Reporting instructions

Hydrogen - Annual data

V 1.1 2023

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1. SUBMISSION AND COMMUNICATION INFORMATION

1.1. DATA SUBMISSION PROCEDURES

Countries reporting to the IEA are requested to complete the questionnaire by 30 September. Earlier submissions are welcome.

Countries reporting to Eurostat are requested to complete the questionnaire by 31 October (Regulation (EC) No 1099/2008 on energy statistics). Earlier submissions are welcome. All data reporting is voluntary for the reporting years 2022 and 2023. **From reporting year 2024 onwards all data points listed in the Energy Statistics Regulation are mandatory**. All data points that remain voluntary after 2024, are marked in *italic* in the reporting template.

Please send your questionnaire to:

- International Energy Agency (IEA/OECD), Energy Data Centre (the IEA will forward the data to the United Nations Economic Commission for Europe in Geneva).
- European Commission, Eurostat, Energy Statistics (for the EU Member States, European Economic Area countries, EU Candidate Countries and Potential Candidates, Energy Community Contracting Parties)
- United Nations Statistics Division, Energy Statistics Section Transmission details are provided in the “Data communication procedures” section.

1.2. DATA COMMUNICATION PROCEDURES

IEA
9 rue de la Fédération, 75739, Paris, Cedex 15, France

Please complete data for your country on the Energy Validation Outlet: https://evo.iea.org. Alternatively, send the completed questionnaire electronically in a CSV or Excel file as an e-mail attachment to: H2AQ@iea.org For questions regarding the questionnaire, contact Nicolas.coent@iea.org.

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European Commission - Eurostat - Unit E.5 (Energy)
5, rue Alphonse Weicker, L-2721 Luxembourg

(for EU Member States, European Economic Area countries, EU Candidate Countries and Potential Candidates, Energy Community Contracting Parties)

The completed MS Excel questionnaire should be transmitted via the Single Entry Point following the implementing procedures of EDAMIS (Electronic Data Files Administration and Management Information System): https://webgate.ec.europa.eu/edamis/ selecting the electronic data collection ENERGY_H2_A.

Countries reporting to Eurostat are reminded of the Revision Policy for Energy Statistics. If you plan to revise historic data, please remember to transmit to Eurostat the Revision pre-announcement form as soon as possible. All countries reporting to Eurostat are required to indicate “Years to Load”. Countries can select either the most recent period(s), full time series or any combination of years. Eurostat will load into its database only the time periods marked.

For questions regarding the questionnaire, contact estat-energy-annual@ec.europa.eu. The fuel manager will get back to you.

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United Nations

United Nations Statistics Division, Energy Statistics Section

2 UN plaza, DC2-1414, New York, NY 10017, USA

The completed questionnaire should be transmitted by e-mail to: Mr. Leonardo Souza, Chief, Energy Statistics Section.

E-mail address: energy_stat@un.org

Fax (1-212)-963-0623

2. PROCEDURES AND DEFINITIONS

2.1. REPORTING INSTRUCTIONS

Data should be reported for calendar years. If fiscal year data have to be used, please state this clearly and specify the period covered.

Reporting should be consistent across all the different fuel time series of any given year, avoiding any inconsistencies between flows, products or technologies.

The definitions and reporting conventions used in this questionnaire are the same as those used in the other annual questionnaires (Crude oil and petroleum products, Coal-Solid fossil fuels and manufactured gases, Natural gas, Renewables and Wastes, and Electricity and heat).

During the reporting process there are many aspects need attention and consideration. Please ensure that data on hydrogen reported in this reporting template are consistent with the relevant flows reported in the other annual questionnaires.

Where data are not available, estimates should be given and identified as such in the Remarks section of this reporting template.

Any data under “Not elsewhere specified” should be explained in the Remarks section.

Kindly insert in the Remarks section any additional information on the hydrogen data reported and/or that could not be reported.

INTERNATIONAL STANDARD INDUSTRIAL CLASSIFICATION

In 2008, the United Nations and the European Commission have published in parallel their revised classification codes for Hydrogen.

United Nations:

International Standard Industrial Classification of all Economic Activities – ISIC, Rev.4

European Commission:

Statistical classification of economic activities in the European Community – NACE code C20

2.2. UNITS AND CONVERSION FACTORS

Report all figures in Terajoules, with three (3) decimal places.

Please report NCV. Net calorific values should be reported in kilojoules per kilogram (kJ/kg) (to the nearest whole number).

Conversion of data from Kg to Terajoules:

Kilograms are to be converted to Terajoules by using conversion factors based on actual density and the net calorific values. The conversion from Kg to TJ units should be by multiplying the average production by the net calorific value (NCV) measured at a certain pressure and temperature.

According to the conversion values of reference published by the IEA in the Hydrogen Report[1].

2.3. DEFINITIONS OF HYDROGEN AND OTHER PRODUCTS

Hydrogen (H_2)

Hydrogen is the chemical element with the symbol H and atomic number 1. Hydrogen is the lightest element in the periodic table. At standard conditions hydrogen is a gas of diatomic molecules having the formula H_2. It is colorless, odorless, tasteless, non-toxic, and highly combustible.

Hydrogen in energy statistics is defined at 98% purity or higher. This value is reasonable for hydrogen for space heating equipment and also the minimum currently requirement in the industries. Pure hydrogen (+99.99% purity) and hydrogen with 99.97% purity can be used in fuel cells and some industrial processes while hydrogen with 99.80% purity can be used for the steel industry.

Note: Reporting only hydrogen above the purity level of 98% is a methodological convention adopted in energy statistics based on the fact that hydrogen is not expected to be used below a

[1] https://www.iea.org/reports/hydrogen

98% purity. Below such purity, hydrogen is considered to be part of a compound (or mixture) which is not to be reported.

Report hydrogen production whether intentional and exclusive or as a by-product.

Example: Hydrogen produced as a by-product of chlorine production.

Do not report hydrogen presence in compounds. However report hydrogen when it is extracted from the compound or if the pure hydrogen is used to produce the compound. It is the currently agreed convention not to report the hydrogen in a compound, whether the compound is used for energy or non-energy purposes. This methodological choice could be revised in the future.

Examples: Mixtures or compounds to be excluded from reporting may include: Mixtures of nitrogen (N2) and hydrogen (H2), hydrides, varigon H_2, hydrochlorofluorocarbons (HCFCs), gas mixtures of hydrogen and xenon.

Note: An exception to this convention is made for some forms of chemical storage or chemical transport of hydrogen where the presence of hydrogen in the compound, which is created specifically for storing or transporting hydrogen, is to be reported.

Do not report the hydrogen contained in intermediately products. This reporting template does not track intermediate energy products. The final energy products once the process is completed are reported where appropriate.

Note: Do not report substances that are intermediate products that result in a non-energy output, in a process where hydrogen was inputted. For instance, if hydrogen is inputted (or mixed) and the output is a feedstock to produce a material, you should not report the intermediate product but report the hydrogen usage in the “final consumption non-energy use” in this questionnaire.

Note: Do not report the percentage of hydrogen in substances that are intermediate energy products which are used for energy purposes and are the result of a process where hydrogen was an input. For instance, if pure hydrogen is inputted (mixed) and the output is used for the heating of a company premises: you should not report the intermediate product use but report the hydrogen used in “final consumption – energy use” in this questionnaire.

Example: Mixtures to be excluded from reporting may include Syngas.

Report hydrogen auto-produced and auto-consumed (captive hydrogen). This may be referred to as “unsold”[2]. An establishment may produce hydrogen which is not sold but used in another process within the establishment.

[2] The terminology “sold and unsold” is used at times to distinguish between energy products that are produced for own use from those used elsewhere.

Example: Hydrogen produced as a by-product of naphtha reforming in petroleum refineries and then used for other refinery processes (e.g. desulphurisation).

Example: Hydrogen produced in steam reforming facilities in refineries and then used in the petroleum refining process. Here hydrogen is required on a large scale and is intentionally produced on site.

Example: Hydrogen auto-produced in waste incineration plants: The recovered heat can be used to create steam to produce shaft motive power for direct use or via electricity generation which can in turn be used in electrolyzers to produce hydrogen.

Example: Hydrogen auto-produced in renewable energy plants.

Indicative parameters for hydrogen:

PARAMETER	VALUE
Density of hydrogen gas	0.0899 kg/Nm3
Liquid hydrogen density	0.0708 kg/L
Energy density of hydrogen gas	10.8 MJ/Nm3
Energy density of liquid hydrogen	8.495 MJ/L
Lower Calorific Power	120 MJ/kg
Higher Calorific Power	142 MJ/kg

Liquid organic hydrogen carriers (LOHC)

Liquid organic hydrogen carriers (LOHC) are organic compounds that can absorb and release hydrogen through chemical reactions. LOHCs can be used for transporting and storing hydrogen on a large scale and long distance.

Example: Hydrogen can be fixed to toluene and converted to methylcyclohexane (205 kJ/mol), which is easy to transport and store at room temperature and normal atmospheric pressure. The toluene-methylcyclohexane system is currently on a demonstration scale with a production of 50 Nm3H2/hr. In the case of hydrogenation, the conversion of toluene reaches 99%, while in dehydrogenation the conversion of methylcyclohexane (MCH) is 95%.

Please see the transformation, storage and trade sections of these reporting instructions for information on how to report hydrogen transformed, stored and/or transported in the form of a LOHC.

Ammonia (NH_3)

Ammonia is an inorganic compound of nitrogen and hydrogen with the formula NH3. Ammonia is a molecule composed by three atoms of hydrogen and one of nitrogen. Ammonia is an energy carrier and can be used for energy and non-energy purposes.

E-fuels (and other synthetic fuels of non-biological origin)

E-fuels are electrofuels, a type of synthetic fuels. They are manufactured using captured carbon dioxide or carbon monoxide, together with hydrogen obtained from sustainable electricity sources such as wind, solar and nuclear power (not from biomass).

This family of products include also other liquid and gaseous synthetic fuels of non-biological origin.

For countries reporting to Eurostat: This category may include Renewable Fuels of Non-Biological Origin (RFNBO) which are fuels defined in the EU Renewable Energy Directive (Art. 2.36). Hydrogen which may fall under this definition however is to be reported in the column for hydrogen. Report under e-fuels all other RFNBOs.

Note: Include only synthetic fuels which are not reported in other annual questionnaires. Synthetic fuels produced from fossil fuels or renewable biomass should be reported in the other annual questionnaires unless hydrogen is extracted as pure and used at a later stage to produce a synthetic fuels (due to the principle of reporting captive hydrogen).

Example: Natural gas used in the Fischer-Tropsch synthesis to produce synthetic gasoline. Report the natural gas usage in the transformation sector (Gas to Liquid) of the natural gas questionnaire and then in “Receipts from other source - Natural gas” in the oil questionnaire.

Example: Natural gas used to produce hydrogen, which is used to produce a synthetic fuel. Report the hydrogen production from natural gas in the hydrogen questionnaire and report the hydrogen transformation under “Transformation Sector - For production of e-fuels”.

Please add any available info one the fuels reported here in the remark sheet.

3. INSTRUCTIONS FOR COMPLETING INDIVIDUAL TABLES

3.1. TABLE 1 - PRODUCTION OF HYDROGEN, AMMONIA AND E-FUELS

3.1.1. Production of hydrogen (H_2)

In the scope of Energy Statistics, hydrogen is not considered a primary energy product but an energy carrier. It is considered to be produced from other energy sources: fossil fuels, renewables, wastes, electricity, nuclear energy, and other natural sources.

a. From natural gas

Report the total hydrogen produced from natural gas.

Main processes:

- Steam methane reforming (SMR). Steam methane reforming of natural gas is an endothermic process based on the reaction of methane with water steam at high temperature in the presence of a catalyst, with an overall yield of 80%, which takes place in several stages. The gases produced pass through a series of condensers to remove the water vapor and subsequently by a PSA (pressure swing adsorption) system for the purification of the output stream, from where hydrogen is obtained with a purity greater than 99.99%.
- Partial oxidation (POX). Partial oxidation consists of the incomplete oxidation of a natural gas or hydrocarbon where only the carbon is oxidized (to CO), leaving the hydrogen present in the molecule free at high temperatures (1300-1500 °C). Efficiencies of 70% can be obtained.
- Auto-thermal reforming (ATR). Auto-thermal reforming is a method that combines the above processes (SMR and POX), so that the heat released in the partial oxidation is used for reforming. 70% efficiencies can be obtained.
- Hydrogen from pyrolysis from natural gas. In the absence of oxygen, methane is decomposed into hydrogen and elemental carbon at high temperatures, usually in the presence of a catalyst.
- From methanol produced using natural gas. In a methanol reformer, water and methanol mixture is pressurized at about 20 bar, vaporized and heated to a temperature of 240-260°C.

b. From crude oil and petroleum products

Report here the quantities of hydrogen produced from oil and petroleum products.

Main processes:

- Production of hydrogen during the oil refining process from catalytic naphtha crackers and steam crackers for dedicated onsite generation and use from crude oil (This onsite production may be supplemented with hydrogen, produced using steam methane reformers, fed with natural gas[3]).

- Production of hydrogen from syngas (CO+H2) with a water-shift reaction and separation. The water-gas shift reaction (WGS) consist on the process of displacing with water the CO produced in the reformer, with water (water-gas shift reaction, WGS) to give rise to H2 and CO2, in an exothermic reaction.
- Gasification of oil refining residues.

c. From solid fuels (coal)

Please report here the hydrogen produced from coal.

Main processes:

- Coal gasification. Gasification is the process of treating a carbonaceous fuel with an amount of oxygen and/or steam of water, resulting in incomplete combustion, to obtain a synthetic gas formed mainly by carbon monoxide and hydrogen. This process generally takes place at a temperature above 700 °C, as the higher the temperature is, the lower the percentage of unoxidised coal. The products obtained must be subsequently subjected to a displacement reaction (water-gas shift reaction, WGS) to create H2 and CO2.

  The CO2 generated can also be captured and stored to reduce the associated greenhouse gas emissions.
- Pyrolysis of coal. Pyrolysis of coal consists in the decomposition of coal through the direct action of heat, in absence of water or oxygen. The final product depends on the temperature and pressure of the operation, the nature of the coal used, and the time the material has been under the pyrolysis processes. The operating temperature is around 1200 °C.

  In general, since there is no air present in the process, carbon oxides (CO, CO2) are not formed, therefore side reactions (of the WGS type) or subsequent purification processes (such as a PSA system), are not used.

d. From renewables (including renewable waste)

Please report here the hydrogen produced from renewables, including renewable waste.

Main processes:

- Production of pure hydrogen as the product of gasification of solid biomass or biofuels, followed by shift reaction and separation.

[3] Hydrogen being generated during catalytic reformulation which produces hydrogen at a rate of 200 Nm3 H2/t crude oil

- Gasification of biomass. There are various gasification technologies available for biomass (i.e. Non-catalytic partial oxidation - POX, auto-thermal reforming - ATR, and catalytic partial oxidation - CPO reformers). The process of gasification is followed by a process of cleaning and purification of the syngas produced (i.e. using a Water Gas Shift unit and a PSA membrane).
- Production of hydrogen through Pyrolysis. Decomposition of a solid fuel through the direct action of heat, in absence of water or oxygen. The final product depends on the temperature and pressure during the process, the nature of the fuel used and the time it has been under such conditions.
- Production of hydrogen as a product of solar-driven processes using light as the agent for hydrogen production (including photo-biological, photo-electrochemical, and solar thermochemical).
- From renewable municipal waste combusted.

  Please report here direct consumption of renewable municipal waste which have been reported in the Renewable Questionnaire and only if waste is used to produce hydrogen directly (not to produce electricity).

  Sustainable biomass and non-sustainable biomass are not reported in the annual hydrogen questionnaire independently.

e. From wastes (non-renewable)

Report here the hydrogen produced from non-renewable wastes. Energy can be recovered from non-renewable waste materials. Hydrogen can be obtained through a variety of processes, including combustion, gasification, pyrolysis, anaerobic digestion and landfill gas recovery.

WITH AND WITHOUT CARBON CAPTURE AND STORAGE (CCS)

For each of the above sources (a) to (e), report total production and the breakdown between production without and with CCS (Carbon Capture and Storage).

> *Info:* CCS is a technology which involves capturing CO_2. CCS can contribute to low-emission hydrogen production by mitigating emissions from existing hydrogen plants in the refining and chemical sectors, and providing a potentially lower cost option to hydrogen produced in regions with abundant low-cost gas and CO_2 storage capacity.

Under "without CCS", include production without CCS technology plus the part produced while not capturing carbon in installations with CCS (for example 30% of production in installation with 70% capturing).

Also include here the production via CCUS (Carbon Capture, Use and Storage) where present.

> *Info:* CCUS is a technology which involves the subsequent utilization of the captured CO_2 as a feedstock in a range of products, or for permanent storage in deep underground geological formations.

Under "with CCS", include the production proportionate to the part captured. It could be up to 95%, however the CO_2 created to produce the steam used in some process will probably not counted.

Note: For production from fossil fuels with CO_2 capture, an estimate of the amount of "zero carbon" hydrogen produced could be derived for simplicity. This would be equivalent to the hydrogen production multiplied by the CO_2 capture rate for the whole facility. For example, a steam methane reformer (SMR) with a capacity of 100 ktH2/yr and CO_2 capture capacity equal to 60% of the CO_2 output of the SMR would be considered to have capacity to produce 60 ktH2/yr of zero carbon hydrogen and 40 ktH2/yr of hydrogen with the CO_2 intensity of the SMR without CO_2 capture.

Kindly report in the remark sheets by source the average percentage of CCS used when producing hydrogen and if possible any additional information regarding this calculation (such as the percentages by facilities if available).

f. From electricity - electrolysis

Report here the hydrogen produced from electricity through electrolysis processes.

Example: Hydrogen produced via electrolysis of electricity generated from the combustion of municipal solid waste through a Rankine cycle[4].

Common type of electrolysis are:

- Proton Exchange Membrane Electrolysis
- Anion Exchange Membrane Electrolysis
- Alkaline Electrolysis
- Electrolysis via Solid Oxide Electrolyser Cell (SOEC)
- High-Temperature Electrolysis

Of which: grid electricity. Please report here the hydrogen produced from grid electricity. The electricity used to produce hydrogen, has been produced from several sources in a central power plant or another infrastructure. Hydrogen produced from electricity is mostly from grid electricity.

Of which: with electricity from renewables (DL). Please report here the hydrogen produced from electricity produced from sustainable renewables therefore via a direct line (DL)

[4] The Rankine cycle or Rankine Vapor Cycle is the process widely used in power plants. In this mechanism, a fuel is used to produce heat within a boiler, converting water into steam which then expands through a turbine producing electricity.

Of which: with electricity from nuclear (DL). Please report here the hydrogen produced from electricity of nuclear origin via direct line (DL). The nuclear energy's role in hydrogen production during next two decades could involve the following process:

A) Cold electrolysis of water, using off-peak capacity (needs 50-55 kWh/kg).

B) Low-temperature steam electrolysis (alkaline, proton exchange membrane, and anion exchange membrane water electrolyses) using heat and electricity from nuclear reactors.

C) High-temperature electrolysis (a reverse reaction of the solid oxide fuel cell (SOFC) technology) using heat and electricity from nuclear reactors.

Of which: with electricity from fossil fuels (DL): Please report here the hydrogen produced via direct line (DL) therefore from electricity which has been produced from fossil fuels through a transformation process in a central power plant or another energy infrastructure.

g. From electricity - Others

Please report here the hydrogen produced from electricity as a by-product and hydrogen produced in other electricity-base processes not listed above.

Example: Hydrogen produced as a by-product during Chlorine production.

h. From other sources (Others)

Report here the production of hydrogen from other sources not detailed above. These should be quantities of hydrogen produced from sources whose production, transformation and consumption are not reported in other energy questionnaires.

The production of hydrogen reported here will be considered as primary production in the energy balances.

Production to be reported here include:

- Pure hydrogen as a by product of a chemical reaction in the petrochemical industry[5].
- Dark fermentation not reported in the renewable and waste questionnaire.
- High-temperature thermolysis production using nuclear heat.
- Thermochemical cycles. There are 300 thermochemical cycles that can be used for this purpose, but the most important are the sulphur-iodine cycles and those of the UT-3 type.
- Hydrogen produced from Lignocellulose (non-combusted biological origin).
- Hydrogen from natural sources. Report here the hydrogen produce from:

[5] Exclude the production of hydrogen in chemical processes in the refineries and in the petrochemical industry which use oil and petroleum products and which are to be reported in the line "From crude oil and petroleum products".

- Injecting CO2 and steam water in grounds with certain composition.
- Fairy circles.
- Water radiolysis.
- Anaerobic fermentation.
- Natural Hydrogen deposits.
- Hydrogen emissions in geothermic plants.
- Hydrogen adsorbed from clay rocks.

3.1.2. Production of Ammonia (NH3) (voluntary)

Report quantities of ammonia produced from other energy sources: fossil fuels, renewables, wastes, electricity, nuclear energy, and other natural sources. Report all ammonia produced regardless if it is for energy or non-energy purposes.

Currently about 80% of ammonia production comes from the use of natural gas. The most common production method is steam reforming.

3.1.3. Production of E-fuels and RFNBO (voluntary)

Report quantities of e-fuels produced from other energy sources: renewables, wastes, electricity, nuclear energy, and other natural sources. The production of synthetic fuels is currently at the early stages of development.

3.1.4. Production from hydrogen, ammonia and e-fuels

Report here the hydrogen, ammonia and e-fuels produced from other sources reported in this reporting template (questionnaires).

Example: Pure hydrogen used to produce ammonia via Haber-Bosch process.

Example: Hydrogen used to produce e-fuels. E-fuels are typically produced with hydrogen obtained in an electrolysis process that uses renewable energies and breaks down water into hydrogen and oxygen. In a second step, hydrogen is combined with CO2 (extracted from the air) in the chemical process “Fischer-Tropsch synthesis”.

Example: Ammonia used to produce hydrogen via a cracking process.

<u>Note: Report the NET amounts (the output of the transformation process). The transformation losses will be determined by the difference between the input amounts reported in the Transformation Sector and the output reported here.</u>

<u>The difference shall be also reported in the Memo item: Transformation losses</u>

3.2. TABLE 2 - STOCKS

Please report here the opening and closing stocks on national territory.

Only total opening and closing stocks levels of hydrogen are mandatory for the countries reporting to Eurostat.

a. Hydrogen stocks

Total Hydrogen: Report here total opening and closing stocks

Pressurized: Report here the hydrogen stored as pressurized. The stocks are normally in smaller tanks. Hydrogen is in its pure form. The hydrogen is compressed at certain pressure and temperature (pressure and temperature are related). The hydrogen has less density per cubic meter and it is more bulky than in other forms.

Liquefied: Report here the hydrogen stored in liquefied form. The stocks are stored in bigger tanks, normally in industries. Hydrogen is in its pure form. This form allows for more density than the pressurized form (less bulky).

As other chemicals: Report here the hydrogen stored in a chemical compound. This is a special storage method for hydrogen. In organic liquids (LOHC) or in metal hydrides (highest density - less bulk - most efficient). Both these methods are under development. Also include the hydrogen stored in the form of methanol and synthetic methane.

Note: Report only the amount of hydrogen in the chemical compound for storage purposes.

When possible specify in the remarks page the amount of chemical storages, the types of chemical, and the % of hydrogen.

Other storage methods: Report here the cryo-compressed hydrogen. This form is under development. Potentially, there are also other forms of non-pressurized hydrogen such as underground storage and in adsorbents such as carbon materials.

When possible give further info in the remarks page.

b. Ammonia stocks

Total Ammonia: Report here total ammonia stocks, regardless if ammonia is stored for future energy or non-energy use.

Of which “hydrogen as ammonia”: Report here the hydrogen stored as ammonia. This is storage method for hydrogen with a hydrogen density of 120 Kg/m3.

c. E-fuels stocks

Total e-fuels: Report here total e-fuel stocks.

3.3. TABLE 3 - TRANSFORMATION AND ENERGY SECTORS, LOSSES AND OTHER TOTALS

Indigenous production

Total automatically reported from Table 1.

Imports

Total automatically reported from trade tables.

Exports

Total automatically reported from trade tables.

Stocks changes

Stocks changes are automatically calculated based on the opening and closing stocks levels in the stocks tables. Closing stocks minus opening, a stock draw is a negative number.

International aviation

Report quantities delivered to aircraft for international voyages (‘also known as International Aviation Bunkers’).

The domestic/international split should be determined on the basis of departure and landing locations and not by the nationality of the airline. Exclude the quantities used by airlines for their road vehicles (see Not elsewhere specified – Transport sector) and military use (see Not elsewhere specified – Other sectors).

International marine bunkers

Report the quantities delivered to ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters.

Exclude consumption by ships engaged in domestic navigation (see domestic navigation).

The domestic/international split should be determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship. Exclude consumption by fishing vessels (see Fishing – Other sectors) and consumption by military forces (see Not elsewhere specified – Other sectors).

Inland consumption (calculated)

Calculated from the values listed above in the table.

It is defined as: + Indigenous production + Imports (Balance) – Exports (Balance) + Stock changes – International aviation – International marine bunkers.

3.3.1. TRANSFORMATION SECTOR (AND BLENDING)

Report the quantities used as feedstock for the production of (transformation into) other energy products. Report the input amounts, including transformation losses. The Transformation Sector and the blending flows are divided into:

Main activity producer electricity

Report quantities used to produce electricity by all main activity producers. For countries reporting to Eurostat, reported quantities should be aggregated by type of unit and not by type of plant.

Auto-producer electricity

Report quantities used to produce electricity by all auto-producers. Hydrogen used by plants containing at least one CHP unit are to be reported under Auto-producer CHP. For countries reporting to Eurostat, reported quantities should be aggregated by type of unit and not by type of plant.

Example: Petrochemical industry producing electricity from hydrogen.

Main activity producer combined heat and power (CHP)

Report quantities used to produce electricity and heat by all main activity producers. For countries reporting to Eurostat, reported quantities should be aggregated by type of unit and not by type of plant.

Auto-producer combined heat and power (CHP)

Report quantities used that correspond to the quantity of electricity produced and heat sold by all auto-producers. For countries reporting to Eurostat, reported quantities should be aggregated by type of unit and not by type of plant.

Main activity producer heat

Report quantities used to produce heat by all main activity producers. For countries reporting to Eurostat, reported quantities should be aggregated by type of unit and not by type of plant.

Auto-producer heat

Report quantities that correspond to the quantity of heat sold by all auto-producers. For countries reporting to Eurostat, reported quantities should be aggregated by type of unit and not by type of plant.

Example: Heat produced and sold by petrochemical plants using hydrogen.

Gas works (and other conversion to gases)

Report quantities used to produce gas at gas works and gasification plants. Quantities used for heating and operation of equipment should not be reported here, but reported as consumption in the Energy sector.

Petroleum refineries

Report all quantities delivered to refineries for transformation purposes. Any hydrogen consumed in support of the refinery processes and operations should be reported in the Energy sector.

There are various hydro and hydro-treating processes in refineries. Including:

- Hydrocracking for crude oil refining[6]. This process employs hydrogen gas to improve the hydrogen-carbon ratio in the cracked molecules and to arrive at a broader range of end products, such as gasoline, kerosene and diesel fuel.
- Hydrodesulphurization (HDS) is a catalytic chemical process widely used to remove sulphur (S) from natural gas and from refined petroleum products.
- Hydro isomerisation: normal paraffins are converted into iso-paraffins to improve the product properties (e.g. RON).
- De-aromatisation: Hydrogenation of aromatics into cyclo-paraffins or alkanes.

Examples: Hydrogen used in refineries in the production of low-emission synthetic hydrocarbon fuels (Synfuels), or for the production of methanol for energy purposes.

Natural gas blending plants

Report quantities blended with natural gas in the natural gas grid.

For blending with motor gasoline/diesel/kerosene

Report here the quantities blended with motor gasoline, diesel and kerosene

For blending with renewables

Report here quantities blended with renewable fuels. The hydrogen reported here will necessarily be only hydrogen that operators are allowed to blend into renewables.

For production of hydrogen

Report here the amounts of ammonia or e-fuels used to produce hydrogen. Report the gross amount (the input of the transformation process). The net output will be reported in Table 1 - Production. The difference between the gross and net values should be reported in the "Memo item: Transformation losses".

[6] Hydrocracking is the most common process in refineries, needing around 300 Nm3 H2/t of product (https://www.fchobservatory.eu/sites/default/files/reports/Chapter_2_Hydrogen_Molecule_Market_070920.pdf)

For production of ammonia

Please report here the amount of hydrogen or e-fuels used to produce ammonia. Report the gross amount (the input of the transformation process). The net output will be reported in Table 1 - Production. The difference between the gross and net values should be reported in the "Memo item: Transformation losses".

Example: Production of ammonia using hydrogen which is combined with nitrogen to produce ammonia via the Haber-Bosch process.

For production of e-fuels

Please report here the amount of hydrogen or ammonia used to produce e-fuels. Report the gross amount (the input of the transformation process). The net output will be reported in Table 1 - Production. The difference between the gross and net values should be reported in the "Memo item: Transformation losses".

Example: Use of hydrogen to produce e-fuel via the Fisher-Tropsch process.

Not elsewhere specified – Transformation

Please report here the quantities used for other transformations.

Data should be reported here if a final breakdown into the above sectors is not available.

Note: Report here the amounts of hydrogen transformed into other energy products by the petrochemical industry.

Examples: Production of methanol outside refineries, production of synthetic methane, biofuels upgrade, production of Hydro-treated Vegetable Oil (HVO).

Note: Hydro-treated Vegetable Oil (HVO) is a form of biodiesel based on advanced raw materials such as residues and waste. HVO is a 2nd generation biodiesel. HVO is produced by hydrogenation and hydrocracking of vegetable oils and animal fats using hydrogen and catalysts at high temperatures and pressures. The conversion usually takes place in two stages: hydro treatment followed by hydrocracking/isomerization. The hydro treatment typically takes place between 300 – 390°C.

Hydro-treated vegetable oil is not to be confused with the hydrogenated vegetable oil, which is normally produced by the food industry, and is reported as a final consumption non-energy use of hydrogen under the industry sector.

Memo item: Transformation losses

Reporthere the losses during transformation processes. These amount should be included in the amount reported in the transformation sector. These include all quantities use in transformation processes which do not enter the final product. It is a Memo item of the amounts reported in the Transformation sector.

Of which: Transformation losses in refineries

Report the losses during transformation processes in petroleum refineries. These include all quantities used in refinery transformation processes which do not enter the final oil products. It is an "of which item" of the amounts reported in the Transformation losses.

Examples: Losses occurred in refineries processes, losses occurred when hydrogen is converted into ammonia, losses occurred during the transformation of hydrogen into another component with better properties for transport.

Inter-questionnaires note: the transformation losses of hydrogen which occur in the refinery processes should be reported as transformation losses in the hydrogen questionnaire and in "Other hydrocarbons - Refinery losses" in Table 1 of the annual oil and petroleum products questionnaire.

Transformation & conversions parameters for reference[7]:

- Specific hydrogen requirement for NH_3 (t/t): 0.180072; Conversion losses 2%
- Specific hydrogen requirement for synthetic Methanol (t/t) 0.191327; Conversion losses 2%
- Specific hydrogen requirement for fossil Methanol (t/t) 0.127551; Conversion losses 2%
- Fischer-Tropsch efficiency for liquid fuels: 73%
- Methanation[8] efficiency: 77%
- Specific hydrogen requirement for HVO diesel: 12.4 MJ Hydrogen/MJ HVO
- Specific hydrogen requirement for HEFA jet: 15.0 MJ Hydrogen/MJ HEFA
- Hydrogen LHV: 120.1 MJ/kg
- Hydrogen density in normal conditions[9]: 0.0899 kg/m^3

3.3.2. ENERGY SECTOR

Report quantities consumed by the Energy sector to support the extraction (mining, oil and gas production) or the plant operations of energy transformation activities.

Note that quantities of hydrogen, ammonia or e-fuels transformed into another energy form should be reported under the Transformation sector.

[7] Source: IEA (2021), Hydrogen Projects Database, https://www.iea.org/reports/hydrogen-projects-database.

[8] Methanation is the conversion of carbon monoxide and carbon dioxide (COx) to methane (CH4) through hydrogenation.

[9] At 0ºC and 1 atmosphere of pressure.

The Energy sector includes ISIC 2 Divisions. The Energy sector includes the manufacture of chemical materials for atomic fission and fusion and the products of these processes.

Examples: Hydrogen used for heating, lighting or operating pumps or compressors. Hydrogen used as refinery fuel to provide steam for refinery processes. Hydrogen consumed as a fuel for production, liquefaction and gasification of other fuels.

Electricity, CHP and heat.

Please report here the quantities consumed as a fuel at electricity plants, combined heat and power plants, and heat plants.

Coal mines

Report quantities consumed as a fuel to support the extraction and preparation of coal within the coal mining industry.

Oil and gas extraction

Report quantities consumed as a fuel in the oil and gas extraction process and in natural gas processing plants. Any hydrogen eventually used to operate the pipelines should be reported in the Transportation sector.

Petroleum refineries

Report quantities consumed as refinery fuel to provide steam for refinery processes. Exclude the quantities that are transformed or blended into a petroleum product (exclude all hydrogen used in processes were the hydrogen ends up in the output product).

Coke ovens

Report quantities consumed as a fuel at coking plants.

Blast furnaces

Report quantities consumed to support blast furnaces operations.

Gas works

Report quantities consumed as a fuel at gas works and coal gasification plants.

Production, liquefaction, gasification of hydrogen (ammonia, e-fuels)

Please report here the quantities consumed as a fuel for production, liquefaction and gasification of hydrogen (ammonia and e-fuels).

Not elsewhere specified – Energy

Data should be reported here only as a last resort if classification is unknown or if a final breakdown into the above sectors is not available.

3.3.3. LOSSES

Transmission and Distribution Losses: Report all losses which occur outside the production facility due to transport and distribution, including eventual pipeline losses.

3.4. TABLE 4 – TRADE: IMPORTS BY ORIGIN AND EXPORTS BY DESTINATION

Report in this table under Imports the quantities of hydrogen, ammonia and e-fuels imported from the country of ultimate origin to the reporting country.

Report in this table under Exports the quantities of hydrogen, ammonia and e-fuel exported from the reporting country to the country of final destination.

Additional transformation processes may be necessary for the transport of hydrogen on long distances. However, the transformation into another chemical compounds with better properties for transport will not be tracked as it is currently done for Natural Gas/LNG because it is not yet statistically relevant. Most hydrogen goes via pipeline (injected or blended) and would be reported under the columns of hydrogen, some is transported internationally by ships in the form of ammonia or in the form of Methyl-cyclohexane.

If the hydrogen is transformed into a compound other than the ammonia (i.e. into Methyl-cyclohexane), the quantity of hydrogen in TJ should be reported under the column of hydrogen. The transformation losses incurred during these processes will be recorded under Transformation losses.

Note: Please explain in the Remarks page when data refer to hydrogen transported in other forms. If available mention the form used.

Geographical notes:

- Australia excludes the overseas territories
- Denmark includes the Danish Faroes and Greenland;
- France includes Monaco and excludes the overseas territories Guadeloupe, Martinique, French Guyana, Reunion, St.-Pierre and Miquelon, New Caledonia, French Polynesia, Wallis and Futuna, Mayotte;
- Italy includes San Marino and the Vatican;
- Japan includes Okinawa;
- The Netherlands excludes the Netherlands Antilles;
- Portugal includes the Azores and Madeira;
- Spain includes the Canary Islands, the Balearic Islands and Ceuta and Melilla;
- Switzerland includes Liechtenstein;
- United Kingdom includes Jersey, Guernsey and the Isle of Man;

- The United States includes the 50 States, District of Columbia, Puerto Rico,Guam, the US Virgin Islands and the Hawaiian Foreign Trade Zone.

Statistical differences may arise if only total imports and exports are available (from customs or refinery surveys) while the geographical breakdown is based on a different survey, source or concept. In this case, report the differences in the ‘Non-specified/Other’ category.

Import origins or export destinations not listed individually in the trade tables should be reported under the appropriate ‘Other’ category (Other Africa, Other Asia, etc.). Where no origin or destination can be reported, the category ‘Non-specified/Other’ should be used.

3.5. TABLE 5 - FINAL CONSUMPTION

Final consumption comprise all hydrogen delivered to final consumers (in the Transport, Industry and Other sectors). It excludes deliveries for transformation, own use of the energy producing industries, distribution losses and statistical differences.

3.5.1. INDUSTRY SECTOR

ENERGY USE: Report quantities consumed by the industrial undertaking in support of its primary activities.
Report quantities consumed in heat plants and CHP plants for the production of heat used by the plant itself. Quantities consumed for the production of heat that is sold, and for the production of electricity, should be reported under the appropriate energy sector.

NON-ENERGY USE: Report quantities consumed by the industrial undertaking in support of its primary activities. Report quantities of hydrogen consumed under the appropriate non-energy sector.

Iron and steel

ISIC Group 241 and Class 2431 (NACE Groups 24.1, 24.2, 24.3; and Classes 24.51 and 24.52).

Note The hydrogen used in the steel production process shall be split between non-energy use (i.e. hydrogen used as reducing agent, for the removal of the oxygen in the steel) and energy use (i.e. production of iron ore during which the hydrogen is combusted for the generation of high-temperature heat).

Note: report all hydrogen used in steel production regardless of its source, including the hydrogen for the production of so-called “green” steel.

Chemical and petrochemical

ISIC Division 20 and 21 (NACE Division 20 and 21).

This heading includes quantities used as fuel (energy use) and as feedstock (non-energy use). To avoid double counting, any quantities reported in the transformation sector should not be included in final consumption in the chemical and petrochemical sector.

Note: Hydrogen used to produce ammonia is not reported here but in Transformation sector – “For production of ammonia”.

Note: Hydrogen used to produce e-fuel is not reported here but in Transformation sector – “For production of e-fuels”.

Note: Do not report here the amount of hydrogen used in processes which transform/add hydrogen into another energy product in the petrochemical industry. These amounts should be reported under “Transformation Sector - not elsewhere specified”. The proportional use of hydrogen in support of these operation in the petrochemical industry should be reported under “Energy Sector - not elsewhere specified”

Note: Report under energy use: hydrogen used to support the operations in chemical and petrochemical industries in the production of non-energy products.

Example: Report under non-energy use: the hydrogen used as feedstock for the production of methanol for non-energy purposes, such as feedstock in the production of paint and solvents.

Example: Report under non-energy use: the hydrogen used as feedstock for the production of hydrogen peroxide (H_2O_2).

Example: Report under non-energy use, the ammonia used for the production of fertilizers, explosives, or pharmaceutical products.

Example: Report under energy use the hydrogen used to produce auto-consumed (unsold) heat in chemical plants.

Non–ferrous metals

ISIC Group 242 and Class 2432 (NACE Group 24.4 and Classes 24.53, 24.54).

Non–metallic minerals

ISIC Division 23 (NACE Division 23). Report quantities use in the production of glass, ceramic, cement and other building materials industries.

Transport equipment

ISIC Divisions 29 and 30 (NACE Divisions 29 and 30).

Machinery

ISIC Divisions 25, 26, 27 and 28 (NACE Divisions 25, 26, 27, and 28). Report use for fabricated metal products, machinery and equipment other than transport equipment.

Mining (excluding energy producing industries) and quarrying

ISIC Divisions 07, 08 and Group 099 (NACE Divisions 07, 08 and Group 09.9).

Food, beverages and tobacco

ISIC Divisions 10, 11 and 12 (NACE Divisions 10, 11 and 12).

Example: Hydrogen used to produce hydrogenated oils in the food industry should be reported under non-energy use. Here hydrogen is used to convert some or all of the unsaturated fat into saturated fat, resulting in a solid or semi-solid consistency.

Paper, pulp and printing

ISIC Divisions 17 and 18 (NACE Divisions 17 and 18). This category includes reproduction of recorded media.

Wood and wood products (other than pulp and paper)

ISIC Division 16 (NACE Division 16).

Construction

ISIC Division 41, 42 and 43 (NACE Division 41, 42 and 43).

Textile and leather

ISIC Divisions 13, 14 and 15 (NACE Divisions 13, 14 and 15).

Not elsewhere specified – Industry

If your country's industrial classification of hydrogen, ammonia or e-fuels consumption does not correspond to the above ISIC (or NACE) codes, please estimate the breakdown by industry and include in Not elsewhere specified only consumption in sectors which are not covered above.

ISIC Division 22, 31 and 32. For NACE, it covers Divisions 22, 31 and 32.

Report here, rather than under the energy sector, the energy use of hydrogen in petroleum refinery plants which produce exclusively non-energy products.

3.5.2. TRANSPORT SECTOR

Report quantities used for all transport activity, regardless of the sector in which the activity occurs (except for military fuel use, see Not elsewhere specified – Other sectors). Quantities used for heating and lighting at railway, bus stations, shipping piers and airports should be reported in the Commercial sector and not in the Transport sector.

Domestic aviation

Report quantities delivered to aircraft for Domestic aviation – commercial, private, agricultural, etc. Include fuel used for purposes other than flying, e.g. bench testing of engines of hydrogen fuelled aircrafts. The domestic/international split should be determined on the basis of departure and landing locations and not by the nationality of the airline. Note that this may include journeys of considerable length between two airports in a country (e.g. San Francisco to Honolulu). Exclude quantities used by airlines for their road vehicles (see Not elsewhere specified – Transport sector) and military use of aviation fuels (see Not elsewhere specified – Other sectors).

Road

Report quantities for use in road vehicles. Include hydrogen or e-fuels used by agricultural vehicles on highways. Exclude use in stationary engines (which should be reported under the relevant economic sector), hydrogen or e-fuels for non–highway use in tractors (see Agriculture/forestry – Other sectors) and military use (see Not elsewhere specified – Other sectors)

Report hydrogen used to power vehicles, both if <u>used in fuel cells to produce electricity</u> (in fuel cell electric vehicles - FCEVs) and if <u>combusted</u> (in vehicles with hydrogen internal combustion engines).

<u>Rail</u>

Report quantities if consumed in rail traffic, including industrial railways. It includes quantities used in rail transport as part of urban or suburban transport systems.

<u>Domestic navigation</u>

Report quantities delivered to vessels of all flags not engaged in international navigation (see international marine bunkers). The domestic/international split should be determined on the basis of port of departure and port of arrival and not by the flag or nationality of the ship. Note that this may include journeys of considerable length between two ports in a country (e.g. San Francisco to Honolulu).

<u>Pipeline transport</u>

Report quantities used as energy in the support and operation of pipelines transporting gases, liquids, slurries and other commodities, including the energy used for pump stations and maintenance of the pipeline. Hydrogen used as energy for the pipeline distribution of natural or manufactured gas, hot water or steam (ISIC 35) from the distributor to final users is excluded and should be reported in the Energy sector, while the hydrogen used for the final distribution of water (ISIC 36) to household, industrial, commercial and other users should be included in the Commercial/public sector. Losses occurring during this transport between distributor and final users should be reported as Distribution losses.

<u>Not elsewhere specified – Transport</u>

Report quantities used for transport activities not included elsewhere. Include quantities used by airlines for their road vehicles.

If a final breakdown into the above sectors is not available, administrations should explain on the Remarks page the basis for any estimates.

3.5.3. OTHER SECTORS

<u>Commercial and public services</u>

ISIC Divisions and NACE Divisions 33, 36, 37, 38, 39, 45, 46, 47, 52, 53, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 84 (exclude Class 8422), 85, 86, 87, 88, 90, 91, 92, 93, 94, 95, 96 and 99. Hydrogen consumed by businesses and offices in the public and private sectors.

Residential

Report hydrogen consumed by all households including households with employed persons (ISIC and NACE Divisions 97 and 98).

Agriculture

ISIC Divisions 01 (NACE Divisions 01). Report hydrogen consumption by users classified as agriculture.

Forestry

ISIC Divisions 02 (NACE Divisions 02). Report hydrogen consumption by users classified as forestry.

Fishing

Report quantities used for inland, coastal and deep–sea fishing. Fishing should cover hydrogen delivered to ships of all flags that have refuelled in the country (include international fishing). Also include energy used in the fishing industry as specified in ISIC Division 03 and NACE Division 03.

Not elsewhere specified – Other

Report activities not included elsewhere. This category includes military use for all mobile and stationary consumption (e.g. ships, aircraft, road and energy used in living quarters), regardless of whether the fuel delivered is for the military of that country or for the military of another country.

3.6. TABLE 6 - CAPACITIES

3.6.1. Production capacity

Report in this section the annual production capacities of the facilities existing at year end.

Where available, please report the capacity breakdown without CCS and with CCS.

Note[10]: For production from fossil fuels with CO_2 capture, an estimate of the "zero carbon" hydrogen production capacity could be derived for simplicity. This would be equivalent to the hydrogen production capacity multiplied by the CO_2 capture rate for the whole facility. For example, a steam methane reformer (SMR) with a capacity of 100 ktH2/yr and CO_2 capture capacity equal to 60% of the CO_2 output of the SMR would be considered to have capacity to

[10] Source: IEA (2021), Hydrogen Projects Database, https://www.iea.org/reports/hydrogen-projects-database.

produce 60 ktH2/yr of zero carbon hydrogen and 40 ktH2/yr of hydrogen with the CO_2 intensity of the SMR without CO_2 capture.

Kindly report in the remark sheets the average percentage of CCS used and if possible any additional information regarding this calculation (such as the percentages by facilities if available).

a. From Natural Gas

Report the production capacity of hydrogen from natural gas.
Of which steam reforming: Please report the capacity of production by steam reforming.

b. From oil and petroleum products

Report here the hydrogen production capacity from oil and petroleum products.
Of which steam reforming: Report the capacity of production by steam reforming.

c. From solid fuels (coal)

Report here the hydrogen production capacity from coal. For example, include coal gasification and pyrolysis capacities.
Of which steam reforming: Report the capacity of production by steam reforming.

d. From renewables (including renewable waste)

Report here the hydrogen and e-fuels production capacity from renewables, including renewable waste.
Of which steam reforming: Report the capacity of production by steam reforming.

e. From non-renewable wastes

Report here the hydrogen and e-fuels production capacity from non-renewables wastes.
Of which steam reforming: Report the capacity of production by steam reforming.

f. From electricity - Electrolysis

Report here the hydrogen and e-fuels produced from electricity through an electrolysis process.

Of which: grid electricity: Report here the hydrogen production capacity from grid electricity.

Of which: with electricity from renewables (Direct Line - DL). Report here the hydrogen production capacity from electricity obtained directly from sustainable renewables.

Of which: with electricity from nuclear (Direct Line - DL). Report here the hydrogen production capacity from electricity of nuclear origin.

Of which: electricity from fossil fuels (Direct Line - DL): Report here the capacity of hydrogen production from electricity which has been produced from fossil fuels through a transformation process in an energy infrastructure.

g. From electricity - Others

Report here the hydrogen production capacity in processes where hydrogen is a by-product such as during chlorine production or other processes based on electricity.

h. From other sources (Others)

Report here the production capacity of hydrogen and e-fuels from other sources not detailed above.

i. Production capacity from hydrogen, ammonia and e-fuels

Report production capacity of hydrogen, ammonia and e-fuels produced from other sources reported in this reporting template (questionnaires), including:

- Imported ammonia used to produce hydrogen.

- Hydrogen used to produce e-fuels

3.6.2. Storage capacity

Report here the sum of physical and chemical storage capacities for hydrogen in the national territory at the end of the year:

- Physical storage capacity is the capacity in TJ of existing infrastructures.
- Chemical storage capacity is the capacity in TJ of hydrogen stored in the form of a chemical compounds (i.e. Hydrides, Liquid organic hydrogen carriers).

Kindly add in the remarks page further description on infrastructure whenever available.

3.6.3. Transport capacity

Hydrogen can be transported via pipeline, trailers, railway and ships. Please provide total annual capacity in TJ of pipelines, fleets, cargos, etc.

If any is available please add in the Remarks page the description or details on the transport system and means whose capacity is being reported.

4. LIST OF ABBREVIATIONS

ALK:Alkaline electrolysis
CCS: Carbon Capture and Storage
CCUS: Carbon Capture, Utilization and Storage
CH4: Synthetic methane
CHP: combined heat and power
cSt: viscosity of oil measured in centistokes
EU: European Union
GCV: gross calorific value
HHV: higher heating value = GCV
IATA: International Air Transport Association
IEA: International Energy Agency
ISIC: International Standard Industrial Classification
Kcal: kilocalorie
Kg: kilogramme
KJ: kilojoule
KPa: kilopascals
Kt: kilotonne
LHV: lower heating value = NCV
H2: Hydrogen in molecular form
LOHC: Liquid organic hydrogen carriers
LOHC: Liquid organic hydrogen carriers
LPG: liquefied petroleum gases
NH3: ammonia
Nm3: normal cubic metre
M3: cubic metre
Mt: million tonnes
NACE: European standard classification of productive economic activities
NCV: net calorific value
NGL: natural gas liquids
OECD: Organisation for Economic Co–Operation and Development
SBP: special boiling point solvents
t: metric ton = tonne = 1.000 kg
TJ: Terajoule
UN: United Nations
PEM: Proton exchange membrane electrolysis
SOEC: Solid oxide electrolysis cells
Unknown PtX: Undisclosed electrolysis type