table 9 shows the implied emission factors of other bituminous coal for the period 2010-2019, as included in the Dutch Emission Registry.

Table 9: Implied CO_2 emission factors of other bituminous coal in coal fired power plants, as calculated from CO_2 emissions in ETS reports and the Dutch Energy statistics for the Dutch Emissions Registry.

Implied CO_2 emission factor (kg CO_2/GJ) from ETS reports and Dutch Energy statistics	
Year	**Other bituminous coal**
2010	93.9
2011	95.2
2012	94.2
2013	94.4
2014	94.4
2015	93.4
2016	93.2
2017	92.8
2018	91.5
2019	91.8
Current emission factor (kg CO_2/GJ) from the Netherlands list of fuels (Zijlema, 2021)	
Year	**Other bituminous coal**
from 1990	94.7

The implied emission factors from Table 9 show that the emission factor can vary by max 4%. The implied emission factors from Table 9 deviate somewhat from the implied emission factors from the environmental reports. The implied CO_2 emission factors reported by the coal-fired power stations in their environmental reports in 2019 varies between 90.8 –96.0 kg/GJ, with a weighted average of 93.2 kg CO_2/GJ. This is 1.5% higher than the implied emission factor of 2019 in Table 9. Differences are mainly caused by differences in fuel consumption and heating value in the energy statistics and the environmental reports. The implied CO_2 emission factors from Table 9 are consistent with the fuel consumption and the heating value in the energy statistics. Therefore, the implied emission factors from Table 9 are used, and the implied emission factors from the environmental reports are only used for comparison.

Most of the implied emission factors in Table 9 for the period 2010-2019 were lower than the emission factor from Zijlema (2021).

Only the IEF of 2011 was higher. Based on Table 9, it is advised to adjust the CO_2 emission factor of other bituminous coal.
A few options are possible:

- Adjust the CO_2 emission factor yearly, based on the factors from Table 9
- Calculate a 5-year average emission factor from the 2015-2019 data (92.7 kg CO_2/GJ), and use this from 2020 onwards

CO_2 emissions from coal combustion in power plants in the National Inventory Report are all based on the reported emissions from the ETS reports, but emissions in other (smaller) sectors are calculated with the country-specific emission factor. A yearly varying emission factor based on power plant data may not be practical for calculating emissions from these other sectors.
The CO_2 emission factor from the Netherlands list of fuels is also used in the 'Reference Approach' calculation, which is made as a comparison with the actual 'Sectoral Approach' emission calculation. A yearly update of the CO_2 emission factor in the Netherlands list of fuels will result in a better emission estimation of the CO_2 emissions in the 'Reference Approach'.

To account for the long term trend in the CO_2 emission factor of other bituminous coal, it is proposed to update the CO_2 emission factor based on a 5-year average (2015-2019) of the implied CO_2 emission factors as calculated from ETS emissions and energy statistics. The 5-year average (2015-2019) CO_2 emission factor equals 92.7 kg CO_2/GJ.

2.4 Waste gases

Related to the current industrial activities within the Netherlands, waste gases can be split into the following individual waste gases:

- Refinery gas
- Chemical waste gas
- Coke oven gas
- Blast furnace gas
- Oxy gas
- Phosphor gas (only used until 2012)

Table 10 provides an overview of the most recent heating values and emission factors (as presented in Zijlema, 2021), for the waste gases mentioned in this paragraph (extract from Table 1). In this paragraph, all of these waste gases are discussed.

Table 10: Overview of the most recent heating values and emission factors (as presented in Zijlema, 2021), for the waste gases mentioned in this paragraph.

Fuel name	Unit	Heating value (MJ/unit)				CO_2 EF (kg/GJ)			
English		**Used in NL in 2019**		**IPCC 2006/2019**		**Used in NL in 2019**		**IPCC 2006/2019**	
Liquid Fossil, Secondary Fuels/ Products									
Refinery Gas	kg	45,2	CS	49,5	(47,5 - 50,6)	67,0	CS	57,6	(48,2 - 69,0)
Chemical Waste Gas	kg	45,2	CS			62,4	CS		
Solid Fossil, Secondary Fuels									
Coke Oven gas	MJ	1,0	CS	38,7	(19,6 - 77,0)	42,8	CS	44,4	(37,3 - 54,1)
Blast Furnace Gas	MJ	1,0	CS	2,5	(1,2 - 5,0)	247,4	CS	260,0	(219,0 - 308,0)
Oxy Gas	MJ	1,0	CS	7,1	(3,8 - 15,0)	191,9	CS	182,0	(145,0 - 202)
Phosphor Gas	Nm3	11,0	CS			143,9	CS		

2.4.1 Refinery Gas

Refinery gas is produced during the refinery process and refers to a mixture of light hydrocarbons (C2+) with small amounts of N, CO, CO_2, O, H and He. In the Netherlands there is a small number of companies involved in the production and use of Refinery Gas.

<u>Heating value</u>

The current heating value in the Netherlands list of fuels is a constant value from Statistics Netherlands. When companies report there fuel consumption statistics to Statistics Netherlands, they are asked to calculate the fuel consumption in MJ and to convert this to tonnes using the default heating value.

Since the companies calculate and report the refinery gas consumption in MJ, the energy statistics already show the correct fuel consumption (independent of the heating value used). For national reporting of CO_2 emissions, it is not necessary to improve the heating value of refinery gas. It is therefore advised to maintain the current heating value in the Netherlands list of fuels.

For comparison, the default heating value can be compared to the heating values from the environmental reports: The 2019 heating values reported by the small group of companies for individual installations in their environmental reports varies from 3.0 – 72.6 MJ/kg, with a weighted average of 18.1 MJ/kg. This is lower than the default heating value of 45.2 MJ/kg. In general, the companies report their own company-specific or installation-specific heating value. The default heating value is only used for flares.

<u>CO_2 emission factor</u>

Statistics Netherlands calculates the CO_2 emissions from refinery gas based on the energy statistics and on the reported CO_2 emissions in ETS reports (Emission Trading Scheme). Table 11 shows the implied CO_2 emission factors of refinery gas for the period 2010-2019, as included in the Dutch Emission Registry.

Table 11: Implied CO_2 emission factors of refinery gas in refineries, calculated from CO_2 emissions in ETS reports and the Dutch Energy statistics for the Dutch Emissions Registry.

Implied CO_2 emission factor (kg CO_2/GJ) from ETS reports and Dutch Energy statistics	
Year	**Refinery gas**
2010	77.2
2011	66.9
2012	65.3
2013	64.7
2014	64.2
2015	65.7
2016	65.5
2017	64.9
2018	63.2
2019	62.7
Current emission factor (kg CO_2/GJ) from the Netherlands list of fuels (Zijlema, 2021)	
Year	**Refinery gas**
1990-2012	66.7
from 2013	67.0

The implied emission factors from Table 11 show that the emission factor can vary by a few percent. The implied emission factors from Table 11 deviate somewhat from the implied emission factors from the environmental reports. The implied CO_2 emission factors reported by the refineries in their environmental reports in 2019 varies between 31.5 – 298.4 kg/GJ, with a weighted average of 68.0 kg CO_2/GJ. This is 8% higher than the implied emission factor of 2019 in Table 11. It must be noted that the implied emission factor from the environmental reports is uncertain, because the companies often report a CO_2 emission for multiple fuels together. The CO_2 emission of refinery gas is calculated by excluding the CO_2 emissions of other fuels. Also the fuel consumption data in the environmental reports is not always in line with the fuel consumption in the energy statistics (for example when companies use mixtures of refinery gas and natural gas and this is reported in the environmental report as refinery gas).

The implied CO_2 emission factors from Table 11 are consistent with the fuel consumption and the heating value in the energy statistics. Therefore, the implied emission factors from Table 11 are used in the UNFCCC reporting, and the implied emission factors from the environmental reports are only used for comparison.

Most of the implied emission factors in Table 11 for the period 2010-2019 were lower than the emission factor from Zijlema (2021). Only the IEF of 2010 was higher. Based on Table 11, it is advised to adjust the CO_2 emission factor of refinery gas. A few options are possible:
- Adjust the CO_2 emission factor yearly, based on the factors from Table 11
- Calculate a 5-year average emission factor from the 2015-2019 data (64.4 kg CO_2/GJ), and use this from 2020 onwards

CO_2 emissions from refinery gas combustion in the National Inventory Report are all based on the reported emissions from the ETS reports.

Also the companies do not use the default emission factor in their environmental reports. Thus, for the national reporting, it does not matter which emission factor is published in the Netherlands list of fuels. The processes that are responsible for the production of refinery gases can vary considerably, resulting in clear yearly variations. For transparency and consistency, it can be useful to update the emission factor of refinery gas based on 5-year averages.

To account for the long term trend in the CO_2 emission factor of refinery gas, it is proposed to update the CO_2 emission factor based on a 5-year average (2015-2019, instead of a yearly varying emission factor) of the implied CO_2 emission factors as calculated from ETS emissions and energy statistics. The 5-year average (2015-2019) CO_2 emission factor equals 64.4 kg CO_2/GJ.

2.4.2 *Chemical Waste Gas*

Chemical waste gas is a gaseous by-product of the chemical industry and the petrochemical industry specifically. In general, chemical waste gas is mixed with other gaseous by-products and natural gas to be used in the production process for heating purposes or to produce electricity.

The actual composition of this gaseous by-product can vary greatly, strongly depending on the raw materials burned and the production conditions. The mixing with other gases (including the addition of natural gas) is determined by the required combustion conditions, the actual technical conditions and the financial-economic situation on the international market.

<u>Heating value</u>

The current heating value in the Netherlands list of fuels is a constant value from Statistics Netherlands. When companies report there fuel consumption statistics to Statistics Netherlands, they are asked to calculate the fuel consumption in MJ and to convert this to tonnes using the default heating value.

Since the companies calculate and report the chemical waste gas consumption in MJ, the energy statistics already show the correct fuel consumption (independent of the heating value used). For national reporting of CO_2 emissions, it is not necessary to improve the heating value of chemical waste gas. It is therefore advised to maintain the current heating value in the Netherlands list of fuels.

For comparison, the default heating value can be compared to the heating values from the environmental reports: The 2019 heating values reported by chemical companies for individual installations varies from 0.002 – 65.2 MJ/kg, with a weighted average of 22.9 MJ/kg. For the lower end of the heating values, it is possible that companies reported their heating value in incorrect units (e.g. in GJ/kg or in MJ/m3, instead of MJ/kg). The weighted average heating value is lower than the default heating value of 45.2 MJ/kg. In general, the companies report their own company-specific or installation-specific heating value. The default heating value is only used by 3 companies for some installations.

<u>CO_2 emission factor</u>

Statistics Netherlands calculates the CO_2 emissions from chemical waste gas based on the energy statistics and on the reported CO_2 emissions in ETS reports (Emission Trading Scheme).

Table 12 shows the implied CO_2 emission factors of chemical waste gas for the period 2010-2019, as included in the Dutch Emission Registry.

Table 12: Implied CO_2 emission factors of chemical waste gas in chemical industry and in power plants, calculated from CO_2 emissions in ETS reports and the Dutch Energy statistics for the Dutch Emissions Registry.

Implied CO_2 emission factor (kg CO_2/GJ) from ETS reports and Dutch Energy statistics	
Year	**Chemical waste gas**
2010	70.1
2011	70.2
2012	65.8
2013	65.9
2014	65.8
2015	58.8
2016	61.6
2017	62.0
2018	63.9
2019	62.7
Current emission factor (kg CO_2/GJ) from the Netherlands list of fuels (Zijlema, 2021)	
Year	**Chemical waste gas**
1990-2012	66.7
from 2013	62.4

The implied emission factors from Table 12 show that the emission factor can vary by a few percent. The implied emission factors from Table 12 deviate somewhat from the implied emission factors from the environmental reports. The implied CO_2 emission factors reported by the chemical industry in their environmental reports in 2019 varies between 29.1 – 533.2 kg/GJ, with a weighted average of 56.2 kg CO_2/GJ. This is 10% lower than the implied emission factor of 2019 in Table 12. It must be noted that the implied emission factor from the environmental reports is uncertain, because the companies often report a CO_2 emission for multiple fuels together. The CO_2 emission of chemical waste gas is calculated by excluding the CO_2 emissions of other fuels. Also the fuel consumption data in the environmental reports is not always in line with the fuel consumption in the energy statistics (for example when companies use mixtures of chemical waste gas and natural gas and this is reported in the environmental report as chemical waste gas).

The implied CO_2 emission factors from Table 12 are consistent with the fuel consumption and the heating value in the energy statistics. Therefore, the implied emission factors from Table 12 are used, and the implied emission factors from the environmental reports are only used for comparison.

The implied emission factors of chemical waste gas in Table 12 for the period 2010-2019 were close to the emission factor from Zijlema (2021). A few options are possible for the emission factor:

- Maintain the current CO_2 emission factor from Zijlema (2021)
- Adjust the CO_2 emission factor yearly, based on the factors from Table 12

- Calculate a 5-year average emission factor from the 2015-2019 data (61.8 kg CO_2/GJ), and use this from 2020 onwards

Most CO_2 emissions from chemical waste gas combustion in the National Inventory Report are based on the reported emissions from the ETS reports. For less than 1% of the emission, the default emission factor is used. If the emission factor is changed for one or more historical years, this means that the CO_2 emissions from these years also needs to be updated. The processes that are responsible for the production of chemical waste gases can vary considerably, resulting in clear yearly variations. For transparency and consistency, it can be useful to update the emission factor of chemical waste gas based on 5-year averages.

To account for the long term trend in the CO_2 emission factor of chemical waste gas, it is proposed to update the CO_2 emission factor based on a 5-year average (2015-2019, instead of a yearly varying emission factor) of the implied CO_2 emission factors as calculated from ETS emissions and energy statistics. The 5-year average (2015-2019) CO_2 emission factor equals 61.8 kg CO_2/GJ.

2.4.3 Blast Furnace Gas, Oxy Gas & Coke Oven Gas

Blast furnace gas, Oxy Gas and Coke Oven Gas are gaseous by-products of the production of steel in modern blast furnaces and oxy furnaces and of the metallurgical coke production. These gases are produced and used by a small selection of collaborating companies, and they are mixed together and with natural gas in order to produce electricity.

The actual composition of these gaseous by-products can vary greatly, strongly depending on the raw materials burned and the production conditions. The mixing with other gases (inclusive the addition of natural gas) is determined by the required combustion conditions, the actual technical conditions and the financial-economic situation on the international market.

<u>Heating value</u>
The heating value is expressed as 1 MJ/MJ, because the amount of these gases is not monitored in kg or m^3. Companies do not report other heating values in their environmental reports.

<u>CO_2 emission factors</u>
Emissions from these gases are reported by three companies in their environmental reports. These environmental reports only contain CO_2 emissions for the mixture of fuels, and not for each fuel separately. It is therefore not possible to calculate an implied CO_2 emission factor for the fuels separately, based on data from the environmental reports.
Instead, it is possible to make a comparison between the reported CO_2 emissions, and the emissions that could be expected based on the reported fuel consumption combined with default emission factors (for the two power plants that use blast furnace gas, oxy gas and coke oven gas). For these companies, the reported CO_2 emissions were 1.2 – 3.0% higher than the emission that could be calculated based on the fuel consumption and the standard CO_2 emission factors in the period 2015-2019 (with a weighted average of 2.0%). However, it should be noted that the fuel consumption according to the environmental reports deviates from the fuel consumption in the energy statistics, which makes this comparison less accurate.

Statistics Netherlands calculates the CO_2 emissions from blast furnace gas, oxy gas and coke oven gas based on the energy statistics and on the reported CO_2 emissions in ETS reports (Emission Trading Scheme). Since companies only report a total CO_2 emission, the implied emission factors have been calculated by assuming that the actual emission factor of coke oven gas is constant (equal to Zijlema, 2021), and that the remaining CO_2 emissions are a result of the Blast Furnace Gas and Oxy Gas together. Table 13 shows the implied emission factors of Blast Furnace Gas / Oxy Gas and Coke Oven Gas, for the period 2010-2019.

Table 13: Implied CO_2 emission factors of Blast Furnace Gas / Oxy Gas and Coke Oven Gas in power plants, calculated from CO_2 emissions in ETS reports and the Dutch Energy statistics for the Dutch Emissions Registry.

Implied CO_2 emission factor (kg CO_2/GJ) from ETS reports and Dutch Energy statistics			
Year	**Blast Furnace Gas / Oxy Gas**	**Coke Oven Gas**	**Blast Furnace Gas / Oxy Gas / Coke Oven Gas**
2010	240.9	42.8	227.8
2011	237.9	42.4	226.8
2012	240.9	42.8	227.4
2013	238.0	42.6	223.3
2014	242.0	42.9	229.8
2015	244.3	42.8	231.8
2016	248.9	42.8	237.9
2017	234.6	42.8	221.4
2018	259.5	42.8	245.3
2019	259.4	42.8	244.0
Current emission factor (kg CO_2/GJ) from the Netherlands list of fuels (Zijlema, 2021)			
Year	**Blast Furnace Gas / Oxy Gas**	**Coke Oven Gas**	**Blast Furnace Gas / Oxy Gas / Coke Oven Gas**
1990-2012	247.4 / 191.9	41.2	
from 2013	247.4 / 191.9	42.8	

Table 13 shows that the implied CO_2 emission factor of Blast Furnace Gas / Oxy Gas is close to the default CO_2 emission factor of Blast Furnace Gas. The environmental reports show that Blast Furnace Gas is used much more than Oxy Gas (3-10 times more, varying per year and per company), which explains why the implied emission factor is close to the default emission factor of blast furnace gas.

Based on the data available in the environmental reports and from Statistics Netherlands, there are a few possibilities for updating the CO_2 emission factor:
- Maintain the current CO_2 emission factor from Zijlema (2021)
- Include a new fuel in the list of fuels for Blast Furnace Gas and Oxy Gas together, and derive an emission factor from Table 13 (yearly, or a 5-year average)
- Include a new fuel in the list of fuels for Blast Furnace Gas, Oxy Gas and Coke Oven Gas together, and derive an emission factor from Table 13 (yearly, or a 5-year average)

- Adjust the CO_2 emission factors of Blast Furnace Gas, Oxy Gas and Coke Oven Gas with +2.0% (based on the comparison with the reported CO_2 emissions in the environmental reports). This would result in emission factors of 252.3 kg CO_2/GJ for Blast Furnace Gas, 195.7 kg CO_2/GJ for Oxy Gas and 43.7 kg CO_2/GJ for Coke Oven Gas.

CO_2 emissions from combustion of blast furnace gas, oxy gas and coke oven gas in the National Inventory Report are all based on the reported emissions from the ETS reports. Also the companies do not use the default emission factors in their environmental reports. Thus, for the national reporting, it does not matter which emission factor is used in the Netherlands list of fuels. For transparency and consistency, it can be useful to update the emission factors, but it can be discussed which emission factor to include in the Netherlands list of fuels. Only the total fuel consumption and the total CO_2 emission of these companies is accurate, but the split between different fuels is more uncertain.

The CO_2 emissions reported in the ETS reports and the environmental reports do not provide sufficient detail to calculate separate implied emission factors for each fuel. Since the total CO_2 emission from these fuels in the national inventory report are all based on ETS reports, it does not matter which emission factor is used in the Netherlands list of fuels. Therefore, it is proposed to maintain the current emission factors in the Netherlands list of fuels.

2.4.4 Phosphor Gas

Phosphor Gas is a gaseous by-product from the production of phosphorus and phosphorus acid. Production in the Netherlands only took place in one single factory which closed at the end of 2012.
As a result, Phosphor Gas is only reported for historical years within the Dutch emission registration. No new CO_2 emission factor needs to be derived.

2.5 Other fuels

The comparison between the country-specific values in the Netherlands list of fuels, and the IPCC default values in the IPCC2006 Guidelines and the IPCC 2019 Refinements, showed notable differences for a few fuels (bitumen, refinery gas, chemical waste gas, waste, gas-/diesel oil, LPG, gas biomass, wastewater biogas, landfill gas and industrial organic waste gas). Some of these fuels were discussed in the previous paragraphs. The other fuels are shortly discussed in this paragraph:

- Waste: The heating value and the CO_2 emission factor of waste is based on yearly analyses of the waste composition (van Hunnik, 2020), and it is expected that these values are representative for the waste combusted in the Netherlands.
- Gas-diesel oil: The CO_2 emission factor is lower than the range in the IPCC Guidelines. The country-specific heating value and CO_2 emission factor have been derived in 2017 (CBS, 2017), and it is expected that these values are representative for the gas-/ diesel oil used in the Netherlands.
- Gas biomass, wastewater biogas, landfill gas and industrial organic waste gas: The emission factors in the Netherlands list of fuels are much higher than the emission factor in the IPCC Guidelines.

This is caused by the fact that the emission factor of gaseous biomass in the IPCC Guidelines is based on the CO_2 emission factor of methane, while gaseous biomass also includes other components (including CO_2 itself).

- Bitumen: The heating value of bitumen in the Netherlands list of fuels is higher than the range in the IPCC Guidelines. The reason for this difference is not known.

The two separate items in the Netherlands list of fuels, i.e., the heating value and the CO_2 emission factor are related by the carbon content. For some fuels, the source of the heating value and CO_2 emission factor differs from each other. Most often, the heating value is country-specific, while the CO_2 emission factor is an IPCC default value. These numbers may be inconsistent. Reporting the carbon fraction, or at least compare the carbon content in the Netherlands list of fuels to the carbon content of specific components expected in the fuel, will help to prevent inconsistencies. The carbon content is the result of multiplying both factors:

Carbon content [%] = NCV * EF * (12/44) / 1000

Where:
EF = Emission factor (kg CO_2/GJ)
NCV = Net calorific value (heating value) (MJ/kg)

Several components have deviating carbon content, from known or expected values. Some remarkable deviations of the carbon content are:

- Aviation gasoline: A carbon content of 86.4% seems unlikely, given high energy content and the implicit aromatics specification. A value of 85.6% equal to gasoline seems more appropriate.
- Naphtha: A carbon content of 88.0% can only be met by high fractions of ethyne, propyne or aromatics. This is an unlikely composition for a liquid fuel with light fractions from cracking. For bionaphtha a value of 84.2% is proposed in this study.
- Other fuels with a relatively high carbon content in the Netherlands list of fuels are petroleum coke, paraffin waxes, white spirit and SBP, other petroleum products, anthracite, lignite and coal tar.

It is recommended to study the carbon content of these fuels further, and to derive new heating values and CO_2 emission factors (if necessary).

3 Conclusion

In chapter 2, the heating values and CO_2 emission factors of a selection of fuels were discussed. Based on these discussions, the following changes to the Netherlands list of fuels are proposed:

<u>Biodiesel and biogasoline</u>
Because of the different types of biodiesel and biogasoline with a wide range in heating values and CO_2 emission factors, it is proposed to expand the Netherlands list of fuels with specific types of biogasoline and biodiesel (and their specific heating values and CO_2 emission factors). The heating values are from RED, and the carbon contents are based on the chemical composition of the fuels.
It is also proposed to maintain the general biogasoline and biodiesel fuels in the Netherlands list of fuels, and to update this yearly following the yearly changing composition of biogasoline and biodiesel.
The factsheet of biogasoline and biodiesel needs to be updated to include a calculation of the weighted average heating value and CO_2 emission factor. Furthermore, new factsheets are needed for the newly added fuels in the Netherlands list of fuels.

<u>LPG</u>
Since the current heating value of LPG in the Netherlands list of fuels is lower than the heating values of propane and butane, it is expected that the current heating value is an underestimate. Before a new heating value is derived, it is advised to investigate the composition of LPG (which can be calculated from measurements of the vapor pressure of LPG). As the heating value is used by Statistics Netherlands to prepare the energy statistics, a decision to update the LPG heating value needs to be made in agreement with Statistics Netherlands.
If it is decided that the LPG heating value is updated, then the CO_2 emission factor also needs to be updated, which can be calculated from carbon content and heating value.
The factsheet of LPG does not need to be updated at the moment. Only when the composition of LPG is re-assessed and a new heating value and CO_2 emission factor are derived, an update of the factsheet is needed.

<u>Other bituminous coal</u>
To account for the long term trend in the CO_2 emission factor of other bituminous coal, it is proposed to update the CO_2 emission factor based on a 5-year average (2015-2019) of the implied CO_2 emission factors as calculated from ETS emissions and energy statistics. This emission factor can be used in the future ETS reports and AERs of companies that do not measure the carbon content of the coal themselves, and it can be used in the Reference Approach calculations.
The factsheet of other bituminous coal needs to be updated to include the new CO_2 emission factor.

<u>Refinery gas</u>
To account for the long term trend in the CO_2 emission factor of refinery gas, it is proposed to update the CO_2 emission factor based on a 5-year average (2015-2019) of the implied CO_2 emission factors as calculated from ETS emissions and energy statistics.

Since the processes that are responsible for the production of refinery gases can vary considerably, it is proposed to calculate a 5-year average (instead of a yearly varying emission factor).
This emission factor will mainly be used for reference only, since all companies derive and report their company-specific CO_2 emissions from refinery gas.
The factsheet of refinery gas needs to be updated to include the new CO_2 emission factor.

<u>Chemical waste gas</u>
To account for the long term trend in the CO_2 emission factor of chemical waste gas, it is proposed to update the CO_2 emission factor based on a 5-year average (2015-2019) of the implied CO_2 emission factors as calculated from ETS emissions and energy statistics. Since the processes that are responsible for the production of chemical waste gases can vary considerably, it is proposed to calculate a 5-year average (instead of a yearly varying emission factor).
This emission factor can be used for calculating emissions of companies that do not measure the CO_2 emissions themselves, and it can be used in the Reference Approach calculations.
The factsheet of chemical waste gas needs to be updated to include the new CO_2 emission factor.

<u>Blast furnace gas, oxy gas and coke oven gas</u>
The CO_2 emissions reported in the ETS reports and the environmental reports do not provide sufficient detail to calculate separate implied emission factors for each fuel. Since the total CO_2 emission from these fuels in the national inventory report are all based on ETS reports, it does not matter which emission factor is used in the Netherlands list of fuels. Therefore, it is proposed to maintain the current emission factors in the Netherlands list of fuels.
The factsheets of blast furnace gas, oxy gas and coke oven gas do not need to be updated, since no new CO_2 emission factors are derived.

<u>Other fuels</u>
Several other fuels were identified for which the heating value or the CO_2 emission factor may need improvement. These fuels are bitumen, aviation gasoline, naphtha, petroleum coke, paraffin waxes, white spirit and SBP, other petroleum products, anthracite, lignite and coal tar. It is recommended to study the carbon content of these fuels further, and to derive new heating values and CO_2 emission factors (if necessary).

Table 14 shows the current heating values and CO_2 emission factors in the Netherlands list of fuels, and the proposed heating values and CO_2 emission factors. This table only shows the heating values and CO_2 emission factors from Zijlema (2021) for the year 2019. The starting date of the new proposed heating values and CO_2 emission factors is to be decided. For biogasoline and biodiesel, the new heating value and CO_2 emission factor of 2019 is shown.

Table 14: Comparison between the current heating values and CO_2 emission factors in the Netherlands list of fuels and the proposed heating values and CO_2 emission factors for the selected fuels. This table only shows the heating values and CO_2 emission factors from Zijlema (2021) for the year 2019. The starting date of the new proposed heating values and CO_2 emission factors is to be decided.

Fuel name	**Heating value (MJ/unit)**						**CO_2 EF (kg/GJ)**			
English	**Zijlema, 2021**			**Proposed new**			**Zijlema, 2021**		**Proposed new**	
Liquid Fossil, Secondary Fuels/ Products										
Liquefied Petroleum Gas (LPG)	45.2	MJ/kg	CS	45.2	MJ/kg	CS	66.7	CS	66.7	CS
Refinery Gas	45.2	MJ/kg	CS	45.2	MJ/kg	CS	67.0	CS	64.4	CS
Chemical Waste Gas	45.2	MJ/kg	CS	45.2	MJ/kg	CS	62.4	CS	61.8	CS
B. Solid Fossil, Primary Fuels										
Other Bituminous Coal	25.0	MJ/kg	CS	25.0	MJ/kg	CS	94.7	CS	92.7	CS
Solid Fossil, Secondary Fuels										
Coke Oven gas	1.0	MJ/MJ	CS	1.0	MJ/MJ	CS	42.8	CS	42.8	CS
Blast Furnace Gas	1.0	MJ/MJ	CS	1.0	MJ/MJ	CS	247.4	CS	247.4	CS
Oxy Gas	1.0	MJ/MJ	CS	1.0	MJ/MJ	CS	191.9	CS	191.9	CS
Biomass										
Biogasoline	27.0	MJ/kg	CS	29.9	MJ/kg	CS	70.7	CS	70.3	CS
Biogasoline ethanol				27.0	MJ/kg	RED			70.9	CS
Biofuel methanol				20.0	MJ/kg	RED			68.8	CS
Biogasoline MTBE				35.0	MJ/kg	RED			71.4	CS
Biogasoline ETBE				36.0	MJ/kg	RED			71.9	CS
Biogasoline synthetic and treated fuels (mainly bionaphtha)				45.0	MJ/kg	RED			68.6	CS
Biodiesels	37.0	MJ/kg	CS	38.5	MJ/kg	CS	76.8	CS	74.3	CS
Biodiesel esters (mainly FAME, but also FAEE)				37.0	MJ/kg	RED			75.4	CS
Biodiesel synthetic and treated fuels (mainly HVO)				44.0	MJ/kg	RED			70.8	CS

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5 Signature

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