VCS Methodology

VM0040

Methodology for Greenhouse Gas Capture and Utilization in Plastic Materials

Version 1.0

23 July 2019

Sectoral Scope 3

This methodology was developed by:

Newlight Technologies

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1 SOURCES

This methodology was informed primarily by CDM methodology AMS-III.BA, *Recovery and recycling of materials from E-Waste*, particularly the principle of using recycled materials to displace virgin materials production.

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

This methodology is globally applicable to project activities that convert carbon dioxide and/or methane, which would have otherwise been emitted into the atmosphere, into a useful plastic material for sale into the plastics market. Such project activities reduce greenhouse gas emissions in two ways. First, project activities sequester carbon dioxide and/or methane into plastic material. Second, the process for manufacturing plastic material from sequestered carbon dioxide and/or methane can be less emission-intensive than the traditional process for manufacturing plastic material.

Additionality and Crediting Method	
Additionality	Activity Method
Crediting Baseline	Project Method

3 DEFINITIONS

In addition to the definitions set out in VCS document *Program Definitions*, the following definitions apply to this methodology:

Additives
Materials that are added in the middle of the production process to provide certain qualities or attributes to the final product. The incorporation of additives must be considered and accounted for when quantifying the total amount of GHG feedstocks used in the final product.

Biodegradable
A material that will decompose in less than 100 years due to the activity of bacteria or other living organisms

DMM (Direct Measurement Method)
The direct measurement method is a method used to calculate the amount of GHGs sequestered into plastic materials. It uses volumetric or mass-flow meters to measure the GHG input as it enters the production process.

Feedstock
The greenhouse gases (i.e., CO_2 and/or CH_4) which are captured as part of project activities to be used along with other materials to produce plastic material

MFR (Molecular Formula Ratio)
The Molecular Formula Ratio is a method used to calculate the amount of GHGs sequestered into plastic materials. It refers to the stoichiometric ratio method, which calculates the quantity of GHGs sequestered based on the chemical formula and weight of the final plastic material.

Non-Qualifying CH_4
Methane which is part of the GHG feedstock, but which would have been captured and destroyed in the baseline scenario (e.g., via a landfill collection system)

Plastic Material
Resins or pelletized material that can be molded into useful products. These materials directly displace conventional plastics such as polypropylene (PP), polystyrene (PS), polyethylene (PE), thermoplastic urethane (TPU), acrylonitrile butadiene styrene (ABS), polycarbonate (PC) and polyethylene terephthalate (PET).

Qualifying CH_4
Methane which is part of the GHG feedstock that would have been emitted into the atmosphere in the baseline scenario

Thermopolymer
Also known as thermoplastic polymers, which form when repeating units called monomers link into chains or branches. Because they soften when heated, thermoplastic polymers are easy to mold into a variety of shapes.

Virgin plastic
Plastic material that is manufactured for the first time and used in products that the project activity would be displacing. Virgin plastic is typically made from petroleum-based materials.

4 APPLICABILITY CONDITIONS

This methodology is globally applicable to project activities that convert carbon dioxide and/or methane, which would have otherwise been emitted into the atmosphere, into a useful plastic material for sale into the plastics market.

Project activities must meet the following conditions:

1) Project activities must produce a useful plastic material through a carbon capture and utilization technology which converts CO_2 and/or CH_4 into a long-chain thermopolymer. Such plastic material must:
    a) Have an expected lifetime (period of non-degradation) of at least 100 years[1], or
    b) Be biodegradable. However, in such cases the project may only calculate emission reductions related to the displacement of virgin plastic, and must NOT account for the

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[1] Plastic materials produced by projects must permanently sequester carbon (i.e., sequester carbon for a period of at least 100 years) in order to claim emission reductions for the capture and sequestration of GHGs. Many plastic materials are well-known to have degradation times significantly greater than 100 years. Please refer to the following articles, which are cited in Section 10 of this methodology: Andrady (2003); Barnes et al. (2009); Browne et al. (2007); Thompson et al. (2004); Thompson et al. (2005).

capture and sequestration of GHGs, which would be re-released to the atmosphere in the case of biodegradable materials.

2) Project activities must produce a plastic material that will be used to produce useful plastic products that are sold in the commercial market.

3) Project activities must produce PHA (polyhydroxyalkanoates) directly from CO_2 or CH_4 through a process in which the resultant material displaces one of the following plastic materials:

   - Polypropylene (PP)
   - Polystyrene (PS)
   - Polyethylene (PE), including high-density and low-density polyethylene (HDPE, LDPE) and linear low-density polyethylene (LLDPE)
   - Thermoplastic urethane (TPU)
   - Acrylonitrile butadiene styrene (ABS)
   - Polycarbonate (PC)
   - Polyethylene terephthalate (PET)
   - Polyvinyl Chloride (PVC)

4) Project activities cannot combine CO_2 and CH_4 as feedstock to create a single plastic material.

5) Where CO_2 is used as a feedstock, it must be derived from a source that would have otherwise emitted it to the atmosphere (i.e., the CO_2 is not processed/produced specifically for this project activity) or it must be derived from direct air capture technology.

6) Where CH_4 is used as feedstock, the project proponent must demonstrate whether the CH_4 is qualifying or non-qualifying, as further defined in Section 8.3 below.

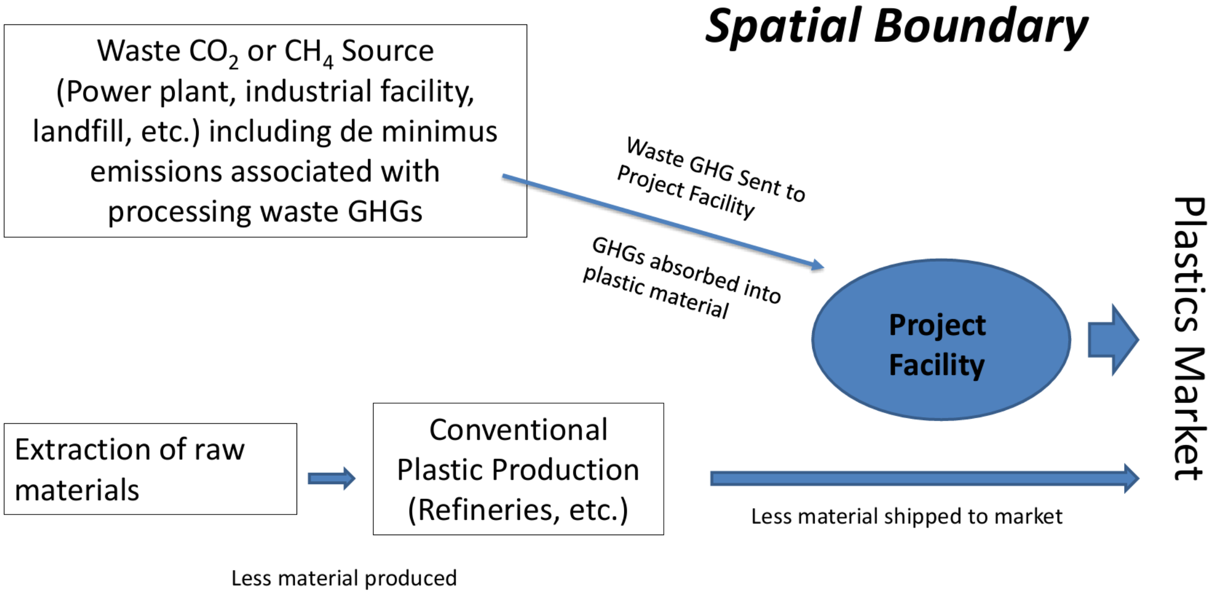
7) Where CH_4 is used as feedstock, the CH_4 used in the project activity cannot be displaced by a more carbon-intensive fuel, as demonstrated by meeting one or more of the conditions set out in Section 8.3 below.

5 PROJECT BOUNDARY

As illustrated below, the spatial extent of the project boundary encompasses:

- The project facility where plastic materials are produced;
- The facilities from which the GHG feedstock is sourced (if not direct air capture);
- The facilities where displaced conventional plastic material is manufactured.

Figure 1. Spatial Boundary of the Project Activity



The greenhouse gases included in or excluded from the project boundary are shown in Table 1 below.

Table 1: GHG Sources Included In or Excluded From the Project Boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Captured GHGs	CO_2	Optional	CO_2 is one of the main gases that can be captured by carbon capture and utilization technology. Note that some projects may use only CH_4 and not CO_2, in which case CO_2 may be excluded from the project boundary. Either CO_2 and/or CH_4 must be included within the project boundary.
		CH_4	Optional	CH_4 is one of the main gases that can be captured by carbon capture and utilization technology. Note that some projects may use only CO_2 and not CH_4, in which case CH_4 may be excluded from the project boundary. Either CO_2 and/or CH_4 must be included within the project boundary.
		N_2O	No	N_2O and any other GHGs are not gases that would be captured and utilized in plastic material with current technology.
		Other	No	N/A
	GHGs from displacement of traditional	CO_2	Yes	The use and combustion of fossil fuels is the primary source of emissions from the traditional process of manufacturing plastics,

Source		Gas	Included?	Justification/Explanation
	plastics production			including the refining of raw materials and process energy for production of plastics. See Appendix II for further detail. Note – transportation of plastic materials is not considered in either the baseline or project scenario because it is assumed that under either scenario, conventional plastics or GHG-captured plastics would require similar means of transport.
		CH_4	No	Excluded for simplicity
		N_2O	No	Excluded for simplicity
		Other	No	N/A
Project	GHGs from the project facility	CO_2	Yes	Use of electricity and combusted natural gas or liquid/solid fuels are the primary energy sources that would be used to power a facility capturing GHGs and manufacturing plastic material, and thus CO_2 would be the primary emission from that combustion.
		CH_4	No	Excluded for simplicity
		N_2O	No	Excluded for simplicity
		Other	No	Excluded for simplicity
	GHGs from burning of plastic material that previously captured and sequestered CO_2 and CH_4	CO_2	Yes	Incineration of plastic material, re-releasing CO_2 into the atmosphere
		CH_4	No	Excluded for simplicity
		N_2O	No	Excluded for simplicity
		Other	No	Excluded for simplicity
	Upstream emissions associated with processing waste GHGs	CO_2	No	Excluded since project upstream emissions are negligible compared to the baseline upstream emissions associated with traditional plastic production.
		CH_4	No	
		N_2O	No	
		Other	No	

6 BASELINE SCENARIO

The baseline scenario is the continuation of manufacturing plastic material through traditional processes (i.e., not through the use of GHG capture and utilization technology). This methodology uses a project method to determine the crediting baseline.

7 ADDITIONALITY

This methodology uses an activity method for the demonstration of additionality.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Standard*.

Step 2: Positive List

The applicability conditions of this methodology represent the positive list. The project must demonstrate that it meets all applicability conditions, and in so doing, it is deemed as complying with the positive list and as being additional.

The positive list was established using the activity penetration option (Option A in the *VCS Standard*). Justification for the activity method is provided in Appendix I.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

Emissions in the baseline scenario are comprised of two components. The first component is the emissions associated with traditional plastic materials production processes. The second component is the emissions from the GHG feedstock which would remain in the atmosphere or be released to the atmosphere in the absence of the project.

Component 1: Plastic production

Emissions associated with the production of virgin plastic through traditional processes that are displaced by the plastic material manufactured by the project must be accounted for in the baseline scenario. Appendix II provides default factors for GHG emissions per metric ton of virgin or new plastic (note that virgin plastic may have some recycled plastic as indicated in Appendix II, Table 3b) produced using traditional plastic production processes for different types of plastic materials. It may be assumed that for every metric ton of plastic material manufactured at a project facility, a metric ton of plastic material produced through traditional processes is displaced.

Component 2: GHG feedstock

Where the project captures CO_2 from flue gases to produce plastics, CO_2 emissions in the baseline scenario are simply those that would otherwise be released to the atmosphere.

Where the project uses CH_4 as feedstock for plastic production, the CH_4 may be derived from two types of sources:

1) **Non-qualifying CH_4:** Methane that comes from a landfill or other source where it is required to be flared or otherwise destroyed in the baseline scenario. Where non-qualifying CH_4 is captured as part of project activities, emissions in the baseline scenario must only be attributed to the CO_2 that is released as a result of the CH_4 flaring or destruction process.

2) **Qualifying CH_4:** Methane that comes from a source where it is not required to be flared or otherwise destroyed in the baseline scenario (e.g., a small landfill or biogas facility). Where qualifying CH_4 is captured as part of project activities, emissions in the baseline scenario are attributed to the release of such CH_4 to the atmosphere.

Baseline emissions in year *y* of the project crediting period (BE_y) is therefore expressed as follows:

$$BE_y = BE_{tp,y} + BE_{cg,y} \qquad (1)$$

Where:

BE_y = Baseline emissions in year y

$BE_{tp,y}$ = Baseline emissions from plastic material production via traditional manufacturing processes (tCO_2e) in time period *y*

$BE_{cg,y}$ = Baseline emissions from the GHG feedstock which would remain in, or be released to, the atmosphere in the absence of the project (tCO_2e) in time period *y*

Baseline emissions from plastic material production via traditional manufacturing processes is calculated as follows:

$$BE_{tp,y} = \sum_i (Q_{p,i,y} * EF_i) \qquad (2)$$

Where:

$BE_{tp,y}$ = Baseline emissions from plastic material production via traditional manufacturing processes (tCO_2e) in time period *y*

$Q_{p,i,y}$ = Net quantity of plastic type *i* produced by the project in year *y* (metric ton)

EF_i = Emission factor associated with the production of virgin plastic materials via traditional manufacturing processes (tCO_2e/metric ton of plastic for plastic type *i*)

The net quantity of plastic type *i* produced by the project in year *y* ($Q_{p,i,y}$) is calculated as follows:

$$Q_{p,i,y} = Q_{gross,i,y} - Q_{add,i,y} \qquad (3)$$

Where:

$Q_{p,i,y}$ = Net quantity of plastic type *i* produced by the project in year *y* (metric ton)

$Q_{gross,i,y}$ = Gross quantity of plastic type *i* produced by the project in year *y* (metric tons)

$Q_{add,i,y\ i}$ = Quantity (mass) of any additives or supplemental material that may be added to the plastic resin for plastic type *i* produced by the project in year *y* (metric tons)

Guidance regarding the calculation of EF_i is given in the parameter tables in Section 9.1 and further details for the calculation of the default values for EF_i can be found in Appendix II. Different types of plastic material have different emission factors, and therefore, where a project produces more than one type of plastic material, the emissions from each type of plastic material must be calculated separately, and then summed.

Baseline emissions from the GHG feedstock which would remain in, or be released to, the atmosphere in the absence of the project is calculated as follows:

$$BE_{cg,y} = Q_{CO2.seq,y} + Q_{CH4.ADJ,y} \quad (4)$$

Where :

$BE_{cg,y}$ = Baseline emissions from the sequestration of GHGs into plastic materials

$Q_{CO2,seq,y}$ = Amount of CO_2 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

$Q_{CH4,ADJ,y}$ = Adjusted amount of CH_4 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

Note – Where the plastic produced by the project activity is biodegradable, then it is assumed that all quantities of GHGs captured will eventually be released, in which case $BE_{cg,y} = 0$.

$Q_{CO2,seq,y}$ and $Q_{CH4,ADJ,y}$ must be determined using the molecular formula ratio (MFR), which determines the quantity of CO_2 or CH_4 captured, based on the molecular formula of the final plastic material. For each type of plastic *i*, the project proponent must provide the molecular formula, as well as the formula for the conversion from the GHGs which convert to the plastic material. An example of how to determine the MFR is provided in Appendix III.

Where CO_2 is used as a feedstock, the quantity of CO_2 sequestered is calculated as follows:

$$Q_{CO2.seq,y} = \sum_i \{[Q_{p,i,y} * (MW_C / MW_{p,i})] / RCM_{CO2}\} \quad (5)$$

Where:

$Q_{CO2,seq,y}$ = Amount of CO_2 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

$Q_{p,i,y}$ = Net quantity of plastic type *i* produced by the project in year *y* (metric ton)

MW_C = Molecular weight of the carbon in the plastic material *i* (g/mol)

$MW_{p,i}$ = Total molecular weight of the plastic material *i* (g/mol)

RCM_{CO2} = Fraction of carbon as part of the carbon dioxide molecule (% carbon in carbon dioxide by molar weight or 27.27%)

Where CH_4 is used as a feedstock, the quantity of CH_4 sequestered is calculated as follows:

$$Q_{CH4.seq,y} = \sum_i [Q_{p,i,y} * (MW_{C,CH4} / MW_{p,i})] / RCM_{CH4} \qquad (6)$$

Where:

$Q_{CH4,seq,y}$ = Amount of CH_4 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

$Q_{p,i,y}$ = Net quantity of plastic type *i* produced by the project in year *y* (metric ton)

$MW_{C,CH4}$ = Molecular weight of the total number of carbon molecules in the plastic material *i* (g/mol)

$MW_{p,i}$ = Total molecular weight of the plastic material *i* (g/mol)

RCM_{CH4} = Fraction of carbon as part of the methane molecule (% carbon in methane by molar weight, or 75%[2])

Where CH_4 is used as a feedstock, adjustments must be made because some of the CH_4 may be non-qualifying, as follows:

$$Q_{CH4.ADJ,y} = (Q_{CH4.seq,y} * GWP_{CH4} * QF_{Per,y}) + [Q_{CH4.seq,y} * 44/16 * (1-QF_{Per,y})] \qquad (7)$$

Where:

$Q_{CH4,ADJ,y}$ = Adjusted amount of CH_4 captured in year *y* to produce plastic material *i* by the project (tCO_2e per year)[3]

$Q_{CH4.seq,y}$ = Amount of CH_4 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

GWP_{CH4} = Global warming potential of methane

$QF_{Per,y}$ = Percentage of methane captured that is qualifying methane

44/16 = Ratio of the molecular weight of CO_2 to CH_4

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[2] Carbon (12) + 4 hydrogen (4) = a molecular weight of 16 g/mol. And 12/16 = 75%

[3] Note that the quantity of any GHG captured in the process must be measured at the very point in which the GHGs are sequestered. In other words, in a multi-step process, GHGs may be captured but some may escape throughout each stage of the process. The meter for captured GHGs should be at the point where as much of the GHGs will be captured as possible.

Projects cannot combine CO_2 and CH_4 as feedstock.[4]

In addition to determining the weight from the molecular formulas, a cross-check must be applied based on the direct monitoring of GHG capture[5]. In this case, directly monitoring the amount of CO_2 and CH_4 going into the process will provide validation of the left side (input) of the molecular formula (the direct measurement method (DMM)). The equation to use for the cross-check is as follows:

$$Q_{GHG,seq,check,y} = Q_{CO2,meter,y} + Q_{CH4,meter,y} \quad (8)$$

Where:

$Q_{GHG,seq,check,y}$ = The cross check of $Q_{CO2,seq,y}$ and $Q_{CH4,ADJ,y.}$ (metric tons)

$Q_{CO2,meter,y}$ = Amount of CO_2 captured in year *y* to produce plastic material by the project, as determined by a flow meter (metric tons)[6]

$Q_{CH4,meter,y}$ = Amount of CH_4 captured in year *y* and used to produce long-lived plastic products (metric tons)

Note that $Q_{CO2,seq,y}$ and $Q_{CH4,ADJ,y}$ will be the variables actually used for baseline emission calculations (metric tons of GHG/year), unless $Q_{GHG,seq,check,y} < Q_{CO2.seq,y} + Q_{CH4.seq,y}$. Where $Q_{GHG,seq,check,y} < Q_{CO2.seq,y} + Q_{CH4.seq,y}$, an explanation and correction must be provided. Where no reasonable explanation or correction can be provided, then the lower, metered values must be used in order to be conservative (i.e., $Q_{CO2.seq,y} = Q_{CO2,meter,y}$ and $Q_{CH4.seq,y} = Q_{CH4,meter,y}$).

8.2 Project Emissions

Project emissions include emissions from electricity use and fossil fuel combustion at the project production facility, and emissions from the amount of plastic made by the project activity that is eventually destroyed by incineration.

Project emissions are calculated as follows:

$$PE_y = PE_{inc,y} + PE_{elec,y} + PE_{ffc,y} \quad (9)$$

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[4] CO_2 and CH_4 cannot be combined together to form a single plastic material because determining the source of the carbon atom in the molecular formula of the plastic, and whether it came from CO_2 or CH_4 would be difficult. A project may use both CO_2 and CH_4 to produce different plastic materials, but there must always be separate reactions each using *either* CO_2 *or* CH_4 or as a feedstock.

[5] Determining GHG input by direct measurement is intended to be used as a validation of the molecular formula ratio because a validation/verification body (VVB) cannot directly measure or test the exact molecular formula of the plastic resin. Because no process is 100% efficient, it would be expected that some GHGs that enter the process are lost at some point before the final plastic is produced. Thus, the measurements of GHGs via the meter should be greater than what is determined to be sequestered into the plastic through the molecular formula ratio for $Q_{p,i,y}$. Thus, where the meter measurements are less than what is determined via the molecular formula ratio, an explanation or corrective action would need to be provided by the project proponent. Where no explanation or correction can be provided by the project proponent, then the project must use the lower, metered values in order to be conservative (i.e., $Q_{CO2.seq,y} = Q_{CO2,meter,y}$ and $Q_{CH4.seq,y} = Q_{CH4,meter,y}$).

[6] Note that the quantity of any GHG captured in the process must be measured at the very point in which the GHGs are sequestered. In other words, in a multi-step process, GHGs may be captured but some may escape throughout each stage of the process. The meter for captured GHGs should be at the point where as much of the GHGs will be captured as possible.

Where:

PE_y = Project emissions for year *y* of the project crediting period (tCO_2e)

$PE_{inc,y}$ = Project emissions from the eventual incineration of a portion of plastic that sequestered GHGs, which are then re-emitted (tCO_2e)

$PE_{elec,y}$ = Project emissions from the use of electricity at the project production facility (tCO_2e)

$PE_{ffc,y}$ = Project emissions from the combustion of fossil fuels at the project production facility (tCO_2e)

Project emissions from the incineration of plastic are calculated as:

$$PE_{inc,y} = (Q_{CO2.seq,y} * DF_{EL}) + (Q_{CH4.seq,y} * DF_{EL} * 44/16) \tag{10}$$

Where:

$PE_{inc,y}$ = Project emissions from the eventual incineration of a portion of plastic that sequestered GHGs, which are then re-emitted (tCO_2e)

$Q_{CO2,seq,y}$ = Amount of CO_2 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

DF_{EL} = Discount factor applied for volume of end-of-life plastic material that can be expected to be incinerated, thus releasing the CO_2 or CH_4 that was originally sequestered.

$Q_{CH4,seq,y}$ = Amount of CH_4 captured in year *y* to produce plastic material *i* by the project (metric tons per year)

Further guidance for calculating DF_{EL}, including a default factor for projects located in the United States and a conservative global default factor, are included in the parameter tables in Section 9.1 and in Appendix II, below.

Project emissions from the use of electricity at the project production facility are calculated as:

$$PE_{elec,y} = Q_{elec,y} * EF_{elec} \tag{11}$$

Where:

$PE_{elec,y}$ = Project emissions from the use of electricity at the facility in year *y*

$Q_{elec,y}$ = Quantity of electricity from the grid in year *y* used to power the project production facility in year *y* (MWH)

EF_{elec} = Emissions intensity of the electricity in tCO_2/MWH.

Project emissions from the combustion of fossil fuels at the project production facility are calculated as follows:

$$PE_{ffc,y} = Q_{ff,y} * FC_y * EF_{a,y} \tag{12}$$

Where:

$PE_{ffc,y}$ = Project emissions from the combustion of fossil fuel in year y

$Q_{ff,y}$ = Quantity of fossil fuel used in year *y*

FC_y = Energy content of fuel type a combusted the year *y* (terajoule or TJ).

$EF_{a,y}$ = Emission factor of fuel in year *y* (tCO_2e/TJ).

8.3 Leakage

There is one potential source of leakage to consider under this project activity. Specifically, where methane was supplied from a landfill to be used as a feedstock for this project activity in sufficient quantities, it is conceivable that the facility previously using that methane would turn to other, potentially more carbon-intensive fuels as a substitute. In order to deal with this potential issue, the project proponent cannot count for qualifying methane any biogas that was already contracted for by another entity to be used for energy production. As indicated in the applicability conditions of this methodology, where methane is to be used as a feedstock, the project proponent must demonstrate whether the methane is qualifying or non-qualifying (e.g., through a representation with the methane supplier or other evidence to the satisfaction of the validation/verification body (VVB)). In addition, in situations where an existing source of methane is supplying feedstock to the project facility, the project proponent must:

- Demonstrate that the methane for the project is coming from an expansion of the methane source where methane was previously being vented (e.g., a landfill that is expanding its gas collection system). In such case, it can be assured that no methane is being diverted from another fuel use because the ability to collect biogas is being increased; or

- Demonstrate there is excess gas supply potential that is not being utilized by the landfill or other methane source. For example, if projections of gas availability (to be provided by the landfill operator) show gas supply should be higher than what was actually being used, it would indicate that there is *potential* for more biogas to be used than is actually the case; or

- Provide other evidence to the satisfaction of the VVB that the methane source is supplying biogas which is not being diverted to another user.

Where the project proponent can demonstrate that one or more of these conditions exist for the project activity, then leakage does not need to be taken into consideration. Where these conditions cannot be definitively confirmed, the methane provided from the facility cannot count towards baseline emissions.

8.4 Net GHG Emission Reduction and Removals

Net GHG emission reductions and removals are calculated as follows:

$$ER_Y = BE_Y - PE_y \quad (13)$$

Where:

ER_Y = Net GHG emissions reductions and removals in year y (tCO_2e)

BE_Y = Baseline emissions in year y (tCO_2e)

PE_y = Project emissions in year y (tCO_2e)

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter	EF_i
Data unit	tCO_2e/metric ton of plastic material type i produced
Description	Emission factor for GHG's caused by the production of virgin plastic materials in tCO_2e/metric ton of plastic material
Equations	2
Source of data	Use values from credible international or national government sources, such as the U.S. EPA (see Appendix II, below, for more information on the data used to calculate this variable in the U.S.).
Value applied	See Appendix II
Justification of choice of data or description of measurement methods and procedures applied	National environmental agencies or similar government and research institutions have accurate data on energy requirements for each segment of the plastic production process including raw materials extraction and the production process itself. To be updated each crediting period if new data exists.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	MW_C
Data unit	g/mol
Description	Molecular weight of CO_2
Equations	5 and 6
Source of data	Periodic Table of Elements
Value applied	44

Justification of choice of data or description of measurement methods and procedures applied	Molecular weights as provided for in the Periodic Table of Elements.
Purpose of Data	Calculation of baseline emissions
Comments	For each type of plastic *i*, the project proponent must provide the molecular formula, as well as the conversion from the original compounds (including the GHGs) which convert to the plastic material. Taking into account the molecular weight of each compound, the project proponent can then illustrate that for each ton of plastic (eg: $C_4H_6O_2$) produced, X tons of CO_2 are required.

Data / Parameter	$MW_{C,CH4}$
Data unit	g/mol
Description	Molecular weight of CH_4
Equations	5 and 6
Source of data	Periodic Table of Elements
Value applied	16
Justification of choice of data or description of measurement methods and procedures applied	Molecular weights as provided for in the Periodic Table of Elements.
Purpose of Data	Calculation of baseline emissions
Comments	For each type of plastic *i*, the project proponent must provide the molecular formula, as well as the conversion from the original compounds (including the GHGs) which convert to the plastic material. Taking into account the molecular weight of each compound, the project proponent can then illustrate that for each ton of plastic (eg: $C_4H_6O_2$) produced, X tons of CO_2 are required.

Data / Parameter	$MW_{p,i}$
Data unit	g/mol
Description	Molecular weight plastic material
Equations	5 and 6
Source of data	Project proponent must provide formula for plastic material
Value applied	N/A

Justification of choice of data or description of measurement methods and procedures applied	Molecular weights as provided for in the Periodic Table of Elements.
Purpose of Data	Calculation of baseline emissions
Comments	For each type of plastic *i*, the project proponent must provide the molecular formula, as well as the conversion from the original compounds (including the GHGs) which convert to the plastic material. Taking into account the molecular weight of each compound, the project proponent can then illustrate that for each ton of plastic (eg: $C_4H_6O_2$) produced, X tons of CO_2 are required.

Data / Parameter	RCM_{CO2} and RCM_{CH4}
Data unit	Percentage
Description	Fraction of carbon as part of the CH_4 and CO_2 molecule (% carbon in CH_4 and CO_2 by molar weight)
Equations	5 and 6
Source of data	Calculated based on molecular weights of carbon, CO_2 and CH_4.
Value applied	RCM_{CO2} = 27.27% RCM_{CH4} = 75%
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	GWP of CH_4
Data unit	tCO_2/tCH_4
Description	Global warming potential of methane
Equations	7
Source of data	IPCC
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* are internationally recognized, and the data provided in the guidelines is peer reviewed
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	DF_{EL}
Data unit	Unitless
Description	Discount factor applied to account for the end of life of plastic material that is incinerated, releasing CO_2
Equations	10
Source of data	U.S. EPA or similar source in other countries (see Appendix II)
Value applied	For projects located in the U.S.: 0.15 For projects located outside of the U.S.: 1) Determine value from credible national government sources (see Appendix II) 2) Global default value: 0.40
Justification of choice of data or description of measurement methods and procedures applied	National environmental agencies or similar government and research institutions have accurate data on the percentage of plastic materials in conventional waste streams and what percentage of those waste stream that is incinerated.
Purpose of Data	Calculation of project emissions – where plastic is incinerated, the captured CO_2 is released, and reductions cannot be credited for this portion of the baseline emissions.
Comments	Discount factor applied to account for the end of life of plastic material that is expected to be incinerated, releasing CO_2. For example, where 20% of plastics in a particular country can be expected to be incinerated instead of recycled or landfilled, then the discount factor is 0.20. To be updated each crediting period if new data exists. Additional Guidance: Projects must apply a discount factor, DF_{EL}, to account for plastics that are destroyed (e.g., through incineration if they enter municipal waste streams), thus releasing the captured CO_2 prior to the end of their lifetime. Accurate data as to the amount of plastic material that is incinerated versus landfilled is well documented in many countries. In the U.S., the Environmental Protection Agency (EPA) estimates that 15% of plastic materials, regardless of type, will eventually be incinerated, with the rest being landfilled or recycled (see Appendix II for further detail). This percentage must be discounted from the calculations of emission reductions, to account for the volume of CO_2 that can be expected to be re-emitted. Where similar data exists in the country where the project is located, this data may be used to inform the discount factor. Appropriate data and data sources include host country officially

	published data, research studies or industry data. Any data or analysis used to inform the discount factor must be explained in the project documentation and assessed by the validation/verification body. The discount factor must distinguish between different types of plastics and/or be conservative for the type of plastic(s) that the project is producing. Where no similar data exists in the country where the project is located, a conservative global default factor may be used, as set out in Appendix II.

Data / Parameter	$FC_{,y}$
Data unit	TJ
Description	Energy content per unit of fuel type y
Equations	12
Source of data	IPCC
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	$EF_{a,y}$
Data unit	tCO_2e/TJ
Description	Emission factor of fuel type y
Equations	12
Source of data	IPCC
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized and the data provided in the guidelines is peer reviewed.
Purpose of Data	Calculation of project emissions
Comments	N/A

9.2 Data and Parameters Monitored

Data / Parameter	$Q_{gross,i,y}$
Data unit	metric tons of plastic type *i*
Description	Quantity of total plastic type *i* sold by the project into the market in time period y from eligible feedstocks
Equations	2 and 3
Source of data	Measurements at project facility
Description of measurement methods and procedures to be applied	Plastic material and additives must be weighed on scales that have available calibration procedures from the manufacturer.
Frequency of monitoring/recording	Daily or monthly
QA/QC procedures to be applied	Calibration of scales must be conducted according to the equipment manufacturer's specifications.
Purpose of data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$Q_{add,i,y}$
Data unit	metric tons of additive
Description	Quantity of any additives weighed before being put into the process.
Equations	2 and 3
Source of data	Measurements at project facility
Description of measurement methods and procedures to be applied	Additives must be weighed on scales that have available calibration procedures from the manufacturer. Additives may be added to the process to make the plastic more flexible or provide other desirable attributes. This supplemental material must be weighed prior to entering the process and subtracted out from the gross weight to obtain the net weight of plastic that has sequestered the GHGs.
Frequency of monitoring/recording	Daily or monthly
QA/QC procedures to be applied	Calibration of scales must be conducted according to the equipment manufacturer's specifications.
Purpose of data	Calculation of baseline emissions

Comments	N/A

Data / Parameter	$QF_{Per,y}$
Data unit	Percentage
Description	The percent of CH_4 during a specific production run of plastic which is qualifying (i.e., the percent of CH_4 that would have been vented to the atmosphere in the absence of the project).
Equations	7
Source of data	Project proponent, based on information from gas suppliers.
Description of measurement methods and procedures to be applied	Project proponent must obtain such information from the gas supplier about the source and baseline status (venting or destruction) of CH_4. The project proponent must interview each gas supplier for the project activity and present survey results to the validation/verification body (VVB), who may wish to interview gas supplier as well. The survey will include the following questions: • Is the gas supplier required by regulation to destroy the methane that is being provided to the project activity? Please describe and provide references to any applicable regulations. • Please provide historical data on any methane destroyed in previous years – including as a percentage of total methane output of the source.[7] Data should be provided from the last three years if available or for the operating history of the methane source if less than three years.
Frequency of monitoring/recording	Once per verification
QA/QC procedures to be applied	Project proponent must obtain information from the gas supplier about the source of methane. That documentation must be provided to the VVB for review.
Purpose of data	Calculation of baseline emissions. For qualifying methane, the GWP of methane is calculated in baseline emissions. For non-qualifying methane, the baseline emission is CO_2. But because that methane was captured instead of destroyed, the

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[7] For example, if in the last three years, the methane source has destroyed an average of 25% of the estimated total output of the source, such data should be provided and $QF_{Per,y}$ would thus be 0.75.

	CO_2 associated with the combustion of CH_4 was not emitted and can therefore be counted as a baseline emission.
Comments	Where the captured and sequestered methane was sourced from a landfill that already has a landfill gas collection system, or where LFG is required to be captured and destroyed, that amount of methane must be assumed to be destroyed and emitted as CO_2. For example, where 60% of the methane for a project facility was sourced from a landfill with an LFG collection system and 40% from an anaerobic digestion facility on a farm that is not required to capture methane, $QF_{Per,y}$ equals 0.4.

Data / Parameter	$Q_{CO2,meter,y}$
Data unit	tCO_2
Description	Amount of CO_2 captured in year *y* to produce plastic material by the project, as determined by a flow meter
Equations	8
Source of data	Measurements at project facility
Description of measurement methods and procedures to be applied	Use calibrated flow meters. Calibration must be conducted according to the equipment manufacturer's specifications. The amount of CO_2 must be metered before entering the plastic production process and must be subject to standard calibration and QA/QC procedures for the measurement of critical data variables. This data must be crosschecked with a pre-production estimate of GHG-to-product ratios to ensure that GHG feedstock is not released during the production process. For example, a process may take two pounds of CO_2 to manufacture one pound of plastic. The project proponent must keep a record of all methane inputted into the process and provide an estimated percentage of qualifying and non-qualifying methane.
Frequency of monitoring/recording	Data must be monitored continuously and recorded on at least a daily basis.
QA/QC procedures to be applied	Calibration of meters must be conducted according to the equipment manufacturer's specifications.
Purpose of data	Calculation of baseline emissions
Comments	Project proponents may use a mass-flow meter to measure mass of CO_2. Project proponents may also use a volumetric meter to determine cubic feet or meters of gas collected, but this number

	must be converted to mass by multiplying the measured volume by the density of CO_2 or CH_4 at normal temperature and pressure (20 degrees C at 1 atmosphere). The density of CO_2 at NTP is 1.842 kg/m3.[8] The density of CH_4 at NTP is 0.668 kg/m3. Determining GHG input by direct measurement is intended to be used as a cross-check of the molecular formula ratio because a verifier cannot directly measure or test the exact molecular formula of the plastic resin. Because no process is 100% efficient, it would be expected that some GHGs that enter the process are lost at some point before the final plastic is produced. Thus, the measurements of GHGs via the meter should be greater than what is determined to be locked into the plastic through the molecular formula ratio for $Q_{p,i,y}$. Where the meter measurements are less, this situation should be explained or corrected to the satisfaction of the VVB

Data / Parameter	$Q_{CH4,meter,y}$
Data unit	tCH_4
Description	Amount of CH_4 captured in year *y* to produce plastic material by the project, as determined by a flow meter
Equations	8
Source of data	Measurements at project facility
Description of measurement methods and procedures to be applied	Use calibrated flow meters. Calibration must be conducted according to the equipment manufacturer’s specifications. The amount of CH_4 must be metered before entering the plastic production process and must be subject to standard calibration and QA/QC procedures for the measurement of critical data variables. This data must be crosschecked with a pre-production estimate of GHG-to-product ratios to ensure that GHG feedstock is not released during the production process. For example, a process may take two pounds of CH_4 to manufacture one pound of plastic. The project proponent must keep a record of all methane inputted into the process and provide an estimated percentage of qualifying and non-qualifying methane.
Frequency of monitoring/recording	Data must be monitored continuously and recorded on at least a daily basis.
QA/QC procedures to be applied	Calibration of meters must be conducted according to the equipment manufacturer’s specifications.

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[8] www.engineeringtoolbox.com/gas-density-d_158.html

Purpose of data	Calculation of baseline emissions
Comments	Project proponents may use a mass-flow meter to measure mass of methane. Project proponents may also use a volumetric meter to determine cubic feet or meters of gas collected, but this number must be converted to mass by multiplying the measured volume by the density of CO_2 or CH_4 at normal temperature and pressure (20 degrees C at 1 atmosphere). The density of CH_4 at NTP is 0.668 kg/m3. Determining GHG input by direct measurement is intended to be used as a cross-check of the molecular formula ratio because a verifier cannot directly measure or test the exact molecular formula of the plastic resin. Because no process is 100% efficient, it would be expected that some GHGs that enter the process are lost at some point before the final plastic is produced. Thus, the measurements of GHGs via the meter should be greater than what is determined to be locked into the plastic through the molecular formula ratio for $Q_{p,i,y}$. Where the meter measurements are less, this situation should be explained or corrected to the satisfaction of the VVB

Data / Parameter	$Q_{elec,y}$
Data unit	MWh
Description	Quantity of electricity used by project facility supplied by the grid in year y
Equations	11
Source of data	Measurements at project facility or electric utility bills
Description of measurement methods and procedures to be applied	Use calibrated electricity meters. Calibration must be conducted according to the equipment manufacturer’s specifications. Alternatively, utility billing data can be used.
Frequency of monitoring/recording	Data must be monitored continuously and recorded on at least a daily basis. If utility data is used, monthly bills are acceptable
QA/QC procedures to be applied	The consistency of metered electricity generation should be cross-checked with receipts from electricity purchases where applicable
Purpose of data	Calculation of project emissions
Comments	N/A

Data / Parameter	EF_{elec}
Data unit	tCO_2e/MWH
Description	Emission intensity of electricity

Equations	11
Source of data	US eGrid or utility data or similar source if the project is in another country.
Description of measurement methods and procedures to be applied	In developing countries, project proponents may use the "Tool to calculate the emission factor for an electricity system" to calculate this parameter. In the US, eGrid emissions factor for the sub-region where the facility is located (latest available information) may be used.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	As per "Tool to calculate the emission factor for an electricity system"
Purpose of data	Calculation of project emissions
Comments	N/A

Data / Parameter	$Q_{ff,y}$
Data unit	Gallons (oil fuels), cubic meters (natural gas), metric tons (solid fuels)
Description	Quantity of fossil fuel used by the project facility in year y
Equations	12
Source of data	Measurements at project facility
Description of measurement methods and procedures to be applied	Use calibrated flow or gas meters. Calibration must be conducted according to the equipment manufacturer's specifications.
Frequency of monitoring/recording	Data must be monitored and recorded monthly.
QA/QC procedures to be applied	The consistency of metered fuel use should be cross-checked with receipts from fuel suppliers where applicable
Purpose of data	Calculation of project emissions
Comments	N/A

9.3 Description of the Monitoring Plan

The project must monitor all key variables, including the following:

- Quantity of CO_2 captured from the atmosphere as a GHG feedstock (where CO_2 is part of the GHG feedstock) for the plastic material. The capture process will capture CO_2, which will then be run through a meter to measure the amount of CO_2 captured in pounds or kg.

- Quantity of methane that is collected (if CH_4 is part of the GHG feedstock) must be piped or shipped into the production facility. The amount of methane captured must be measured through traditional metering methods.

  Note that both the CO_2 and CH_4 captured must be crossed checked with pre-defined, estimated ratios of GHG input to plastic output, which must be included in the quality control section of the monitoring tables. In addition, the project proponent is required to account for any GHGs that escape during the manufacturing process (although the point of measurement should be the latest point just prior to when the GHG feedstock combines with other materials to form the plastic material and is thus sequestered). To confirm the level of baseline emissions from the capture of the GHGs for sequestration into the plastic material, the project proponent must calculate both the MFR and the DMM (the stoichiometric ratio method and direct measurement method).
- Production of plastic material, as monitored through appropriate weighing techniques.
- In cases where methane is used as a feedstock, an analysis of whether that methane would be qualifying or non-qualifying.
- An analysis of the potential for leakage as described in Section 8.3 above.
- Quantities of electricity and any fossil fuel used at the facility (for project emissions). Gas and electricity meter readings shall be the primary method for monitoring these data parameters. Utility-supplied data (gas and electricity bills) are acceptable.

The project proponent must establish, maintain and apply a monitoring plan and GHG information system that includes criteria and procedures for obtaining, recording, compiling and analyzing data, parameters and other information important for quantifying and reporting GHG emissions relevant for the project and baseline scenarios. Monitoring procedures must address the following:

- Types of data and information to be reported;
- Units of measurement;
- Origin of the data;
- Monitoring methodologies (e.g., estimation, modeling, measurement and calculation);
- Type of equipment used;
- Monitoring times and frequencies;
- QA/QC procedures;
- Monitoring roles and responsibilities, including experience and training requirements;
- GHG information management systems, including the location, back up, and retention of stored data.

Where measurement and monitoring equipment is used, the project proponent must ensure the equipment is calibrated according to current good practice (e.g., relevant industry standards).

All data collected as part of monitoring must be archived electronically and kept at least for 2 years after the end of the last project crediting period. QA/QC procedures must include, but are not limited to:

- Data gathering, input and handling measures;
- Input data checked for typical errors, including inconsistent physical units, unit conversion errors;
- Typographical errors caused by data transcription from one document to another, and missing data for specific time periods or physical units;
- Input time series data checked for large unexpected variations (e.g., orders of magnitude) that could indicate input errors;
- All electronic files to use version control to ensure consistency;
- Physical protection of monitoring equipment;
- Physical protection of records of monitored data (e.g., hard copy and electronic records);
- Input data units checked and documented;
- All sources of data, assumptions and emission factors documented.

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APPENDIX I: JUSTIFICATION OF THE ACTIVITY METHOD

Background

The concept of using greenhouse gases (GHGs) as a raw material for the production of useful products is only a few years old. A number of start-up companies are developing technologies that use captured GHGs to produce tangible products, with what has been termed “Carbon Capture and Utilization” (CCU). Products created through CCU processes can act as long-term storage of the captured GHGs used in their production and displace products created through conventional processes. The level of commercial activity for CCU products is very low, as it is a new technology. This is particularly true for the use of CCU to create plastic materials that could displace plastics produced through conventional processes in the commercial market.

As of the writing of this methodology, there is no large-scale commercial application of CCU technology to capture and sequester GHGs in plastic materials, and there is only limited activity in using CCU to produce concrete and other similar building materials. As of 2018, the company closest towards commercialization of CCU technology in the plastics sector has only a small plant that could provide materials for commercial customers, operated by a start-up company called Newlight Technologies, Inc. As a result, essentially 100 percent of all plastic materials in any market are produced using conventional, petroleum-based materials and processes, with the exception of some niche plastics made from food crops like corn or sugarcane, which do not sequester GHGs long-term.

In addition, it should be noted that as of the writing of this methodology, Newlight’s technology for CCU in plastic materials has been available for more than three years, demonstrating that while the project is commercially available at a modest scale, its growth has been limited – indicating barriers to penetration in the wider market.

Approach

The activity penetration option requires that the total amount of plastic production from this alternative, GHG-capturing process, does not amount to more than five percent of total plastic production worldwide. Activity penetration is equal to: Observed Activity (OA) divided by the Maximum Adoption Potential (MAP).

In this case, as mentioned above, this project activity has not reached commercial scale. The one company, Newlight Technologies, Inc., which produces the only known plastic material from GHG feedstock, has only a small pilot facility which has produced plastic for a few clients. However, this particular plastic used shipped CO_2 from another source, not a waste source like the flue gas from a power plant. Thus, the “total number of instances installed at a given date in year *y*” is zero, and OA can be considered to be zero.

Given the early stage of CCU technology, it is difficult to say exactly what the resource and other constraints are to adoption of this technology. The feedstocks, CO_2 and CH_4, are ubiquitous, and there are no particular barriers (e.g., market access or customer acceptance) that would limit the adoption of this technology. Thus, for the purposes of this methodology, the MAP is the entire market for each specific type of plastic the project facility will produce, within the country where that facility is located.

Therefore, clearly the activity penetration level of the project activity covered by this methodology is below the five percent threshold, and the project activity may be deemed additional.

Additionally, given the low penetration of this activity, the only baseline scenarios that are reasonable to consider are: 1) the continued manufacturing of traditional plastic material with no plastic production involving GHG sequestration or perhaps; 2) the large-scale adoption of this technology many years into the future, at which point the five percent threshold for activity penetration would be exceeded and the activity would no longer be eligible for crediting.

APPENDIX II: EMISSION FACTORS

Introduction

This appendix provides additional information about the calculation of the following emission factors:

1) EF_i: the emission factor for GHGs caused by the production of virgin plastic materials; and
2) DF_{EL}: the discount factor applied to account for the end of life of plastic material that is incinerated, releasing CO_2

Emission Factor for the Production of Plastic Material (EF_i)

Introduction and Background

This methodology relies on emission factors for each type of plastic produced by the project activity in order to calculate baseline emissions associated with the displacement of virgin plastic production (EF_i). This appendix provides additional information about how EF_i is determined, including default factors for projects located in the United States and the process that must be used by projects located outside of the United States to calculate EF_i.

Emissions associated with the manufacture of plastic materials through conventional processes include the extraction and processing of raw materials, which are primarily petroleum products, emissions associated with the manufacturing process itself, and emissions associated with the transportation of plastic materials. These emissions vary depending on the type of plastic material – the production of polypropylene, for example, generates almost 40% fewer emissions than the production of polystyrene.

Calculation of Default Factors for Projects in the United States

Projects located in the United States may use a default value for EF_i, based on the United States Environmental Protection Agency (U.S. EPA) Waste Reduction Model (WARM), which was created to calculate the GHG emissions of waste management practices in the United States, including from the recycling and landfilling of plastic materials.

The WARM model disaggregates the different sources of emissions associated with plastic production and includes process energy from the petroleum refining process, process non-energy emissions, and transportation emissions, as shown in Table 3a below[9]. For the purposes of this methodology, only process and process non-energy emissions are included because emissions from the transportation of plastic materials are not expected to be different in the baseline and project scenarios (e.g., because traditional plastic or GHG-containing plastic both must be transported to their final destination).

Note – The tCO_2e in Table 3a and Table 3b, below, are expressed in short tons. For the purposes of calculating baseline emissions in Equation 2, the default values included in Table 4, below, have been converted into metric tCO_2e.

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[9] https://www.epa.gov/sites/production/files/2016-03/documents/warm_v14_containers_packaging_non-durable_goods_materials.pdf

Table 3a: Source Reduction Emission Factors for Plastic

Material (a)	Process Energy (b)	Transportation Energy (c)	Process Non-Energy (d)	Net emissions (e) [e=b+c+d]
HDPE	1.18	0.15	0.20	1.53
LDPE	1.40	0.15	0.21	1.76
PET	1.74	0.07	0.39	2.20
LLDPE	1.14	0.15	0.25	1.54
PP	1.17	0.13	0.21	1.51
PS	1.86	0.15	0.45	2.46
PVC	1.68	0.08	0.14	1.90

The WARM model takes into account that some plastic is created from recycled materials, and therefore not all plastic materials on the market are from 100% raw materials, in its calculation of net emissions from plastic production. Table 3b, below, includes the emissions from “raw material acquisition” for the current mix of recycled vs. virgin plastic in the market (column “b”), as opposed to column “c” which calculates the emission factor for 100% virgin inputs. Note that the values in Table 3b are negative because this section of the WARM model is referencing reductions in emissions for every ton of plastic where its use is avoided.

Note that the figures in column “e” in Table 3a do not match column “b” in Table 3b below. This is because the transportation energy in the WARM model does not include retail transportation, which is 0.04 tCO_2/t of plastic for all plastic types[10]. The values in column “e” of Table 3a are equal to: [net emissions from 100% virgin inputs, Table 3b] – [0.04].

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[10] See Table 5-4 on page 5-5: https://www.epa.gov/sites/production/files/2016-03/documents/warm_v14_containers_packaging_non-durable_goods_materials.pdf.

Table 3b: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Plastics (tCO_2e/Short Ton)

Material (a)	Raw Material Acquisition and Manufacturing for Current Mix of Inputs (b)	Raw Material Acquisition and Manufacturing for 100% Virgin Inputs (c)	Net Emissions for Current Mix of Inputs (d)	Net Emissions for 100% Virgin Inputs (e)
HDPE	-1.47	-1.57	-1.47	-1.57
LDPE	-1.80	-1.80	-1.80	-1.80
PET	-2.20	-2.24	-2.20	-2.24
LLDPE	-1.58	-1.58	-1.58	-1.58
PP	-1.55	-1.55	-1.55	-1.55
PS	-2.50	-2.50	-2.50	-2.50
PVC	-1.95	-1.95	-1.95	-1.95
Mixed Plastics	-1.92	-1.98	-1.92	-1.98

The net emission factor (EF_i) for each type of plastic is calculated as:

> [(net emissions for current mix of inputs (Table 3b)) – (transportation energy (Table 3a)) – (retail transportation)] x (conversion factor from short tons to metric tons, equal to 1.102)

For example, the net emissions factor for HDPE would be equal to:

> [(1.47) – (0.15) – (0.04)] x (1.102) = 1.41

There are a few types of plastic material eligible to be produced through project activities, but not included in the U.S. EPA WARM model report. These forms of plastic are:

- Thermoplastic urethane (TPU)
- Acrylonitrile butadiene styrene (ABS)
- Polycarbonate (PC)

Emission factors for these plastic materials were derived from a report prepared for the City of Winnipeg[11]. The emission factors included in this report are inclusive of emissions associated with transportation. Therefore, to calculate emission factors for ABS, TPU and PC that are equivalent to the emission factors for other eligible plastic materials, an estimate of transportation emissions was subtracted from the total emissions. The EPA data from the WARM model specifies 0.19 metric tons of CO_2/per short ton of plastic (equal to 0.21 metric ton of CO_2/per metric ton of plastic) as the highest (and therefore most conservative) value for emissions from transportation. This value was subtracted from total emissions for the emission factors for ABS, TPU and PC included in Table 4 below. It is reasonable to

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[11] https://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf

infer that transporting ABS, TPU and PC would be similar in cost and energy to all other types of plastics, a point reinforced by the fact that the transport figures in the WARM model (except for PVC) are all in a very small range. The emission factors for TPU and PC were derived from the "Other Plastics" emission factor.

Table 4: Default Emission Factors for EF_i for projects located in the United States

Plastic Type	Emission Factor (tCO_2e/metric ton of plastic material produced)
HDPE	1.41
LDPE	1.77
PET	2.30
LLDPE	1.53
PP	1.52
PS	2.55
PVC	2.02
ABS	3.25
TPU	2.49
PC	2.49

Note that project proponents must use the latest version of the WARM model (or similar sources of data in other countries) when developing a new project.

Discount Factor for Incinerated Plastic Material (DF_{EL})

Introduction

DF_{EL} is the discount factor that is applied to account for the fact that a certain amount of GHGs captured as part of the project may be re-released when plastic is incinerated. Where plastic materials that are made through project activities are incinerated, CO_2 would be released to the atmosphere through the combustion process, and therefore the incinerated plastic materials would not represent a permanent sequestration of the GHG feedstock used in the production process. DF_{EL} represents the proportion of incinerated plastic to non-incinerated plastic.

This section sets out in more detail the three ways that DF_{EL} can be determined: 1) a default value for U.S.-based projects; 2) criteria for projects to determine DF_{EL} where appropriate data is available, and; 3) a conservative global default value.

Default Factor for Projects Located in the United States

The U.S. Environmental Protection Agency (U.S. EPA) has collected and reported data on the generation and disposition of waste in the United States for more than 30 years. This information is used to measure the success of waste reduction and recycling programs across the country and characterize the U.S. national waste stream, and can be used to determine DF_{EL} in the United States.

Based on the information included in the U.S. EPA *Advancing Sustainable Materials Management: 2014 Fact Sheet Assessing Trends in Material Generate, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States* (November 2016)[12], 15% of total plastics are incinerated in the U.S. Therefore, the default factor for DF_{EL} in the U.S. is: 0.15.

Procedure for Projects Located Outside of the United States

Where projects are located outside of the United States, they must determine the percent of plastic incinerated in the country or geographic region of the project in order to determine $DF_{EL.}$ Independent market estimates from government, academic or trade association sources may be used to determine the level of plastic incineration in a particular country. Where a single source does not include sufficient information to determine the percent of plastic incinerated in a particular country, multiple sources of data may be used. For example, where 5 million tons of waste is incinerated in a country and 10% of such waste is plastic products, then 500,000 tons of plastic may be assumed to be incinerated in that country. Where another source shows that 1.5 million tons of plastics is consumed in that country, then the default factor may be set at 30% (equal to: (plastic products incinerated) / (total plastic consumed) = (500,000) / (1,500,000)).

The project proponent must calculate DF_{EL} in terms of tCO_2e/metric ton of plastic material produced and apply this calculated discount factor to determine emissions in Equation 2.

Global Default Value

Where data is not available to determine a specific default factor for the percent of plastic that is incinerated in a particular country, a conservative global default value must be used. The conservative global default for DF_{EL} is: 0.40.

This conservative global default value for DF_{EL} is based on an estimate of the percent of plastic that is incinerated in Europe, which has the highest level of plastics incineration of any known country or region. According to a report from Plastics Europe[13], 36% of post-consumer plastic produced in Europe was incinerated for energy generation. Therefore, for the purposes of the methodology, where a project proponent cannot find data on the level of baseline plastics incineration in a country where a project facility is located, the global default value for DF_{EL} is conservatively set at 40%.

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[12] See *Table 1. Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of Materials in MSW, 2014*,* in the column for "combustion as a percent of generation" in the *Advancing Sustainable Materials Management: 2014 Fact Sheet Assessing Trends in Material Generate, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States* (U.S. EPA November 2016), which refers to the percent combusted as a percent of total waste generation for that category. and can be accessed at: https://www.epa.gov/sites/production/files/2016-11/documents/2014_smmfactsheet_508.pdf

[13] http://vitalsigns.worldwatch.org/sites/default/files/vital_signs_trend_plastic_full_pdf.pdf, the original source is PlasticsEurope, *Plastics–The Facts 2014: An Analysis of European Plastics Production, Demand and Waste Data* (Brussels: 2014).

APPENDIX III: EXAMPLE CALCULATION FOR MOLECULAR FORMULA RATIO (MFR)

The molecular formula ratio (MFR) determines the quantity of CO_2 or CH_4 captured by observing the molecular formula of the final plastic material. As set out in Section 8 above, the project proponent must provide the molecular formula for each type of plastic *i*, and the formula for the conversion from the GHGs which convert to the plastic material. This appendix sets out an example of how to determine the MFR.

For example, where the plastic material has the molecular formula $C_4H_6O_2$, the project proponent will provide the following molecular formula:

$$33H_2 + 12O_2 + 4CO_2 \rightarrow C_4H_6O_2 + 30H_2O$$

The following calculations are used to derive the amount of CO_2 sequestered in a given quantity of the example plastic material above. The example calculation is based on the following conditions:

1) The plastic production process produces 27.7 metric tons of a plastic material;

2) The plastic has a molecular formula of $C_4H_6O_2$, with a molar weight of 86[14] grams per mole, equal to 55.8% carbon by weight; and

3) The carbon in the plastic material is 100% derived from sequestered CO_2, and CO_2 is 27.27%[15] carbon.

Therefore, to calculate the amount of CO_2 embodied in the final plastic material, the equation is as follows:

1) 27.7 MT of plastic material x 55.81% carbon in the material = 15.46 MT carbon in material.

2) If 100% of the carbon comes from CO_2, that means that of 15.46 MT carbon in the material, it would take 56.6 MT of CO_2 to provide enough carbon for the 15.46 MT. This is because the carbon in the CO2 is 27.27% of the weight of the CO_2 molecule[16]. If there are 56.6 MT of CO_2 required to produce 27.7 MT of plastic, the ratio of CO_2 embodied in the plastic material is 2.043:1 sequestered CO_2:plastic by weight.

3) Thus, the project proponent (and the validation/verification body (VVB)) would know that for every 100 metric tons of plastic produced, 204.33 metric tons of CO_2 is sequestered.

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[14] Molecular weight of carbon is 12, oxygen is 16 and hydrogen is 1. Therefore, $C_4H_6O_2$=12*4 + 1*6 + 16*2 = 86. The four carbon atoms amount to 48, and 48/86 = 55.8%.

[15] The molecular weight of carbon is 12, oxygen is 16 and thus CO_2 = 44. The percentage of weight that is carbon is 12/44 or 27.27%.

[16] 15.46 MT / 0.2727 = 56.6 MT

Example of quantifying GHGs sequestered when CO_2 is used as a feedstock:

As Equation 5 states:

$$Q_{CO2.seq,y} = \sum_i \{[Q_{p,i,y} * (MW_C / MW_{p,i})] / RCM_{CO2}\}$$

Where:

$Q_{CO2,seq,y}$	= amount of CO_2 captured in year *y* to produce plastic material *i* by the project (metric tons per year)
$Q_{p,i,y}$	= Net quantity of plastic type *i* produced by the project in year *y* (metric ton)
MW_C	= the molecular weight of the carbon in the plastic material *i* (g/mol)
$MW_{p,i}$	= the total molecular weight of the plastic material *i* (g/mol)
RCM_{CO2}	= the fraction of carbon as part of the carbon dioxide molecule (% carbon in carbon dioxide by molar weight or 27.27%)

If $Q_{p,i,y}$ were 27.7 tons, using the numbers from the above example would yield the following:

$$Q_{CO2.seq,y} = [Q_{p,i,y} * (MW_C / MW_{p,i})] / RCM_{CO2}$$

$Q_{CO2.seq,y}$ = [27.7 * (48/86)] / 0.2727 = 56.6 metric tons of CO_2 sequestered