Life Cycle Assessment (LCA) Guidelines for Greenhouse Gas Emissions accounting in Carbon Removal and Recycling (CR2) Technologies

Edition 2.5 2024

Life Cycle Assessment Society of Japan

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1. Introduction

1.1 Background of formulation of guidelines

In the Paris Agreement adopted in 2015, the long-term goal was set of keeping the increase in the global average temperature to well below 2°C above pre-industrial levels. However, reports from IPCC and other documents suggest that if the current concentration status of greenhouse gases (GHG) in the atmosphere continues, it will be difficult to achieve the above long-term goal. To tackle this issue, the development of technologies for capturing and storing CO_2 from the atmosphere (negative emission technologies; NETs, or carbon dioxide removal; CDR methods), as well as technologies for effectively using CO_2 captured from exhaust gas (carbon recycling) and storing it (Carbon Capture, Utilization and Storage; CCUS) is underway in recent years.

However, there are many unclear points in their overall effectiveness because these technologies consume energy and resources and emit CO_2 and other GHG in processes including carbon capture and sequestration or storage. Furthermore, the influence of the storage duration and by-products, and their side effects on nature are highly uncertain. For these reasons, quantitative assessments of impacts of NETs and CCUS technologies using life cycle assessment (LCA) is encouraged.

The NETs Research Project is a working group in the Life Cycle Assessment Society of Japan to collect and systematically organize cases of existing LCA research on NETs and CCUS in order to discuss precautions that should be considered when setting assumptions and other factors for appropriate LCA practice. In addition, we recognized that not only assessment of NETs, but also CCUS under which technologies are shared with NETs, is useful in the establishment of a future industry map of NETs. In the project; therefore, we have defined a term, Carbon Removal and Recycling Technologies (CR2 technologies), which collectively refer NETs, CCUS, and other technologies that share fundamental technologies with NETs, and set the entire CR2 technologies as the scope of our project.

This document provides guidance on how to quantitively account the amount of greenhouse gas emission in each CR2 technology, which have been discussed in our project.

1.2 Purpose and scope of the guidelines

The guidelines provide the methods to account the amount of the GHG emission and removal through introduction of CR2 technologies in the span of the whole life cycle.

However, if emissions of remarkable substances other than GHG and/or large-scale of resource consumption are expected, remarks on them should be made.

1.3 Relationships with existing standards/guidelines

This document was prepared with reference to the following international standards.

- ISO 14040: 2006 Environmental management — Life Cycle Assessment — Principles and framework
- ISO 14044:2006 Environmental management — Life Cycle Assessment — Requirements and guidelines

The evaluation methodology in the document is organized in align with the following guidelines and others.

- The Institute of Life Cycle Assessment, Japan: Guidelines for Contributed Amount in GHG Reduction (provisional translation), https://www.ilcaj.org/lcahp/doc/guideline20150224.pdf
- Ministry of Economy, Trade and Industry: Guidelines for Quantification of Contributed Amount in GHG Reduction (provisional translation), https://www.meti.go.jp/press/2017/03/20180330002/20180330002-1.pdf
- IPCC: 2006 IPCC Guidelines for National Greenhouse Gas Inventories
- IPCC: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
- Müller, L. J. et al. 2020: A guideline for life cycle assessment of carbon capture and utilization. Frontiers in Energy Research 8: 15.
- For matters not listed in these guidelines, refer to the above standards and guidelines.

1.4 Utilization of guidelines

These guidelines assume that researchers and development practitioners concerning CR2 technologies calculate the amount of GHG emission and removal due to CR2 technologies and use the results inside the organization as well as for communication with outside organizations through academic presentations and descriptions in the CSR report and other documents.

These guidelines also assume to be used by parties including the national government, autonomous bodies, and industrial groups as a guide for implementations of measures to reduce the amount of GHG emission through CR2 technologies.

2. Definition of Carbon Removal and Recycling Technologies (CR2 technologies)

In this document, CR2 technologies are defined as an integration of “NETs” and “systems in which technologies that can emit GHG through the use of fossil fuel and CCUS technologies are combined.” Technologies that can emit GHG through the use of fossil fuel refer to technologies that emit GHG not only due to the use of fossil fuel, but also from industrial processes themselves. NETs are defined as “technologies that capture GHG from the atmosphere, and store and sequester it” with reference to the broad definition “intentional human efforts to remove CO_2 emissions from the atmosphere” by Minx et al. (2018).

In this document, the amount of GHG emission to the atmosphere through CR2 technologies (or amount of GHG removed from the atmosphere) is determined as follows. A negative obtained value means a net removal of GHG from the atmosphere.

(GHG emission amount balanced by CR2 technologies)
=(Amount of GHG generated by using raw materials and fossil fuel)
+(Amount of GHG emission due to introduction of CR2 technologies)
−(Amount of GHG stored/sequestered due to introduction of CR2 technologies)
••••••••••••••••Formula (1)

In Formula (1), when the source of the GHG captured by CR2 technologies is not from technologies using raw material and fossil fuel (when GHG captured by the NETs do not include GHG originated from technologies using fossil fuel), the first term on the right side is omitted, but the second and third terms are included.

Details of the first, second, and third terms on the right side in Formula (1) are shown in 3.5.1, 3.5.2, and 3.5.3, respectively.

Note 1: Examples of the calculation of GHG emission amount balanced by various CR2 technologies are shown Appendix.

Note 2: The GHG in the third term of the right side in Formula (1) does not include naturally occurring GHG stored/sequestered from natural CO_2 dome, as often seen in current CO_2 EOR.

3. Methods of calculating GHG emissions by CR2 technologies

3.1 Definition of goal

[Requirement]

- The product or system/technology of a study shall be clearly defined, when conducting the LCA.

[Recommendation]

- The reason for the calculation, party to report to, and reporting means should be clearly declared.

3.2 Functional unit

[Requirement]

- A function and functional unit of the system/technology being studied shall be specified. A functional unit is a quantified function of the system in a certain unit.
- The period and geographical coverage for which GHG emission amount is determined shall be identified. For setting the period, the scientific basis for storage and sequestration of GHG by each CR2 technology shall be presented.

Note: Example of functional unit

Biochar: biochar mass of 1 kg
BECCS (Bioenergy with CCS): power generation of 1 kWh (power transmission end)
Afforestation: afforestation area of 1 ha

3.3 Scope of the assessment

[Requirement]

- Processes in an assessment (system boundary) shall be identified.
- In principle, all the energies, raw materials, and wastes to be used/disposed in processes shall be included in the introduction and emission of (input to and output from) the system border. The capital goods that constitute processes shall also be included in the system boundary.
- When part of the processes inside the system boundary is excluded, those processes and the reason for the exclusion shall be clearly stated.

3.4 GHG to be assessed and global warming potential

[Requirement]

- Seven GHG (carbon dioxide (CO_2), methane (CH_4), nitrogen monoxide (N_2O), hydrofluorocarbon (HFCs), perfluorocarbon (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)) for which an agreement was made in the United Nations Framework Convention on Climate Change shall be subjects for the assessment.
- For the global warming potential of GHG, the latest potential in the assessment report and other documents of the Intergovernmental Panel on Climate Change shall be used. Among them, we recommend using the 100-year GWP (Global Warming Potential).

[Permitted matters]

- Only specific GHG may be assessed only when the reason is clearly presented.

3.5 Calculation methods

3.5.1 The amount of GHG generated from technologies using fossil fuel (first term on the right side of Formula (1))

[Requirement]

- When a CR2 technology system in the study captures GHG from technologies that use fossil fuel, the energies, raw materials thrown into the technologies, as well as industrial waste processing and others shall be included. At the same time, the amount of GHG emissions related to the production of the capital goods in the corresponding technologies shall also be included.

[Permitted matters]

- In principle, GHG generated from the production of capital goods are subject to the assessment, but capital goods that are not attributable to the implementation of the project and whose GHG generated are considered to be much smaller than the GHG generated from the operation of technologies using fossil fuels may be excluded from the calculation. However, a rational explanation of the reason for such exclusion shall be provided.

3.5.2 The amount of GHG emissions due to introduction of CR2 technologies (second term on the right side of Formula (1))

[Requirement]

- GHG emissions due to the use of energy and raw materials, waste disposal, and others as a result of introduction of the CR2 technology shall be determined. At the same time, GHG emissions associated with the production of capital goods of the technology shall be determined.

[Permitted matters]

- In principle, GHG emissions from the production of capital goods are subject to the assessment, but capital goods that are not attributable to the implementation of the project and whose GHG emissions are considered to be much smaller than the GHG emissions from the operation of technologies using fossil fuels may be excluded from the calculation. However, a rational explanation of the reason for such exclusion shall be provided.

3.5.3 The amount of GHG stored/sequestered due to the introduction of CR2 technologies (third term on the right side of Formula (1))

Storage and sequestration of GHG captured by CR2 technologies include the geological storage of GHG by CCS, sequestration of GHG as a product by CCU, and sequestration of GHG dependent of a natural process.

Note 1: Sequestration as a product refers to GHG fixed through an artificial process. Such products may include synthetic fuel, concrete structure, and biochar. They also include temporary sequestration by CCU.

Note 2: Sequestration dependent of a natural process may include afforestation, cropland soil, blue carbon, and enhanced rock weathering.

Note 3: As with sequestration of GHG by biochar as a product, there are some cases in which natural processes must be considered, such as the conditions of the application site.

[Requirement]

- For geological storage of GHG by CCS, the actual amount of GHG stored shall be determined. In this case, the amount obtained by subtracting the amount of GHG leaked out to the atmosphere during the transportation and storage process from the amount of GHG captured shall be stated as the storage/sequestration amount.

- When sequestering GHG as a product through CCU:
  (1) Amount of GHG contained in products out of the amount captured
  (2) Amount of GHG obtained by subtracting the amount of GHG unused in products from the amount of GHG captured

  The amount of GHG sequestered shall be determined by either of the above methods and clearly stated. The average GHG sequestration duration as a product shall be clearly addressed.
- When conducting assessments technologies involving natural processes, carbon sequestration sites (carbon pools) shall be defined, and the increase or decrease in the amount of carbon in the pool per time (accumulation or decomposition rate) and the activity data (e.g., the area of the storage site) shall be clarified.

[Recommendation]

- To store/sequester GHG through CCS or a natural process, the amount of leakage of GHG being stored/sequestered should be monitored.
- For technologies involving a natural process, major carbon pools should be included as much as possible.

[Permitted matters]

- If monitoring of the amount of GHG leakage during storage/sequestration is difficult, an estimate value may be used. For example, leakage due to decomposition during carbon sequestration by biochar may be determined using the percentage of carbon remaining after 100 years.
- When it is difficult to measure accumulation/decomposition rates when assessing GHG sequestration involving natural processes, the default values specified in the IPCC guidelines may be used.

3.6 Determination of cost of CR2 technologies

[Recommendation]

- The cost associated with CR2 technologies should be assessed.
- When avoided GHG emissions are evaluated (Chapter 4), the cost per amount of avoided GHG emission should be appended.

3.7 Data collection and data quality

[Requirement]

- The data collection and data quality shall be compliant with ISO 14040:2006 standard, JIS Q 14040:2010 and ISO 14044:2006 standards, and JIS Q 14044:2010.

3.8 Sensitivity analysis and uncertainty analysis

[Recommendation]

- In the determination of GHG emission, sensitivity analyses and uncertainty analyses should be conducted to examine the contribution of the preconditions to the results.

4. Avoided GHG emissions by CR2 technologies

4.1 Definition of avoided GHG emissions and the goal

In this document, the avoided GHG emissions by CR2 technologies are defined as "net reduction of GHG emission from the whole system to which CR2 technologies have been introduced.

[Requirement]

- When evaluating the avoided GHG emissions by CR2 technologies, the CR2 technologies of the subject, and in the case of CCUs, the products used for GHG sequestration shall be clearly identified.

[Recommendation]

- The goal and reason for assessing the avoided GHG emissions by CR2 technologies as well as the recipients and means of reporting should be clarified.
- The point in time, period, and region where the avoided GHG emissions by CR2 technology is analyzed should be specified.

4.2 Determination of avoided GHG emissions

The amount of avoided GHG emissions by CR2 technologies is determined by the following formula.

Avoided GHG emissions by CR2 technologies =
Amount of GHG emission from reference system
− Amount of GHG emission from CR2 system

････････････････Formula (2)

Note: Examples of calculation of the avoided GHG emissions by CR2 technologies are shown in Appendix.

4.3 Reference system

[Requirement]

- The reference system shall have the same functional unit as the system with CR2 technology in the study.
- The reference system shall be assumed to exist in the region and at the time when there is no

CR2 system in place.

Note 1: For the DACCS (Direct Air Capture and Carbon Storage) system, the zero-emission state before DACCS investment may be set as a reference.

- The functional unit and its quantity shall be the same between the first term on the right side of Formula (2) (GHG emission from reference system) and the second term on the right side of Formula (2) (GHG emission from CR2 system).
- The scope of assessment must be the same between the first term on the right side of Formula (2) (GHG emission from reference system) and the second term on the right side of Formula (2) (GHG emission from CR2 system).

[Recommendation]

- When there are multiple functional units in the system, each functional unit should be clearly stated.

Note: Example of multiple functional units (CCU)

Where CO_2 is captured in the cement production and methanol is produced using the captured CO_2 (Appendix 2), there are two functional units: 1 t of cement and 1 t of methanol.

[Permitted matters]

- When there are multiple functional units and when it is extremely difficult to observe, obtain, and estimate the data, only one functional unit may be assumed.
- When there are multiple functional units and the amount of GHG emissions/avoided emissions associated with a certain functional unit is considerably small, the corresponding functional unit may be ignored.
- In general, wide scope of the assessment is preferable. However, when the amounts of GHG emissions from both “reference system” and “CR2 system” are the same or when parts of the systems can be regarded as the same, those systems may be excluded from the scope of assessment with clear explanation.

Note 1: For methanol production, both methanol produced by an existing process and by CCU may be regarded to go through the same processes after shipment. The scope of assessment; therefore, may include only methanol production process, and exclude the processes after methanol shipment.

Note 2: In some cases, the main and co-products of a CR2 technology may contribute to significant GHG emission reductions, either indirectly or through ripple effects (e.g., reduction in chemical fertilizer use through soil plowing of biochar, reduction in GHG emissions from chemical fertilizer production). In such cases, the GHG emission reductions may be specifically and in detail described (and both positive and negative effects accounted for on a net basis) and accounted for as avoided GHG emissions by the CR2 technology.

5. Report

[Recommendation]

- When communicating the results of GHG emissions accounting with stakeholders and others, the communication method may vary depending on the purpose. The report for third parties should include the following requirements
  a. Definition of goal
  b. CR2 technology assessed
  c. Functional units (including storage period and geographical range)
  d. [Impact categories evaluated]
  e. Definition of scope
  f. List of GHG accounted and global warming potential applied
  g. Methodologies of determination of the amount of GHG storage/isolation and the results
  h. Data collection and calculation procedures
  i. Data quality
  j. Interpretation
  k. Critical review

6. Critical review and verification

[Recommendation]

- The report should be subject to critical review or verification. However, it is not necessarily limited to a third party.

7. Glossary

CCS (carbon dioxide capture and storage): process consisting of the separation of CO_2 from industrial and energy related sources, transportation, and injection into a geological formation, resulting in its long-term isolation from the atmosphere (ISO/TR27915:2017)

(Below are auxiliary explanation of CCS by ISO 27917.)

Note 1 to entry: CCS is often referred to as Carbon Capture and Storage. This terminology is not encouraged because it is inaccurate: the objective is the capture of carbon dioxide and not the capture of carbon. Afforestation is another form of carbon capture that does not precisely describe the physical process of removing CO_2 from industrial emission sources.

Note 2 to entry: The term "sequestration" is also used alternatively to "storage". The term "storage" is preferred since “sequestration” is more generic and can also refer to biological processes (absorption of carbon by living organisms).

Note 3 to entry: Long term means the minimum period necessary for geological storage of CO2 to be considered an effective and environmentally safe climate change mitigation option.

Note 4 to entry: The term Carbon dioxide Capture, Utilization (or use) and Storage (CCUS) include the concept that isolation from the atmosphere could be associated with a beneficial outcome. CCUS is embodied within the definition of CCS to the extent that long term isolation of CO2 occurs through storage within geological formations. CCU is Carbon Capture and Utilization (or use) without storage within geological formations.

Note 5 to entry: CCS should also ensure long term isolation of CO2 from oceans, lakes, potable water supplies and other natural resources.

Carbon Dioxide Removal (CDR): Human activity capturing carbon dioxide (CO2) from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes enhancement of biological or geochemical CO2 sinks and direct air carbon capture and storage (DACCS), but excludes natural CO2 uptake not directly caused by human activities (Smith et al. 2024).

GHG (greenhouse gas): gaseous constituent of the atmosphere, natural or anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds (ISO/TR27915:2017)

GHG removal: total mass of GHG removed from the atmosphere over a specified period of time (ISO/TR27915:2017)

GHG/CO_2 emission reduction: calculated net decrease of GHG emissions between a baseline scenario and the output assessment target technology (ISO/TR27915:2017)

CCU (carbon dioxide capture and utilization): act of capturing carbon dioxide (CO_2) in exhaust gas or the atmosphere and converting it into products.

Reference documents

ISO 14040:2006 Environmental management — Life Cycle Assessment — Principles and framework

ISO 14044:2006 Environmental management — Life Cycle Assessment — Requirements and guidelines

ISO 27917:2017 Carbon dioxide capture, transportation and geological storage — Vocabulary — Cross-cutting terms

ISO/TR27915:2017 Carbon dioxide capture, transportation and geological storage – Quantification and verification

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Appendix. Examples for Accounting of GHG Emissions and Avoided Emissions in CR2 Technology systems

Appendix 1. GHG emissions and avoided emissions in a power generation CCS system

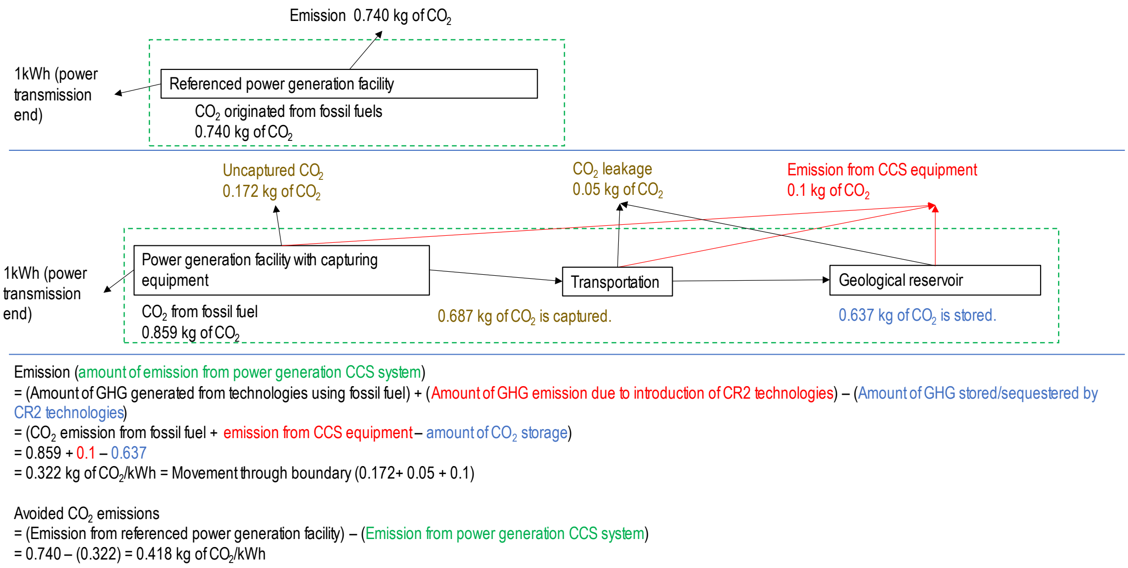


Figure A-1. Example of GHG emissions and avoided emissions in a power generation CCS system

Appendix 2. GHG emissions and avoided emissions in CCU system that uses raw fossil fuel

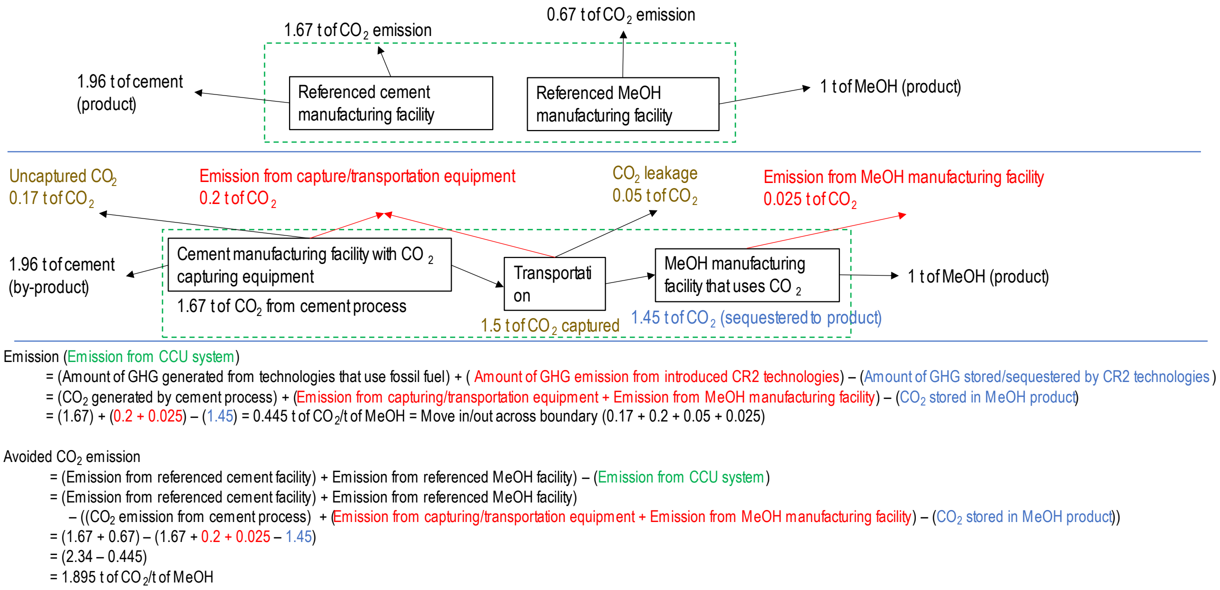
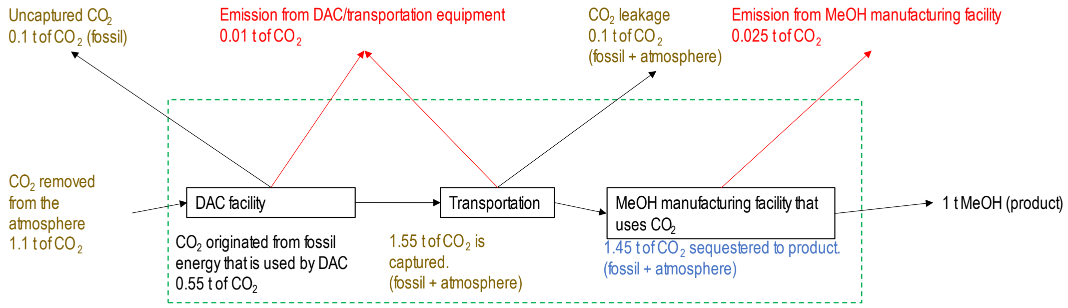


Figure A-2. Example of GHG emissions and avoided emissions in CCU system that uses raw fossil fuel (two functional units)

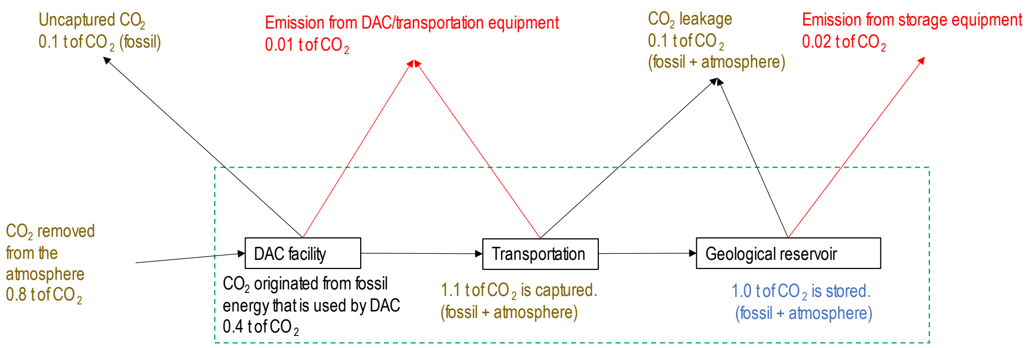
Appendix 3. GHG emission from DAC + CCU system (removal if the value is negative)



Emission (emission from DAC + CCU system)
= (Amount of GHG generated by technologies that use fossil fuel) + (Amount of GHG emission from introduced CR2 technologies) – (Amount of GHG stored/sequestered by CR2 technologies)
= (CO_2 generated from fossil fuel) +(Emission from DAC/transportation equipment + Emission from MeOH manufacturing facility) – (CO_2 stored in MeOH product)
= 0.55 + (0.01 + 0.025) – 1.45
= -0.865 t of CO_2/t of MeOH = Move in/out across boundary (0.1 + 0.01 + 0.1 + 0.025 – 1.1)

Figure A-3. Example of GHG emission from DAC + CCU system (removal if the value is negative)

Appendix 4 GHG emission from DAC + CCS system (or removal if the value is negative)



Amount of Emission = (Amount of GHG generated from technologies that use fossil fuel) + (Amount of GHG emission from introduced CR2 technologies) – (Amount of GHG stored/sequestered by introduced of CR2 technologies)
= (CO_2 generated from fossil fuel that is used by DAC) + (Emission from DAC/transportation equipment + emission from storage facility) – (Amount of CO_2 storage)
= 0.4 + (0.01 + 0.02) – (1.0)
= -0.57 t of CO_2/t of CO_2 stored = Move in/out across boundary (0.1 + 0.01 + 0.1 + 0.02 – 0.8)

Figure A-4. Example of GHG Emission from DAC + CCS system (or removal if the value is negative)

Appendix 5. GHG emission (or removal if the value is negative) and avoided emissions in mixed combustion BECCS (fossil: biomass = 1:2) system

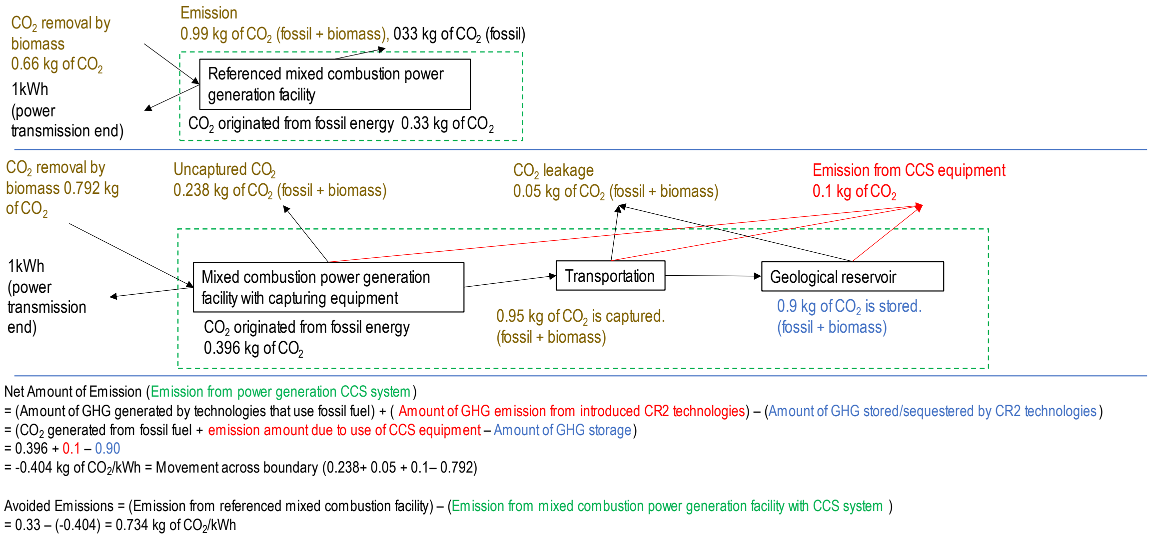


Figure A-5. Example of GHG emission (or removal if the value is negative) and avoided emissions in mixed combustion BECCS (fossil: biomass = 1:2) system

Appendix 6. GHG emission accounting in biochar (or removal if the value is negative)

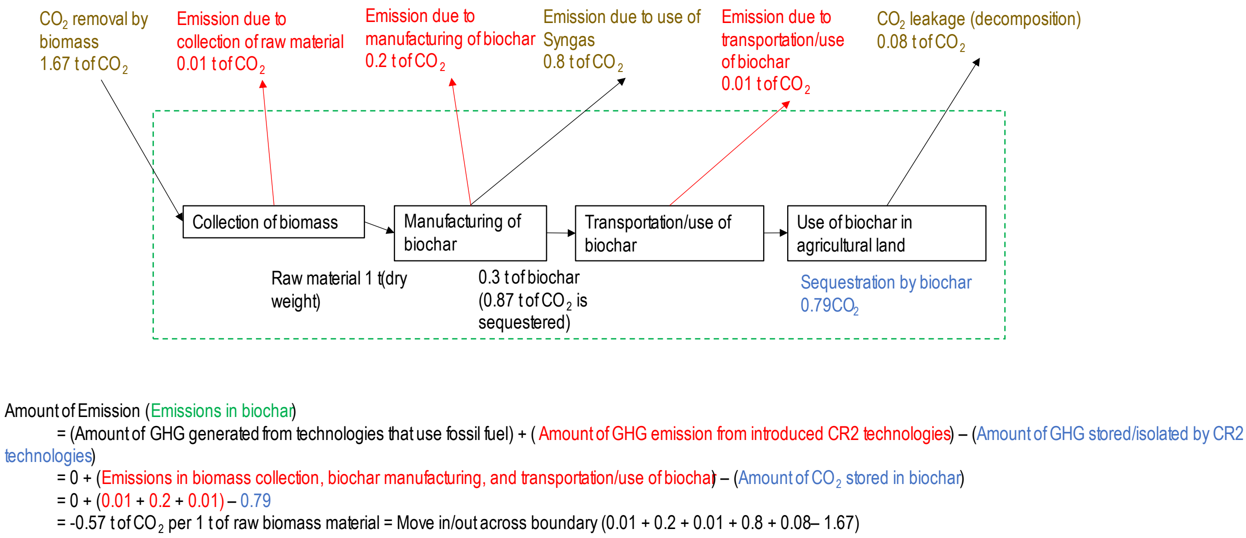


Figure A-6. Example of GHG emission accounting in biochar (or removal if the value is negative)