Department for
Business, Energy
& Industrial Strategy

The Data Annex to the Low Carbon Hydrogen Standard

Data required to calculate the greenhouse gas emissions under the low carbon hydrogen standard

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1 Default Data

1.1 Default Data Overview

The default data provided is based on components per the emissions calculation in the standard guidance as shown in below.

$$E_T = E_{feedstock\ supply} + E_{energy\ supply} + E_{input\ materials} + E_{process} + E_{fugitive\ non\text{-}CO2} + E_{CCS\ process\ and\ infrastructure} - E_{CO2\ sequestration} + E_{compression\ and\ purification}$$

$$\text{Where } E_T = \text{Total emissions } gCO_{2e}$$

The default data is based on several pathways:

- Steam Methane Reformation using UK natural gas with carbon capture and storage
- Auto thermal reformation using UK natural gas with carbon capture and storage
- Food waste biomethane auto thermal reformation with carbon capture and storage (if carbon capture and storage not in use, this component can be left out)
- Forestry residue mixed waste gasification with carbon capture and storage (if carbon capture and storage not in use, this component can be left out)
- Biogenic and Fossil fractions of mixed municipal solid waste gasification with carbon capture and storage (if carbon capture and storage not in use, this component can be left out)
- Electrolysis using grid electricity
- Electrolysis using renewable electricity
- Electrolysis using electricity from nuclear generation

Each component will be broken down into the data available for each production pathway. Not all components are relevant to all pathways.

Partial oxidation processes must use projected or actual data.

Default data is **not** provided for the process CO_2, CO_2 sequestration and fugitive emissions components. These will have to be projected by projects (and later reported with actual data). For compression and purification, the energy supply default data provided already accounts for the emissions associated with reaching the theoretical minimum pressure and purity, therefore there is no specific pressure and purity default data to add on top of the energy supply defaults. However, if projected or actual data for energy supply is being used, and the hydrogen output pressure or purity is below the theoretical minimum, the data and methodology provided in Data Annex 2 should be used to calculate the theoretical added emissions.

The standard guidance is being developed into a hydrogen emissions calculator (HEC) to support hydrogen producers to check compliance against the standard. The default data provided below will be built into the calculator.

1.1.1 Conservative factor

To ensure that the default data provided is conservative, the central scenario values taken from BEIS modelling have each been multiplied by a factor of 1.4 to derive the default values presented in this Annex.

This excepts feedstock supply emissions for natural gas and energy supply emissions for electrolysis, neither of which were scaled by the conservative factor.

All default data for electricity inputs in production pathways has been derived assuming an estimated 2025 UK grid electricity GHG intensity of 34.17$gCO2_e/MJ_e$ delivered (UK Green Book).

1.1.2 Default Data Tables

1.1.2.1 Feedstock Supply

The GHG emissions arising from feedstock extraction, cultivation, harvesting, collection, pre-processing, storage and transportation. Depending on the production pathway, this term could include fossil natural gas, biomethane, solid biomass feedstocks and waste feedstocks. Note that upstream supply for the food waste biomethane pathway includes the emissions from food waste collection through AD biogas production up to the point of biomethane delivery.

Table 1: Default data for feedstock supply

Production pathway	Emissions intensity (gCO_2e/MJ_{LHV})
SMR + CCS	8.59
ATR + CCS	8.04
Food waste biomethane ATR + CCS	5.45
Forest Residue gasification + CCS	7.96
Biogenic fraction waste gasification + CCS	4.54
Fossil fraction waste gasification + CCS	4.54
Electrolysis using Grid electricity (averaged)	0.00

Electrolysis using renewable electricity	0.00
Electrolysis using nuclear-generated electricity	0.00

1.1.2.2 Energy Supply

This is the emissions associated with electricity, steam and heat usage for hydrogen production.

Table 2: Default data for energy supply

Production pathway	Emissions intensity (gCO_2e/MJ_{LHV})
SMR + CCS	0.79
ATR + CCS	4.05
Food waste biomethane ATR + CCS	4.05
Forestry residue gasification + CCS	0.23
Biogenic fraction waste gasification + CCS	8.38
Fossil fraction waste gasification + CCS	8.38
Electrolysis using grid electricity (averaged)	31.47
Electrolysis using renewable electricity	0.00
Electrolysis using nuclear-generated electricity	8.59

1.1.2.3 Input Materials

Input supply refers to upstream emissions associated with any input materials (except those covered in feedstock emissions) to a system. This could include key inputs such as gasifier oxygen, water, salts, catalysts, solvents.

Table 3: Default data for input supply

Production pathway	Emissions intensity (gCO_2e/MJ_{LHV})
SMR + CCS	0.00
ATR + CCS	0.00

Food waste biomethane ATR + CCS	0.00
Forestry Residue gasification + CCS	1.56
Biogenic fraction waste gasification + CCS	3.28
Fossil fraction waste gasification + CCS	3.28
Electrolysis using grid electricity (averaged)	0.15
Electrolysis using renewable electricity	0.15
Electrolysis using nuclear-generated electricity	0.15

2 Theoretical Pressure and Purity Calculations

2.1 Compression of hydrogen

Hydrogen producers with an actual or projected output pressure of less than 3MPa are required to calculate the theoretical added emissions associated with theoretical compression up to 3MPa.

If using default data and final output H_2 is below or equal to 3MPa

If default energy supply data is being used, the emissions associated with hydrogen compression to 3MPa has already been accounted for, and the formulae below do not need to be used.

If using projected or actual data for H_2 output pressure below or equal to 3MPa

If projected or actual energy supply data is being used, and the hydrogen output pressure is less than 3MPa, the formulae below should be used to calculate the additional theoretical GHG emissions to add to your projected or actual GHG emissions result.

If projected output H_2 pressure is above 3MPa

For hydrogen producers with a projected hydrogen output pressure greater than 3MPa, the total emissions associated with compression to the outlet pressure must be accounted for.

If producers need to use default data in this case (if projected or actual data is available this should be used instead), they can use the formulae below to calculate the theoretical additional emissions associated with raising the hydrogen pressure from 3 MPa to their actual outlet pressure. This value can then be added to the 3 MPa default data.

If actual output H_2 pressure is above 3MPa

Hydrogen producers should report all actual emissions associated with actual compression and do not need to use the equation below.

2.1.1 How to calculate emissions associated with theoretical compression

The carbon emissions from energy use for compression are calculated as follows:

$$C = A \times B \times \frac{1000g}{120\ MJ_{LHV}} \quad (1)$$

Where:

A = Energy required to compress hydrogen (with losses), $kWh_e/kg\ H_2$

B = Energy source emissions factor, $kgCO_{2e}/kWh_e$, select the factor relevant to your process from Table 5, (for renewable or nuclear this must a demonstrable input).

C = GHG emissions from energy use for compression, in $gCO_2e/MJ_{LHV}\ H_2$

Compression energy, A, is calculated as follows:

$$A = \frac{W}{(3.6 \times 10^6)\eta} \quad (2)$$

Where W is the specific compression power, defined in equation 3, and η is the adiabatic efficiency, which can be taken from Table 5.

$$W = \left[\frac{n}{n-1}\right] \times p_0 \times V_0 \times \left[\left(\frac{p_1}{p_0}\right)^{\frac{(n-1)}{n}} - 1\right] \quad (3)$$

Where W is the specific compression power, n is the adiabatic coefficient, p_o and p_1 are inlet and outlet pressure and V_0 is input specific volume (of hydrogen) these terms are defined in Table 4.

2.2 Purification of hydrogen

Hydrogen producers with actual hydrogen purity of less than 99.9% by volume are required to calculate the theoretical emissions associated with theoretical purification up to 99.9% by volume. To utilise this equation to calculate the emissions associated with purification, the emissions associated with compression to a minimum of 3MPa must have already been accounted for either theoretically using the steps in 2.1.1 or based on actual emissions.

This purification equations assumes a minimum starting pressure of 3MPa into pressure swing absorption (PSA).

If default data is being used, the emissions associated with purification to 99.9% by volume has already been accounted for.

2.2.1 How to calculate emissions associated with theoretical purification

The carbon emissions from energy use for purification are calculated as follows:

$$E = D \times B \times \frac{1000g}{120\ MJ_{LHV}}$$

Where:

D = Energy required to purify hydrogen (with losses), $kWh_e/kg\ H_2$
The power required to purify hydrogen of 3MPa or higher to a purity of 99.9% can be assumed as P_C - the purity correction factor as found in Table 5.

B = Energy source emissions factor, $kgCO_{2e}/kWh_e$, select the factor relevant to your process from Table 5, (for renewable or nuclear this must a demonstrable input).

E = GHG emissions from energy use for purification $gCO_2e/MJ_{LHV}\ H_2$

2.3 Compression and Purification Terms, Units, and Data

Table 2: Terms and units for factors required to calculate emissions associated with compression and purification

Term	Units	Definition
W	J/kg	Specific compression power
p_o	Pa	Input pressure
p_1	Pa	Output pressure
V_0*	m^3/kg	Input specific volume
n	-	Adiabatic coefficient
η	%	Adiabatic efficiency

*V_0 can be found from Table 6.

Table 3: Data provided for pressure and purity calculations.

Term	Provided value	Units	Definition
p_1	3,000,000	Pa	Output pressure
n	1.41	-	Adiabatic coefficient
η	0.6	-	Adiabatic efficiency
P_C	0.0013	kWh/kgH_2	Purity correction factor (assuming starting pressure ≥ 3MPa)
B(grid)	0.121	$kgCO_{2e}/kWh$	Carbon factor of energy source

B(nuclear)	0.014	$kgCO_{2e}$/kWh	Carbon factor of energy source
B(renewable)	0.000	$kgCO_{2e}$/kWh	Carbon factor of energy source

This data is not conservative as this is a theoretical calculation.

Table 4: Line of best fit equations for specific volume vs inlet pressure at specific temperatures

Temperature (°C)	k	α
0	1.1651	-0.935
25	1.2691	-0.939
50	1.373	-0.943
75	1.4767	-0.946
100	1.5804	-0.949
125	1.6839	-0.952

$$y = kx^{\alpha} \quad (4)$$

y= specific volume (m^3/kg) and x= inlet pressure (MPa), α is the power law exponent and k is a constant.

α and k should be taken from table 6 above, dependent on temperature required.

Equation (4) provides an approximation of the relationship between inlet pressure and specific volume, based on a line of best fit equation derived from density of hydrogen data from H_2 Tools [1] and can be used to calculate an approximate specific volume of hydrogen based on the data provided in Table 6. The closest temperature to the compressor inlet temperature should be used (this should be the closest temperature to the hydrogen outlet temperature form the hydrogen production facility). For example, if the compressor inlet has a temperature of 40°C, then the α and k values for 50°C would be used.

[1] https://h2tools.org/hyarc/hydrogen-data/hydrogen-density-different-temperatures-and-pressures, data source NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP): Version 8.0

3 Actual Data for Natural gas upstream emissions

3.1 UK gas network

Given the complexity of calculating upstream emissions associated with natural gas drawn from the UK gas network, for the calculations of projected and actual data, projects may use a figure of 6.29gCO_2e/MJ_{LHV} natural gas. BEIS will update this figure on a regular basis.