विद्युत मंत्रालय
MINISTRY OF
POWER

सत्यमेव जयते

Ministry of Environment, Forest and Climate Change

METHODOLOGY

BM IN02.002

Hydrogen production using methane extracted from biogas

INDIAN Carbon MARKET

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Version 1.0

Sectoral scope(s): Industries

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1. Introduction

1. This methodology is adopted and refers to the latest approved version of the UNFCCC Clean Development Mechanism Methodology AMS-III.O (as valid from 24 July 2015).

2. It shall be the responsibility of the non-obligated entity and Accredited Carbon Verification Agency (ACVA) to note of any subsequent changes or revisions in the above-mentioned methodology while developing projects and performing validation and/or verification activity respectively.

3. The following table describes the key elements of the methodology:

Table 1. Methodology key elements

Typical project(s)	Installation of biogas purification system to isolate methane from biogas for the production of hydrogen displacing LPG as both feedstock and fuel in a hydrogen production unit.
Type of GHG emissions mitigation action	Fuel and feedstock switch: Fuel and feed stock switch to reduce consumption of fossil fuel

2. Scope & Applicability

2.1. Scope

4. The methodology comprises of installation of biogas purification system to isolate methane from biogas to produce hydrogen.

2.2. Applicability

5. The project activity installs

   (a) A biogas purification system to isolate methane from biogas, which is being flared in the baseline situation for the production of hydrogen displacing liquefied petroleum gas (LPG) as both feedstock and fuel in a hydrogen production unit; or

   (b) A biogas purification system in combination with installation of new measures that recover methane from biogenic organic matter from wastewater treatment plants or landfills, using technologies/measures covered in BM WA03.001.

6. Emission reductions resulting from the installation of methane recovery system shall be calculated as per BM WA03.001.

7. There is no diversion of biogas that is already being used for thermal or electrical energy generation or utilized in any other (chemical) process in the baseline.

8. The project activity complies with all local regulations including all safety related measures.

9. This methodology is not applicable to technologies displacing the production of hydrogen from electrolysis.

2.3. Methodology Approval Date

10. The date of adoption of this document shall be effective from 27 March 2025.

2.4. Applicability of sectoral scopes

11. For validation and verification of ICM projects and programme of activities by a designated ACVA using this methodology, application of sectoral scope "*02: Industries*" is mandatory.

2.5. Applicability of approved adopted tools

12. This methodology also refers to the latest approved versions of the following adopted ICM tools:

(a) "BM-T-001: Combined tool to identify the baseline scenario and demonstrate additionality" (hereinafter referred to as BM-T-001);

(b) "BM-T-002: Tool to calculate project or leakage CO2 emissions from fossil fuel combustion" (hereinafter referred to as BM-T-002);

(c) "BM-T-003: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation" (hereinafter referred to as BM-T-003);

3. Methodology: Baseline Component

3.1. Project boundary

13. The project boundary is the physical, geographical sites where methane is captured, extracted and hydrogen is produced from biogas and LPG. The boundary also extends to other equipment consuming biogas or methane in the same site where applicable.

3.2. Additionality

14. The additionality for the project activity shall be determined in accordance with BM-T-001.

3.3. Baseline

15. The baseline emissions are calculated as the summation of the following:

(a) CO_2 generated in reactions of LPG (displaced by methane extracted from biogas in the project scenario) as feedstock during the steam-reforming/shift-reaction;

(b) CO_2 generated in the combustion process of LPG (displaced by methane extracted from biogas in the project scenario) as fuel to the reactors.

16. The composition of LPG for the purpose of baseline emission calculations shall be determined based on the composition analysis of stand-by LPG[1] stock. This shall be based on:

    (a) Information provided by the supplier; or

    (b) Compositional analysis conducted by an independent certified laboratory; or

    (c) Product specification statement provided by the national gas supplier of the host-country.

17. The CO_2 emissions generated in reactions of LPG during the steam-reforming/shift-reaction is determined by calculating the CO_2 generation potential per mol of hydrogen produced from the baseline feedstock LPG ($R_{CO2/H2}$) and the molar quantity of hydrogen produced using methane extracted from biogas as feedstock. The $R_{CO2/H2}$ ratio is calculated through analysis of the steam-reforming/shift-reactions specified in paragraph 18, involving the individual molecules contained in LPG (typically propane and butane).

$$BE_{LPG\_FEED} = R_{CO2/H2} \times m_{H2,BIO} \times MW_{CO2} \times C_1 \qquad \text{Equation (1)}$$

Where:

BE_{LPG_FEED}	=	Annual baseline CO_2 emissions from the displaced LPG feedstock in the hydrogen production unit (t CO_2e)
$R_{CO2/H2}$	=	CO_2 generation potential per mol of hydrogen produced with LPG as feedstock as defined in paragraph 25 (kmol-CO_2/kmol-H_2)
$m_{H2,BIO}$	=	Molar quantity of hydrogen produced annually from methane extracted from biogas as defined in paragraph 29 (kmol-H_2)
MW_{CO2}	=	Molecular weight of CO_2 (44 kg/kmol)
C_1	=	Conversion factor kilograms to tonnes (0.001)

18. The generic steam reforming reaction is:

$$C_n H_m + nH_2O \leftrightarrow nCO + \left(\frac{m}{2} + n\right) H_2 \qquad \text{Equation (2)}$$

19. The generic shift reaction is:

$$nCO + nH_2O \leftrightarrow nCO_2 + nH_2 \qquad \text{Equation (3)}$$

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[1] Stand-by LPG is essential for process reliability. Standby LPG is the LPG stock stored by the operator to cover situations where biogas is not available in sufficient amount or production of hydrogen from biogas has halted for some reasons. For example in prolonged dry season wastewater treatment facility treating wastewaters such as palm oil mill effluent may not be operating in full capacity and therefore producing less biogas. Other possibilities include temporary non-availability of H2S removal system due to maintenance/ repair.

20. The net reaction from the above reactions is the sum of the above equations (2) and (3):

$$C_nH_m + 2nH_2O \leftrightarrow nCO_2 + \left(\frac{m}{2} + 2n\right)H_2$$ Equation (4)

21. Based on stoichiometric rules:

(a) 1 mol of C_nH_m and 2n mol of H_2O produce n mol of CO_2 and ((m/2)+2n)) mol of H_2;

(b) For example: 1 mol of propane gas (C_3H_8) and 6 mol of H_2O reacts to 3 mol of CO_2 and 10 mol of H_2.

22. For LPG containing m_1 mol of propane and m_2 mol of butane, the reactions are summarized as follow:

Table 2. LPG reactions during hydrogen production

Source Gas	Reaction Type	Ref. Eq.	Reaction
Propane	Steam Reforming	(A)	$C_3H_8 + 3H_2O \leftrightarrow 3CO + 7H_2$
	Shift-Conversion	(B)	$3CO + 3H_2O \leftrightarrow 3CO_2 + 3H_2$
	Sub-total	(C)=(A)+(B)	$C_3H_8 + 6H_2O \leftrightarrow 3CO_2 + 10H_2$
Butane	Steam Reforming	(D)	$C_4H_{10} + 4H_2O \leftrightarrow 4CO + 9H_2$
	Shift-Conversion	(E)	$4CO + 4H_2O \leftrightarrow 4CO_2 + 4H_2$
	Sub-total	(F)=(D)+(E)	$C_4H_{10} + 8H_2O \leftrightarrow 4CO_2 + 13H_2$

23. For 100 mol of LPG mixture containing m_1 mol of propane and m_2 mol of butane, the reactions are:

Table 3. Reactions during hydrogen production from 100 mol of LPG

Source Gas	Composition in 100 mol	Ref. Reaction from	Reactions
Propane	m_1	(C)	$[m_1]C_3H_8 + [6m_1]H_2O \leftrightarrow [3m_1]CO_2 + [10m_1]H_2$
Butane	m_2	(F)	$[m_2]C_4H_{10} + [8m_2]H_2O \leftrightarrow [4m_2]CO_2 + [13m_2]H_2$
Total	$m_1 + m_2$	(G)	As $100molLPG = [m_1]C_3H_8 + [m_2]C_4H_{10}$, (1) + (2) is $100molLPG + [6m_1 + 8m_2]H_2O \leftrightarrow [3m_1 + 4m_2]CO_2 + [10m_1 + 13$

24. Based on reaction G in Table 3, the *hydrogen production potential per mol of LPG* is defined as:

$$R_{H2/LPG} = \frac{\lfloor 10m_1 + 13m_2 \rfloor}{100}$$ Equation (5)

25. Based on reaction G in Table 3, the *CO_2 generation potential per mol of hydrogen produced* is defined as:

$$R_{CO2/H2} = \frac{\lfloor 3m_1 + 4m_2 \rfloor}{[10m_1 + 13m_2]}$$ Equation (6)

26. The CO_2 emissions from LPG combusted, as fuel in the reactors in the baseline (displaced by methane extracted from biogas in the project scenario) shall be calculated based on:

(a) The specific fuel consumption of the hydrogen production unit using LPG as fuel as described under monitoring methodology; and

(b) The amount of hydrogen produced using methane extracted from biogas as fuel as calculated in paragraphs 26 and 27.

$$BE_{LPG\_FUEL} = SFC_{LPG} \times V_{H2,BIO} \times EF_{LPG} \times C_2$$ Equation (7)

Where:

BE_{LPG_FUEL}	=	Annual baseline CO_2 emission from LPG used as fuel in the reactors that is displaced by methane extracted from biogas in the project scenario (t CO_2e)
SFC_{LPG}	=	Specific fuel consumption of the hydrogen production unit using LPG as fuel (kg-LPG/Nm^3-H_2)
$V_{H2,BIO}$	=	Volume of hydrogen produced from methane extracted from biogas under normal condition. (Nm^3-H_2) annually as defined in paragraphs 30 and 31
EF_{LPG}	=	Emission factor of LPG (kg-CO_2/kg LPG)
C_2	=	Conversion factor kilograms to tones (0.001)

27. The molar amount of hydrogen produced from methane extracted from biogas ($m_{H2,BIO}$) is calculated as the difference between the total molar amount of hydrogen produced ($m_{H2,T}$) and the molar amount of hydrogen produced from the stand-by LPG ($m_{H2,LPG}$).

$$m_{H2,BIO} = m_{H2,T} - m_{H2,LPG}$$ Equation (8)

Where:

$m_{H2,BIO}$	=	Molar amount of hydrogen produced from methane extracted from biogas annually (kmol-H_2)
$m_{H2,T}$	=	Total molar amount of hydrogen produced annually. This parameter shall be based on monitoring of volume of hydrogen produced by the hydrogen production unit. If the volume is reported as normal volume, the equivalent molar amount can be calculated using ideal gas relationship described in paragraph 31 (kmol-H_2)

$m_{H2,LPG}$	=	Molar amount of hydrogen produced from LPG annually as calculated in paragraph 30 (kmol-H_2)

28. The molar amount of hydrogen produced from LPG ($m_{H2,LPG}$) should be calculated through monitored amount of LPG used as feedstock to the reaction (M_{LPG}) multiplied by the hydrogen production potential calculated in equation (5).

$$m_{H2,LPG} = R_{H2/LPG} \times \frac{M_{LPG}}{MW_{LPG}}$$

Equation (9)

$$MW_{LPG} = m_1 \times MW_{C3H8} + m_2 \times MW_{C4H10}$$

Equation (10)

Where:

$m_{H2,LPG}$	=	Molar amount of hydrogen produced from LPG annually (kmol-H_2)
$R_{H2/LPG}$	=	Hydrogen production potential as define in equation (5) (kmol H_2/kmol-LPG)
M_{LPG}	=	Mass of LPG used as reaction feedstock annually (kg-LPG)
MW_{LPG}	=	Molecular weight of LPG (kg-LPG/kmol-LPG)
m_1	=	% mol of propane in LPG (mol/mol)
MW_{C3H8}	=	Molecular weight of propane (44 kg/kmol)
m_2	=	% mol of butane in LPG (mol/mol)
MW_{C4H10}	=	Molecular weight of butane (66 kg/kmol)

29. The amount of molecules per volume of low-pressure gas is defined by '*ideal gas*' relationship shown in equation (11). Using this relationship, a molar amount of hydrogen can be converted into its equivalent volume of low-pressure gas or vice-versa.

$$P_N.V_N = m_{H2}.R.T_N.C_3$$

Equation (11)

Where:

$V_{N,H2}$	=	Normalized volume of hydrogen produced annually (Nm^3)
P_N	=	Pressure in Pascal at normal condition (Pa)
T_N	=	Temperature in Kelvin at normal condition (273 K)
R	=	Gas constant in SI Unit (8.314 $Pa.m^3.mol^{-1}.K^{-1}$)
C_3	=	Conversion factor kmol to mol (1000)

m_{H2}	=	Molar amount of hydrogen produced (kmol)

3.4. Project Emissions

30. The project emissions are calculated as the summation of the emissions from fossil fuels and/or electricity used, unless it is demonstrated that electricity/steam used is generated from renewable energy sources with no possibility for emissions:

    (a) The emissions from fossil fuels and/or electricity used to generate steam for the purpose of regeneration of the biogas purification system for operating the biogas purification system calculated in accordance with the methods specified in BM-T-002 and BM-T-003

31. If additional chemicals or energy is used to regenerate the adsorbent or absorbent for purpose of biogas purification, contribution of the used chemicals to GHG emissions during the lifecycle shall be taken into account, if not already included in paragraph 32.

3.5. Leakage

32. If the project equipment is transferred from another activity, or if the displaced equipment is transferred to another activity, such that emissions increase in the other facility on account of a new equipment and the use of energy/fuel, leakage is to be considered.

3.6. Emission reductions

33. The emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y - LE_y \quad \text{Equation (12)}$$

Where:

ER_y	=	Emission reductions in the year *y* (t CO_2e)
PE_y	=	Project activity emissions in year *y* (t CO_2e)
LE_y	=	Leakage in year *y* (t CO_2e)

4. Methodology: Monitoring Component

4.1. Data and Parameters not monitored

Data / Parameter table 1.

Data / Parameter:	***EF_{LPG}***
Data unit:	kg-CO_2/kg LPG
Description:	Emission factor of LPG
Source of data:	-

Measurement procedures (if any):	The emission factor is based on; (a) evaluation of carbon content of LPG or (b) IPCC default value
Any comment:	-

Data / Parameter table 2.

Data / Parameter:	***SFC_{LPG}***
Data unit:	kg-LPG/Nm^3-H_2
Description:	Specific fuel consumption of baseline process
Source of data:	-
Measurement procedures (if any):	Specific fuel consumption of LPG is should be based on one of the following options: (a) Measurements during crediting period when the hydrogen plant is operated with LPG as fuel; (b) Minimum 1 year historical data; (c) Manufacturer's specification.
Any comment:	Option (b) and (c) can only be used if (a) is not the case, i.e. LPG is not used as a fuel during the crediting period.

4.2. Data and Parameters monitored

34. The non-obligated entities shall maintain a biogas (or methane) balance based on:

(a) Continuous measurement of biogas produced by the waste water, treatment system, landfill gas capture system or other process producing biogas; and

(b) Continuous measurement of biogas used for various purposes in the project activity: e.g. heat, electricity, flare, and hydrogen production. The difference is considered as loss due to physical leakage and deducted from the emission reductions. The method of monitoring should follow the provisions specified in either BM WA03.001 or provisions of the "Project emissions from flaring" in the event of flaring (where applicable).

Data / Parameter table 3.

Data / Parameter:	***V_{H2BIO}***
Data unit:	Nm^3-H_2
Description:	Volume of hydrogen produced from methane extracted from biogas under normal condition
Source of data:	-
Measurement procedures (if any):	Continuous metering of on volumetric basis
Any comment:	-

Data / Parameter table 4.

Data / Parameter:	M_{LPG}
Data unit:	kg-LPG
Description:	LPG used as feedstock to hydrogen production unit
Source of data:	-
Measurement procedures (if any):	Continuous metering
Any comment:	-

Data / Parameter table 5.

Data / Parameter:	m_1
Data unit:	*%*
Description:	*% mol of Propane in LPG*
Source of data:	-
Measurement procedures (if any):	LPG molar composition analysis performed every quarter
Any comment:	

Data / Parameter table 6.

Data / Parameter:	m_2
Data unit:	*%*
Description:	*% mol of butane in LPG*
Source of data:	-
Measurement procedures (if any):	LPG molar composition analysis performed every quarter
Any comment:	-

Data / Parameter table 7.

Data / Parameter:	PE_{Elec}
Data unit:	tCO_2/year
Description:	Project emissions from electricity consumption in year y
Source of data:	As per BM-T-003
Measurement procedures (if any):	As per BM-T-003
Any comment:	-

Data / Parameter table 8.

Data / Parameter:	PE_{FF}
Data unit:	tCO_2/year
Description:	Project emissions from fossil fuel consumption in year y

Source of data:	As per BM-T-002
Measurement procedures (if any):	As per BM-T-002
Any comment:	-

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Revision/Changes in the Document

Version	*Date*	*Description*
1.0	27 March 2025	Initial Adoption