Indicative simplified baseline and monitoring methodologies
for selected small-scale CDM project activity categories

TYPE III - OTHER PROJECT ACTIVITIES

Project participants shall take into account the general guidance to the methodologies, information on additionality, abbreviations and general guidance on leakage provided at http://cdm.unfccc.int/methodologies/SSCmethodologies/approved.html.

III.O. Hydrogen production using methane extracted from biogas

Technology/measure

1. This methodology is applicable to project activities that install a 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. Examples of project activities covered under this methodology are installation of a biogas purification system to isolate methane from biogas which is being flared in the baseline situation or installation of a biogas purification system in combination with installation of new measures that recover methane from biogenic organic matter from waste water treatment plants or landfills, using technologies/measures covered in AMS III.H. or AMS III.G. Emission reductions resulting from the installation of methane recovery system shall be calculated as per AMS III.H. or AMS III.G.

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

3. The methodology is only applicable if it can be ensured that 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.

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

5. Measures are limited to those that result in aggregate emission reductions of less than or equal to 60,000 tCO_2 equivalent annually from all type III components.

Boundary

6. 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.

Baseline

7. 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.

8. 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.

9. 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 10, involving the individual molecules contained in LPG (typically propane and butane).

$$BE_{LPG\_FEED} = R_{CO2/H2} \times m_{H2,BIO} \times MW_{CO2} \times C_1 \tag{1}$$

Where:

BE_{LPG_FEED}	Annual baseline CO_2 emissions from the displaced LPG feedstock in the hydrogen production unit (tCO_2e)
$R_{CO2/H2}$	CO_2 generation potential per mol of hydrogen produced with LPG as feedstock as defined in paragraph 13 (kmol-CO_2/kmol-H_2)
$m_{H2,BIO}$	Molar quantity of hydrogen produced annually from methane extracted from biogas as defined in paragraph 16 (kmol-H_2)
MW_{CO2}	Molecular weight of CO_2 (44 kg/kmol)
C_1	Conversion factor kilograms to tonnes (0.001)

10. The generic steam reforming reaction is:

$$C_n\mathrm{H}_m + \mathrm{nH_2O} \leftrightarrow \mathrm{nCO} + \left(\frac{\mathrm{m}}{2} + n\right)H_2 \tag{2}$$

The generic shift reaction is:

$$nCO + \mathrm{nH_2O} \leftrightarrow \mathrm{nCO_2} + \mathrm{n}H_2 \tag{3}$$

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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 H_2S removal system due to maintenance/ repair.

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

$$C_n\mathrm{H}_m + 2n\mathrm{H}_2\mathrm{O} \leftrightarrow n\mathrm{CO}_2 + \left(\frac{m}{2} + 2n\right)H_2 \qquad \textbf{(4)}$$

Based on stoichiometric rules:

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.

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.

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

Table III.O-1 – 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)	$C_4H_{10} + 8H_2O \leftrightarrow 4CO_2 + 13H_2$

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

Table III.O-2 – 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 $100molLPG + [6m_1 + 8m_2]H_2O \leftrightarrow [3m_1 + 4m_2]CO_2 + [10m_1 + 13m_2]H_2$

12. Based on reaction G in Table III.O-2, the *hydrogen production potential per mol of LPG* is defined as:

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

13. Based on reaction G in Table III.O-2, the *CO_2 generation potential per mol of hydrogen produced* is defined as:

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

14. 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 in paragraph 15; and

(b) The amount of hydrogen produced using methane extracted from biogas as fuel as calculated in paragraph 16 and 17.

$$BE_{LPG\_FUEL} = SFC_{LPG} \times V_{H2,BIO} \times EF_{LPG} \times C_3 \qquad \textbf{(7)}$$

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 (tCO_2e).
SFC_{LPG}	Specific fuel consumption of the hydrogen production unit using LPG as fuel (kg-LPG/Nm^3-H_2) as defined in paragraph 15.
$V_{H2,BIO}$	Volume of hydrogen produced from methane extracted from biogas under normal condition. (Nm^3-H_2) annually as defined in paragraph 17 and 18.
EF_{LPG}	Emission factor of LPG based on (a) evaluation of carbon content of LPG or (b) IPCC default value (kg-CO_2/kg LPG)
C_3	Conversion factor kilograms to tones (0.001)

15. The specific fuel consumption of baseline process (SFC_{LPG}) refers to the fuel consumption per normal volume H_2 produced if LPG is used as fuel for the hydrogen production process. This 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.

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.

16. 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 ($m_{H2,LPG}$)

$$m_{H2,BIO} = m_{H2,T} - m_{H2,LPG} \qquad \textbf{(8)}$$

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 18 (kmol-H_2)
$m_{H2,LPG}$	Molar amount of hydrogen produced from LPG annually as calculated in paragraph 17 (kmol-H_2).

17. 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 formula (5).

$$m_{H2,LPG} = R_{H2/LPG} \times \frac{M_{LPG}}{MW_{LPG}} \qquad \textbf{(9)}$$

$$MW_{LPG} = m_1 \times MW_{C3H8} + m_2 \times MW_{C4H10} \qquad \textbf{(10)}$$

Where:

$m_{H2,LPG}$	Molar amount of hydrogen produced from LPG annually (kmol-H_2)
$R_{H2/LPG}$	Hydrogen production potential as define in formula (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)

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

$$P_N.V_N = m_{H2}.R.T_N.C_2 \tag{11}$$

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_2	Conversion factor kmol to mol (1000)
m_{H2}	Molar amount of hydrogen produced (kmol)

Project Activity Emissions

19. The project activity emissions are calculated as the summation of the following 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 for operating the biogas purification system calculated in accordance with the methods specified in AMS I.D, and

(b) Emissions from fossil fuels used to generate steam for the purpose of regeneration of the biogas purification system calculated in accordance with the 'Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion'.

20. 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 19.

Leakage

21. If the project equipment is transferred from another activity, or if the displaced equipment is transferred to another activity, leakage is to be considered.

Monitoring

22. Monitoring shall consists of:

(a) Continuous metering of hydrogen produced by the project activity on volumetric basis;

(b) Continuous metering of LPG used as feedstock to hydrogen production unit;

(c) LPG molar composition analysis performed every quarter;

(d) Continuous monitoring of specific fuel consumption of LPG when biogas is not available in sufficient quantity;

(e) Continuous measurement of electricity and fuel used by the biogas purification system.

23. The project proponents 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 AMS-III.H, or AMS III.G. or provisions of the “Tool to determine project emissions from flaring gases containing methane“ in the event of flaring (where applicable).

24. The emission reduction achieved by the project activity shall be calculated as the difference between the baseline emissions and the sum of the project emissions and leakage.

$$ERy = BEy - PEy - Leakage \quad \textbf{(12)}$$

Where:

ERy Emission reductions in the year “y” (tCO_2 e)

PEy Project activity emissions in year “y” (tCO_2 e)

Leakage Leakage in year “y” (tCO_2 e)

Project activity under a programme of activities

25. It is not envisaged this category will be applied to a project activity under a Programme of Activities.

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History of the document

Version	**Date**	**Nature of revision**
01	EB35, Annex 24 19 October 2007	Initial adoption