Clean Development Mechanism
Designated National Authority

Saudi Arabia's Greenhouse Gas Crediting & Offsetting Mechanism (GCOM)

Methodology for Determining Emission Reductions Resulting from the Application of Hydrogen in Iron and Steel Production

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1. Background and environmental integrity

The methodology for determining emission reductions from the usage of hydrogen in the production of iron and/or steel prepared for the Kingdom of Saudi Arabia's GHG Crediting and Offsetting Mechanism is designed to provide an easy-to-use set of equations and calculations, while at the same time ensuring environmental integrity in its application.

In order to ensure an excellent quality standard of the underlying approach, existing Clean Development Mechanism (CDM) methodologies and tools have been taken as the starting point for developing this methodology, including: AM0082 "Use of charcoal from planted renewable biomass in a new iron ore reduction system" Ver. 2.0[1], AMS-I.F "Renewable electricity generation for captive use and mini-grid", Ver. 3.0[2] and the methodological tools "Tool to calculate baseline, project and/or leakage emissions from electricity consumption" Ver. 3[3], and "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion" Ver. 3[4]. There is broad international consensus on CDM methodologies and tools being robust, conservative and relying on science-based approaches for the quantification of the emission reductions. All CDM methodologies have been approved by the United Nations Framework Convention on Climate Change (UNFCCC) after a detailed review and approval process. This ensures that any CDM methodology meets highest standard in terms of quality and environmental integrity.

In order to reduce transaction costs while ensuring environmental integrity, simplifications have been made to reduce complexity in the application of the methodology guidance, as well as to tailor the guidance to the Saudi Arabian context.

This methodology includes approaches to baseline, project, and leakage (where relevant) calculations building on equations contained in approved CDM methodologies. The monitoring, reporting and verification (MRV) requirements ensure comprehensiveness and accuracy while recognizing data availability issues.

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[1] https://cdm.unfccc.int/filestorage/S/4/3/S43YIV7WB0P19AC2T86JQMF5NLDHEX/EB101_repan07_AM0082.pdf?t=Q1J8cmM0bzdtfDC1rHyYfupxgytkxMfGdVKQ

[2] https://cdm.unfccc.int/filestorage/Y/P/1/YP1U4E0H976Z3WDMV2NGSTBLQIRCK5/EB81_repan26_AMSI.F_ver03.0.pdf?t=UFZ8cmM0czFnfDCQLLvb4iWw3i8RARzwika9

[3] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf

[4] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf

2. Generic considerations

Globally, GHG-emissions from steel production account for about 8% of global- and about 7% of Saudi Arabia`s CO_2-emissions. Since energy efficiency improvements in traditional steel production will likely soon be exhausted, new technologies will be required to further reduce steel related CO_2-emissions. One promising way to produce low-carbon steel is the utilization of low-carbon hydrogen. Hydrogen is an energy carrier with zero direct emissions. The production of hydrogen though can – depending on the production process – produce significant greenhouse gas emissions. In addition, and following latest research (Ocko et. al 2019, 2022), hydrogen is considered an indirect greenhouse gas. While the short-term global warming potential (GWP) is even higher due to the short half-life period of hydrogen, the commonly used 100-yr GWP of hydrogen is 5 and needs to be considered for leakage emissions.

There are 3 possible ways how to utilize hydrogen in the steel production:

1. Hydrogen injection in Blast-Furnaces (BF)

   H_2 can be used as an auxiliary reducing gas for iron-ore in the BF steel production pathway.
2. Hydrogen in direct reduced iron process (DRI)

   H_2 can be used as a reducing agent in the DRI process.
3. H_2 can be used for direct combustion, in order to supply the necessary process heat for parts of the iron/steel production facility.

3. Definitions

Iron/steel production facility

Iron/steel production facility refers to an industrial plant where iron and or steel is produced. In the context of this methodology, this term only refers to activities which are directly related to the reduction of iron ore (i.e., blast furnaces, direct iron reduction plant) or the production of steel out of sponge iron/pig iron/steel scrap in an electric arc furnace or a basic oxygen furnace. This term explicitly does not refer to upstream processes like sinter, pellet or coke production.

Electricity grid

Electricity grid is an interconnected network for electricity delivery from producers to consumers. Localized grids, i.e., grids in which a limited number of power plants not dispatched by a dispatch center are connected, are excluded from this definition

Blast Furnace

A blast furnace is a metallurgical furnace which is mainly used to reduce iron ore to pig iron. Traditionally coke, iron ore and limestone are continuously supplied to the furnace to produce pig iron.

Direct Reduced Iron Process (DRI)

This process is used to reduce solid state iron ore at temperatures below the melting point of iron to sponge iron. Traditionally natural gas is used for this process.

Captive Power Plant

A captive power plant is an electricity generation facility used and managed by an industrial or commercial energy user for their own energy consumption. Captive power plants can operate off-grid, or they can be connected to the electricity grid.

Green Hydrogen

Green hydrogen refers to hydrogen which is produced by water electrolysis, with required electric power delivered exclusively by renewable energies.

Blue Hydrogen

Blue hydrogen refers to hydrogen which is generated from the steam reduction of natural gas and the capturing of the generated CO_2 by Carbon Capture and Storage technologies (CCS). During this process, natural gas is split into hydrogen and CO_2. In this steam reforming process, however, the carbon dioxide is not emitted into the atmosphere; instead, it is captured by carbon capture technologies and then processed transported and stored permanently.

In this context blue hydrogen production encompasses the hydrogen production including capture, treatment & conditioning, transportation, reception and injection of the CO_2-rich gas stream.

Carbon Capture and Storage (CCS)

The process of separation and capture of carbon dioxide from a point source or directly from the atmosphere, its transport (if applicable) and subsequent safe and permanent storage in deep underground geological formations.

4. Eligibility requirements

1. This methodology applies to project activities that reduce GHG emissions to the atmosphere by using low-carbon hydrogen instead of fossil fuels in an iron/steel production facility.
2. The methodology is applicable if project proponents meet the following requirements:
   - The hydrogen used for the project activity is either green hydrogen or produced by technologies generally referred to as blue hydrogen
     - If blue hydrogen production technologies are applied for producing the hydrogen used in the iron/steel production facility, the project proponent has to meet the eligibility criteria of the *Methodology for determining emission reductions resulting from CCS/CCUS activities* of the Saudi GHG Crediting and Offsetting Mechanism. Furthermore, chapter 11 and Annex 1&2 of the *Methodology for determining emission reductions resulting from CCS/CCUS activities* of the Saudi GHG Crediting and Offsetting Mechanism apply in case of using blue hydrogen for iron/steel production.

- The carbon intensity of the hydrogen used for the project activity is equal or below 4.36 kg CO_2e/kg H_2 (0.131 kgCO_2e/kWh H_2; 0.036 kgCO_2e/MJ H_2) . In order to calculate the emission intensity of hydrogen, the emissions sources are considered[5]:
  - CO_2-emissions from the electricity consumption for producing hydrogen;
  - CO_2- and CH_4-emissions from the blue hydrogen production which are not captured by the carbon capture unit;
  - CO_2-emissions from the energy supply for the blue hydrogen production;
  - Potential seepage emissions of injected CO_2 escaping from the geosphere (if applicable); and
  - Emissions from leakage of hydrogen to the atmosphere need to be considered within the project boundaries.
  - Embodied emissions (Scope 3) related to production, processing and transport of hydrogen are excluded.
- No regulations/laws oblige the iron/steel producer to use low-carbon reducing agents or fuels;
- The project activity does not result in increased total GHG emissions as compared to emissions in the absence of the project activity;
- An appropriate monitoring plan for the GHG emissions from the iron/steel production facility is defined and approved by the Saudi DNA; and
- An appropriate monitoring plan for the GHG emission from the hydrogen production is defined and approved by the Saudi DNA.

3. The methodology is applicable for the retrofitting of already existing iron/steel production facilities and for the construction of new iron/steel production facilities with the purpose to use low-carbon hydrogen in the production process.
4. In case blast furnace gas is recovered and used outside of the project boundary for electricity and/or heat generation in the baseline situation, the project activity shall provide similar and/or equivalent energy outputs as the ones identified in the baseline scenario aiming to avoid impacts outside the project boundary due to the project implementation.

5. Quantification of GHG offset-credits (overview)

GHG offset-credits will be quantified by comparing “project emissions” to “business-as-usual (BAU)” emissions Equation (1) summarizes the generic quantification method.

$$\boldsymbol{ER_y = (BE_y - PE_y - LE_y)} \quad (1)$$

Where:

ER_y	=	Emission reductions achieved by project in the year y (t CO_2e/yr)
BE_y	=	Baseline emissions in the year y (t CO_2e/yr)
PE_y	=	Project emissions in the year y (t CO_2e/yr)
LE_y	=	Leakage emissions in the year y (t CO_2e/yr)

[5] 4.36 kgCO_2/kgH_2 is the carbon intensity threshold defined by CertifHy, the European flagship standard setter for hydrogen, defining certification requirements of low-carbon hydrogen. https://www.certifhy.eu/

6. Project boundary

The project boundary encompasses all emissions of the iron/steel production facility including emissions of the electricity used in the production facility (specified in Table 1). Additionally, the following emission sources are included in the project boundary.

- Emissions from the electricity consumption of producing hydrogen
- Emissions from the blue hydrogen production which are not captured by the carbon capture unit
- Potential seepage emissions as a result of injected CO_2 escaping from the storage complex (if applicable)

The emissions from processing of hydrogen and transport to the steel plant are excluded from the project boundary. Furthermore, upstream emissions from coke production are excluded due to simplicity and conservativeness. The emission sources and considered greenhouse gases are shown in Table 1.

Table 1 Emission sources and greenhouse gases included in or excluded from the project boundary

	Source	Gas	Included?	Justification/Explanation
Baseline	Electricity for iron/steel production	CO_2	Yes	Main emission source
		CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
	Fossil fuels for iron/steel production	CO_2	Yes	Main emission source
		CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
Project activity	Electricity for hydrogen production	CO_2	Yes	Main emission source
		CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
	Electricity for iron/steel production	CO_2	Yes	Main emission source
		CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
		CO_2	Yes	Main emission source

	Source	Gas	Included?	Justification/Explanation
	Fossil fuels for iron/steel production	CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
	Energy for blue hydrogen production	CO_2	Yes	Main emission source
		CH_4	Yes	Major emission source
		N_2O	No	Excluded for simplicity, minor emission source
	Residual emissions of blue hydrogen production after carbon capture	CO_2	Yes	Main emission source
		CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
	Project emissions from seepage	CO_2	Yes	Main emission source
		CH_4	No	Excluded for simplicity, minor emission source
		N_2O	No	Excluded for simplicity, minor emission source
Leakage	Hydrogen leakage	H_2	Yes	Main leakage emission source

7. Baseline scenario

In case of constructing a new iron/steel production facility, the average emissions intensity (t $CO_2/t_{iron,steel}$) of all existing, operational iron/steel production facilities in Saudi Arabia should be determined and applied. The average emissions intensity shall be calculated as the average of the last three historical years, and be differentiated between blast furnace steel production (BF) and electric arc furnace steel production (EAF). If the new installation is BF, then the average emissions intensity of all BF facilities needs to be applied. If the new installation is EAF, then the average emissions intensity of all EAF facilities needs to be applied.

In order to calculate the baseline emissions, this emission factor is multiplied by the tonnes of iron/steel produced in year y ($P_{y\ (steel,iron)}$) according to *equation (2)*. For projects starting after 2027, the baseline (benchmark) values need to be updated to reflect technological progress (best available technology, BAT).

The baseline emissions for retrofitting an existing iron/steel production facility are calculated with the average emission factor (t $CO_2e/t_{steel,iron}$) of the existing iron/steel production facility from the most recent three historical years before the project activity and the amount of tonnes of steel/iron produced during each year y of the project activity.

For conservativeness, updated yearly values for each year y of the project activity are applied for determining the:

- CO_2 emission coefficients of fossil fuels,
- Emission factor of the national electricity grid,
- Weighted average mass fraction of carbon in fuel type,
- Average technical transmission and distribution losses for providing electricity from the grid,
- Emission factor of the captive power plant,
- Weighted average mass fraction of carbon in fuel type,
- Weighted average net calorific value of fuel type,
- Weighted average CO_2 emission factor of fuel type.

Baseline emissions include i) emissions from the combustion of fossil fuels for thermal energy production, ii) emissions from the usage of fossil fuels for chemical processes iii) emissions from the consumption of electricity for the entire iron/steel production facility.

The baseline emissions are calculated as follows:

$$BE_y = EF_{BL\ (steel,iron),avg}\ x\ P_{y\ (steel,iron)} \quad (2)$$

Where:

BE_y	=	Baseline emissions for year y (t CO_2e/yr)
$EF_{\mathrm{BL\ (steel,iron),avg}}$	=	Average emission factor for the production of one ton of steel/iron during the most recent three historical years prior to the project activity (t $CO_2e/t_{steel,iron}$)
$P_{\mathrm{y\ (steel,iron)}}$	=	Overall production of iron/steel in year y ($t_{steel,iron}$/yr).

The $EF_{BL\ (Steel,iron),avg}$ is calculated as follows

$$\mathrm{EF}_{\mathrm{BL(Steel,iron)},avg} = \frac{BE_{FC,avg} + BE_{grid,avg} + BE_{CP,avg}}{\mathrm{P}_{avg\ (steel,iron)}} \quad (3)$$

Where:

$BE_{FC,avg}$	=	Average annual baseline emissions from the consumption of fossil fuels in the iron/steel production facility during the most recent three historical years prior to the implementation of the project activity (t CO_2e/yr)
$BE_{grid,avg}$	=	Average annual baseline emissions from electricity consumption from the grid for the iron/steel production facility during the most recent three historical years prior to the implementation of the project activity (t CO_2e/yr)
$BE_{CP,avg}$	=	Average annual baseline emissions from electricity consumption from the captive production plant for the iron/steel production facility during the most recent three historical years prior to the implementation of the project activity (t CO_2e/yr)
$\mathrm{P}_{avg\ (steel,iron)}$	=	Average annual iron/steel production during the most recent three historical years prior to the implementation of the project activity ($t_{steel,iron}$/yr).

$$\mathrm{P}_{avg\ (steel,iron)} = \sum_{x=1}^{3} \frac{\mathrm{P}_{x\ (steel,iron)}}{3} \quad (4)$$

Where:

$\mathrm{P}_{x\ (steel,iron)}$	=	Annual iron/steel production prior the project activity in year x ($t_{steel,iron}$/yr)
x	=	One of the most recent three historical years before project activity

Note that the quantification method introduced above is a generic guidance that might need to be adjusted to fit the concrete project design. Baseline emissions (BE) need to be estimated ex-ante according to the guidance, in order to get a realistic understanding of the net-benefits of the project activity. The real benefit and resulting quantities of carbon credits will be determined by ex-post monitoring of baseline emissions. Project proponents must elaborate an appropriate MRV-plan, to be approved by the Saudi DNA.

Step 1: Determination of CO_2 emissions from fossil fuel consumption

The baseline emissions from fossil fuels are calculated as follows:

$$BE_{FC,avg} = \frac{\sum_{x=1}^{3} \sum_{i} FC_{BL,i,x} \times COEF_{i,y}}{number\ of\ years\ considered} \tag{5}$$

Where:

$FC_{BL,i,x}$	=	Quantity of fossil fuel type *i* used in the iron/steel production facility prior to the project activity in year x (mass unit/yr).
$COEF_{i,y}$	=	CO_2 emission coefficient of fossil fuel type *i* in year y (t CO_2e/mass unit of fossil fuels)
i	=	Fossil fuel type used

The CO_2 emission coefficient of fuel type *i* can be calculated using one of the following two options in accordance with the *CDM tool 03: "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion" Ver.3*[6]:

1) Option A: the CO_2 emission coefficient is calculated based on the chemical composition of the fossil fuel type i via the following approach:

   If $FC_{BL,i,x}$ is measured in a mass unit:

$$COEF_{i,y} = w_{C,i,y} \times \frac{44}{12} \tag{6}$$

   Where:

$w_{C,i,y}$	=	Weighted average mass fraction of carbon in fuel type *i* in year y (t CO_2e/mass unit of fossil fuels)

2) Option B: The CO_2 emission coefficient is calculated based on net calorific value and CO_2 emission factor of the fuel type *i* via the following approach:

$$COEF_{i,y} = NCV_{i,y} \times EF_{CO2,i,y} \tag{7}$$

   Where:

$NCV_{i,y}$	=	Weighted average net calorific value of the fuel type *i* in year *y* (GJ/mass or volume unit)
$EF_{CO2,i,y}$	=	Weighted average CO_2 emission factor of fuel type *i* in year y (t CO_2e/GJ)

[6] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf

Step 2: Determination of CO_2 emissions from consumption of grid-electricity

Baseline emissions from grid electricity consumption are calculated in accordance with the *CDM tool 03*: "*Tool to calculate baseline, project and/or leakage emissions from electricity consumption Ver. 3*[7] as follows:

$$BE_{grid,avg} = \frac{\sum_{x=1}^{3} EC_{BL,grid,x} \times EF_{grid,y} \times \left(1 + TDL_y\right)}{number\ of\ years\ considered} \quad (8)$$

Where:

$EC_{\mathrm{BL,grid,x}}$	=	Quantity of electricity consumed from the grid in the iron/steel production facility prior to the project activity in year x (MWh/yr)
$EF_{grid,y}$	=	Emission factor of the electricity grid to which the production facility is connected in year y (t CO_2e/MWh). In case of connection to the Saudi national electricity grid, the latest grid emission factor published by the Saudi DNA is to be applied.
TDL_y	=	Average technical transmission and distribution losses for providing electricity from the grid in year y

As for the electricity emission factor ($EF_{grid,y}$), project proponents can use the latest grid emission factor for Saudi Arabia as published by the Saudi DNA.

As for TDL_y use a conservative assumption. If no data is available, a default value of 20 % is recommended in accordance with CDM Tool 05[8].

Step 3: Determination of CO_2 emissions from electricity consumption of the captive power plant

Baseline emissions from electricity consumption from the captive power plant are calculated as follows:

$$BE_{CP,avg} = \frac{\sum_{x=1}^{3} EC_{BL,cp,x} \times EF_{cp,y}}{number\ of\ years\ considered} \quad (9)$$

Where:

$EC_{\mathrm{BL,cp,x}}$	=	Quantity of electricity consumed in the iron/steel production facility from the captive power plant (if applicable) prior to the project activity in year x (MWh/yr)
$EF_{cp,y}$	=	Emission factor of the captive power plant in year y (t CO_2e/MWh)

If there is a captive power plant for captive use, the specific emission factor of this plant shall be used (t CO_2e/MWh).

[7] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf
[8] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf

The emission factor of the captive power plant can be calculated as follows:

$$EF_{cp,y} = \frac{\sum_i FC_{cp,y,i} \times NCV_{i,y} \times EF_{CO2,i,y}}{EG_y} \quad (10)$$

Where:

$FC_{cp,i,y}$	=	Quantity of fossil fuel type *i* fired in the captive power plant in year y (mass unit/yr).
EG_y	=	Quantity of electricity generated in the captive power plant in year y (MWh/yr)

8. Calculation of project emissions

Project emissions (PE) need to be estimated ex-ante according to the quantification methods provided below, in order to get a realistic understanding of the net-benefits of the project activity. The real benefit and resulting quantities of carbon credits will be determined by ex-post monitoring of parameters required to determine project emissions.

Project emissions include i) emissions from the combustion of fossil fuels for thermal energy production; ii) emissions from the usage of fossil fuels for chemical processes; iii) emissions from the use of electricity for the complete iron/steel production facility; iv) all emissions generated from the production of green/blue hydrogen which is used in the production process; v) potential seepage emissions.

Project emissions are calculated as follows:

$$PE_y = PE_{FC,y} + PE_{grid,y} + PE_{CP,y} + PE_{H2,y} \quad (11)$$

Where:

PE_y	=	Project emissions in year *y* (t CO_2e/yr)
$PE_{FC,y}$	=	Project emissions from the consumption of fossil fuels that are used in the iron/steel production facility in year y (t CO_2e/yr)
$PE_{grid,y}$	=	Project emissions from consumption of grid electricity in year y (t CO_2e/yr)
$PE_{CP,y}$	=	Project emissions from electricity consumption from the captive power plant in year y (t CO_2e/yr)
$PE_{H2,y}$	=	Project emissions from the production of the consumed hydrogen in the iron/steel production facility in year y (t CO_2e/yr)

Step 1: Determination of project CO_2 emissions from fossil fuel and electricity consumption

- For the determination of $PE_{FC,y}$ refer to the formulas in section 7 step 1 and use
    - i. $PE_{FC,y}$ instead of $BE_{FC,avg}$
    - ii. $FC_{P,i,y}$ instead of $FC_{BL,i,x}$.
- For the determination of $PE_{grid,y}$ refer to the formulas in section 7 step 2 and use
    - i. $PE_{grid,y}$ instead of $BE_{grid,avg}$
    - ii. $EC_{P,grid,y}$ instead of $EC_{BL,grid,x}$.
- For the determination of $PE_{CP,y}$ refer to the formulas in section 7 step 3 and use
    - i. $PE_{CP,y}$ instead of $BE_{CP,avg}$
    - ii. $EC_{P,cp,y}$ instead of $EC_{BL,cp,x}$

Where:

$FC_{P,i,y}$	=	Quantity of fossil fuel type *i* consumed in the iron/steel production facility during the project activity in year y (mass unit/yr)
$EC_{P,grid,y}$	=	Quantity of electricity consumed from the grid in the iron/steel production facility in year y during the project activity (MWh/yr)
$EC_{P,cp,y}$	=	Quantity of electricity consumed by the iron/steel production facility from the captive power plant (if applicable) during the project activity in year y (MWh/yr)

Step 2: Determination of project CO_2 emissions from the production of hydrogen used in the iron/steel production

The CO_2 emission of hydrogen used in the project activity can be calculated as follows:

$$PE_{H2,y} = H_{2g}C_y * EF_{H2g,y} + H_{2b}C_y * EF_{H2b,y} + PE_{Seepage,y} \quad (12)$$

Where:

$H_{2g}C_y$	=	Quantity of green hydrogen consumed in the iron/steel production facility in year y during the project activity ($t\ H_2/\ t_{steel,iron}$)
$EF_{H2g,y}$	=	Emission factor of green hydrogen in year y ($t\ CO_2e/t\ H_2$)
$H_{2b}C_y$	=	Quantity of blue hydrogen consumed in the iron/steel production facility in year y during the project activity ($t\ H_2/\ t_{steel,iron}$)
$EF_{H2b,y}$	=	Emission factor of blue hydrogen in year y ($t\ CO_2e/t\ H_2$)
$PE_{Seepage,y}$	=	Project emissions from seepage in year y (tCO_2/yr)

$PE_{Seepage,y}$ is calculated and monitored according to the *Methodology for determining emission reductions resulting from CCS/CCUS activities* of the Saudi GHG Crediting and Offsetting Mechanism.

The emission factor of one ton of green hydrogen is calculated as follows:

$$EF_{H2g,y} = \frac{EC_{H2g,\mathrm{grid},y} \times EF_{grid,y} \times (1+TDL_y) + EC_{H2g,\mathrm{cp},y} \times EF_{\mathrm{H2g,cp},y}}{P_{H2g,y}} \quad (13)$$

Where:

$EC_{H2g,\mathrm{grid},y}$	=	Quantity of electricity consumed from the grid by the green hydrogen production plant in year y (MWh/yr)
TDL_y	=	Average technical transmission and distribution losses for providing electricity to the hydrogen production facility in year y
$EC_{H2g,cp,y}$	=	Quantity of electricity consumed from the captive power plant by the green hydrogen production plant in year y (MWh/yr)
$EF_{H2g,cp,y}$	=	Emission factor of the captive power plant for the production of one ton of green hydrogen (t CO_2e/MWh)
$P_{H2g,y}$	=	Quantity of green hydrogen produced in year y (t H_2/yr)

For the determination of $EF_{H2,CP,y}$ refer to the formulas in section 7 step 3 and use

- $EF_{H2g,cp,y}$ instead of $EF_{cp,y}$
- $FC_{H2g,cp,y,i}$ instead of $FC_{cp,y,i}$
- $EG_{H2g,y}$ instead of EG_y

Where:

$FC_{H2g,cp,y,i}$	=	Quantity of fossil fuel type *i* fired in the captive power plant connected to the green hydrogen production in year y (mass unit/yr)
$EG_{H2g,y}$	=	Quantity of electricity generated in the captive power plant connected to the green hydrogen production plant in the year y (MWh/yr)

The emission factor of one ton of blue hydrogen is calculated as follows:

$$EF_{H2b,y} = \frac{EC_{H2b,\mathrm{grid},y} \times EF_{grid,y} \times (1+TDL_y) + EC_{H2b,\mathrm{cp},y} \times EF_{\mathrm{H2b,cp},y} + FC_{H2b,i,y} \times COEF_{i,y}}{P_{H2b,y}} - CC_{H2b} \quad (14)$$

Where:

$EC_{H2b,\mathrm{grid},y}$	=	Quantity of electricity consumed from the grid for blue hydrogen production in year y (MWh/yr)
TDL_y	=	Average technical transmission and distribution losses for providing electricity to the hydrogen production in year y
$EC_{H2b,cp,y}$	=	Quantity of electricity consumed from the captive power plant for blue hydrogen production in year y (MWh/yr)
$EF_{H2b,cp,y}$	=	Emission factor of the captive power plant for producing one ton of blue hydrogen (t CO_2e/MWh)
$P_{H2b,y}$	=	Quantity of blue hydrogen produced in year y (t H_2/yr)
$FC_{H2b,i,y}$	=	Quantity of fossil fuel type *i* used in the blue hydrogen production in year y (mass unit/yr)

$CC_{H2b,y}$	=	Quantity of carbon captured and permanently stored in year y (t CO_2/yr). Please refer to latest version of the "Methodology for determining emission reductions resulting from CCS/CCUS activities" for determining $CC_{H2b,y}$.

For the determination of $EF_{H2b,CP,y}$ refer to the formulas in section 7 step 3 and use

- $EF_{H2b,cp,y}$ instead of $EF_{cp,y}$
- $FC_{H2b,cp,i,y}$ instead of $FC_{cp,i,y}$
- $EG_{H2b,y}$ instead of EG_y

Where:

$FC_{H2b,cp,i,y}$	=	Quantity of fossil fuel type *i* fired in the captive power plant connected to the blue hydrogen production in year y (mass unit/yr)
$EG_{H2b,y}$	=	Quantity of electricity generated in the captive power plant connected to the blue hydrogen production plant in the year y (MWh/yr)

9. Calculation of leakage emissions

Following latest research (Derwent, 2018; Paulot et al., 2021; Field and Derwent, 2021), hydrogen is considered an indirect greenhouse gas. While the short-term global warming potential (GWP) is even higher due to the short half-life period of hydrogen, the commonly used 100-yr GWP of hydrogen is 5 and needs to be considered for leakage emissions.

Leakage emissions strongly depend on the technical design of hydrogen production, processing, transport and storage – and therefore needs to be estimated project-specifically. As stated in section 6 (project boundary), emissions from processing of hydrogen and transport to the steel plant are excluded for simplicity reasons. Hence, leakage only needs to be considered for handling of hydrogen on the iron/steel plant.

$$LE_{H2,y} = H_2C_y \times LR_{H2,y} \quad (15)$$

Where:

$LE_{H2,y}$	=	Leakage emissions from the leakage of hydrogen onsite of the iron/steel plant (t CO_2e/yr)
$LR_{H2,y}$	=	Sum of all hydrogen leakage rates along the hydrogen supply chain including leakages in production, processing, transport and utilization in year y (%)

10. Securing sustainability

In order to generate emission reduction credits under the Saudi GHG Crediting and Offsetting Mechanism, the project must not be economically attractive so that it would be implemented also without generation of emission reduction credits. Project proponents need to demonstrate this in a reasonable manner to the Saudi DNA.

Therefore, the CDM Tool 01: "Tool for the demonstration and assessment of additionality" Ver.7[9] can be used as a guideline.

11. Monitoring plan

Project proponents need to elaborate a comprehensive monitoring plan, describing in detail how all technical parameters will be monitored (*Where? How? How frequent?*). This applies to all parameters listed in Equations (1) – (15)

1. The CO_2e-emission intensity of the iron and steel production before and after the retrofitting, in order to include hydrogen in the production process, must be measured based on internationally approved standards or national standards.
2. The following parameters should be monitored and recorded before the period of crediting:

Variable (unit)	Description	Monitoring/accounting concept
$FC_{BL,i,x}$ (mass unit/yr)	Quantity of fossil fuel type *i* used in the iron/steel production facility prior to the project activity in year x	Shall be accounted and determined before crediting period
$EC_{BL,grid,x}$ (MWh/yr)	Quantity of electricity consumed from the grid in the iron/steel production facility prior to the project activity in year x	Shall be accounted and determined before crediting period
$EC_{BL,cp,x}$ (MWh/yr)	Quantity of electricity consumed in the iron/steel production facility from the captive power plant (if applicable) prior to the project activity in year x	Shall be accounted and determined before crediting period
$P_{x\ (steel,iron)}$ ($t_{steel,iron}$/yr):	Annual iron/steel production prior the project activity in year x	Shall be determined and accounted before crediting period

3. The following parameters should be monitored and recorded during the period of crediting:

Variable (unit)	Description	Monitoring/accounting concept
P_y ($t_{steel,iron}$/yr)	Overall production in tons of iron/steel during the project activity in year y	Shall be determined on a regular basis and be crosschecked with an annual balance that is based on sold quantities and stock changes

[9] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v7.0.0.pdf

Variable (unit)	Description	Monitoring/accounting concept
$FC_{P,i,y}$ (mass unit/yr)	Quantity of fuel type *i* used in the iron/steel production facility during the project activity in year y	Shall be determined by onsite measurements on a regular basis and crosschecked with an annual energy balance that is based on purchased quantities and stock changes.
$EC_{P,\mathrm{grid},y}$ (MWh/yr)	The quantity of electricity consumed from the grid in the iron/steel production facility during the project activity	Shall be continuously measured by onsite meters and be crosschecked with annual energy bills
$EC_{P,cp,y}$ (MWh/yr)	The quantity of electricity consumed from the captive power plant in the iron/steel production facility during the project activity	Shall be continuously measured with meters
$FC_{cp,i,y}$ (mass unit per year)	Quantity of fossil fuel type i fired in the captive power plant connected to the iron/steel production facility in year y	Shall be monitored via volume or mass meters, and crosschecked with an annual energy balance that is based on purchased quantities and stock changes
EG_y (MWh/yr)	Quantity of electricity generated in captive power plant connected to the iron/steel production facility in year y	Shall be continuously measured on-site via meters
$COEF_{i,y}$ (t CO_2e/mass unit)	CO_2 emission coefficient of fossil fuel type *i* in year y	Shall be reported on an annual basis
$NCV_{i,y}$ (GJ/mass unit)	the average net calorific value of fossil fuel type *i* in year y	Shall be recovered from values provided by the fuel manufacturer, measurements made by the project participants, regional or national default values, or IPPC default values at the upper or lower limit (the most conservative option)
$EF_{grid,y}$ (tCO_2e/MWh)	The emission factor from grid electricity during the project activity in year y	Shall be reported on an annual basis
H_2C_y (t H_2/yr)	Quantity of hydrogen consumed in the iron/steel production facility in year y	Shall be continuously monitored via volume or mass meters
$P_{H2g/b,y}$ (t H_2/yr)	Quantity of green/blue hydrogen produced in the hydrogen production plant	Shall be continuously measured onsite via volume or mass meters
$FC_{H2g/b,cp,i,y}$ (mass unit per year)	Quantity of fossil fuel type *i* fired in the captive	Shall be monitored via volume or mass meters, and crosschecked with an annual

Variable (unit)	Description	Monitoring/accounting concept
	power plant connected to the green/blue hydrogen production during the project activity in year y	energy balance that is based on purchased quantities and stock changes
$EG_{H2g/b,y}$ (MWh/yr)	Quantity of electricity that is generated in the captive power plant connected to the green/blue hydrogen production during the project activity in year y	Shall be continuously monitored by onsite measurements
$FC_{H2b,i,y}$ (mass unit per year)	Quantity of fossil fuel type *i* used in the blue hydrogen production during the project activity in year y	Shall be monitored via volume or mass meters
$CC_{H2b,y}$ (t CO_2/yr)	Quantity of carbon captured and permanently stored by the blue hydrogen production in year y	Shall be continuously monitored by onsite measurements
$PE_{Seepage,y}$ (tCO2/yr)	Project emissions from seepage in year y	Shall be monitored according to the *Methodology for determining emission reductions resulting from CCS/CCUS activities* of the Saudi GHG Crediting and Offsetting Mechanism
$LR_{H2,y}$ (%)	The hydrogen leakage rate is the sum of all leakages along the hydrogen supply chain	Shall be calculated by adding up the continuously measured leakage rates of each step of the hydrogen supply chain or (in case this not possible) the default values in section 8 shall be applied