LIFE CYCLE ASSESSMENT OF LIMENET COMBINED WITH BIOMASS GASIFICATION FOR REMOVING AND STORING ATMOSPHERIC CO_2

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Introduction

LIMENET is a technology for capturing and storing CO_2 in the form of bicarbonate ions (HCO_3^-) in the sea using slaked lime ($Ca(OH)_2$). The chemical background of the process is the same of Buffered Accelerated Weathering of Limestone (BAWL) presented by Caserini et al. (2021). Instead of BAWL, the benefit of LIMENET process consists in the use of only slaked lime which reacts faster with CO_2 forming HCO_3^- avoiding the installation of long submarine pipeline necessary for the slow dissolution of $CaCO_3$ in the seawater. Thus, LIMENET stores CO_2 coming from the calcination of calcium carbonate for the production of slaked lime.

The proposed process is a combination of the biomass gasification with the limestone for producing negative emissions. Atmospheric CO_2 is absorbed by plants through the photosynthesis. Then, the plant biomass is used as feedstock for gasification. The hot syngas released is used for the calcination of limestone. All the CO_2 produced by during the process is stored in the sea in the form of bicarbonates using the slaked lime produced from the calcination.

In this report, the potential environmental impacts of the NET LIMENET-DAC are evaluated using Life Cycle Assessment (LCA) methodology standardized by the ISO norms 14040 and 14044 (ISO, 2006a; 2006b). LCA applied to LIMENTE-DAC will be presented following the phases of LCA:

- **Goal and scope** where the aim of the study, the functional unit (FU), the system boundary, the selected impact categories and the main assumptions are presented;
- **Life cycle inventory** where the material and energy consumptions of the process are expressed per FU;
- **Life cycle impacts assessment** where the potential environmental impacts will be analysed;
- **Interpretation**, LCA phase applied that during the whole study to guarantee that LCA is coherent with the defined goal and scope and the inventory is complete and proper for the study aim, and to analyse the results of LCA.

Goal and scope

The aim of the study is to assess the potential environmental impacts of the LIMENET process combined with biomass gasification according to LCA methodology through a “cradle to grave” approach. Special focus on overall potential greenhouse gas (GHG) emissions is given in order to assess the efficacy and the efficiency of LIMENET process combined with biomass gasification, i.e., negative emissions are achieved and how much respectively. In addition to Climate change impact, the potential impacts in other 15 impact categories (resumed in Table 1) are assessed applying Environmental Footprint (EF) method implemented in SimaPro software.

The potential impacts and the material and energy data of the process are referred to the Functional Unit (FU) which should represents the function of the process. In this LCA, 1 tonne of CO_2 removed from the atmosphere and stored in the form of HCO_3^- in the sea is chosen as FU.

The mass and energy flows are reported in Figure 1, where the system boundaries of the study through LCA are shown.

Table 1. Impact categories of EF method with their impact category indicator and impact category characterization model for the impacts assessment.

	Impact category	Impact category indicator	Impact category characterization model
1	Climate change	kg CO_2 eq	Bern model – Global Warming Potentials (GWPs) over a 100-year time horizon (IPCC, 2013)
2	Ozone depletion	kg CFC-11 eq	EDIP model based on the Ozone Depletion Potentials (ODP) of the World Meteorological Organization (WMO) over an infinite time horizon (WMO, 1999)
3	Ionising radiation, HH	kBq U_{235} eq	Human Health effect (Dreicer et al., 1995)
4	Photochemical ozone formation, HH	kg NMVOC eq	LOTOS-EUROS (Van Zeim et al., 2008)
5	Particulate matter	disease inc.	PM method (Fantke et al., 2016)
6	Human toxicity, non-cancer	CTUh	USEtox (Rosenbaum et al., 2008)
7	Human toxicity, cancer	CTUh	USEtox (Rosenbaum et al., 2008)
8	Acidification	mol H^+ eq	Accumulated Exceedance (Seppälä et al., 2006; Posch et al., 2008)
9	Eutrophication, freshwater	kg P eq	EUTREND (Struijs et al., 2009)
10	Eutrophication, marine	kg N eq	EUTREND (Struijs et al., 2009)
11	Eutrophication, terrestrial	mol N eq	Accumulated Exceedance (Seppälä et al., 2006; Posch et al., 2008)
12	Ecotoxicity, freshwater	CTUe	USEtox (Rosenbaum et al., 2008)
13	Land use	Pt	CFs set re-calculated by JRC starting from LANCA® v 2.5 as baseline model. (Bos et al., 2016)
14	Water use	m^3 depriv.	Available Water Remaining (Boulay et al., 2016)
15	Resource use, fossils	MJ	ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016).
16	Resource use, minerals and metals	kg Sb eq	ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016).

Life cycle inventory

The mass and energy flows of the process (represented in Figure 1) are provided by the process designers. Further data are collected from Ecoinvent (version 3.8) database. In Table 2, data and Ecoinvent processes are reported.

The analysed system is assumed a TRL9 LIMENET plant producing 100,000 tCO_2 per year working 8000 hours for 25 years.

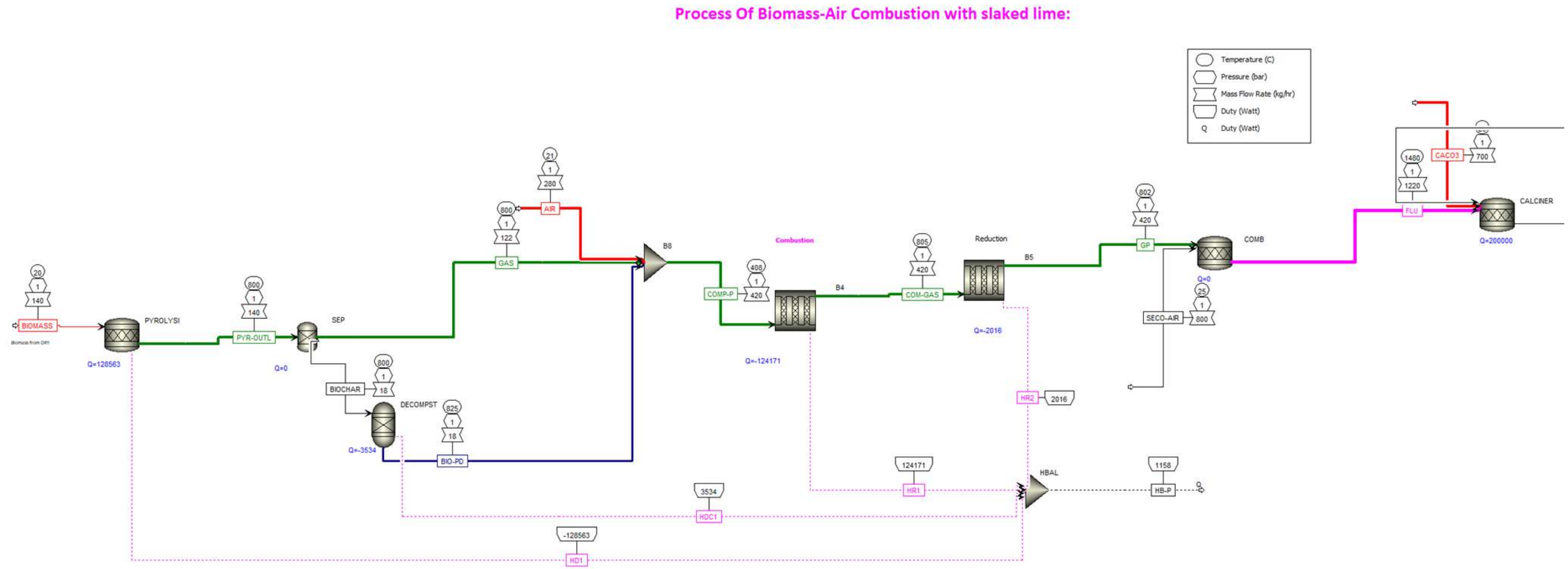

Figure 1. LIMENET-DAC scheme and system boundaries provided by the process designers (data are expressed per FU).

Table 2. Life cycle inventory of LIMENET combined with biomass gasification.

Process unit	Process phase	Ecoinvent process	Amount per FU	Note
Biomass supply	Biomass production	Wood chips, wet, measured as dry mass | softwood forestry, pine, sustainable forest management	665 kg	Wood chips with carbon content of 51% dry matter and LHV equal to 18.76 MJ/kg
	Biomass transport	Transport, freight, lorry, unspecified	33 tkm	Assumed 50 km.
Limestone supply	Limestone production	Limestone, unprocessed | limestone quarry operation	2890 kg	Including blasting material, land transformation, diesel for operating condition, particulate matter emission.
	Limestone transport	Transport, freight, lorry, unspecified	58 tkm	Assumed 20 km.
Electricity consumption	Electricity consumption	Electricity, medium voltage	194 kWh	Data from process designers for oxygen production.
Water supply	Water supply	Tap water	520 kg	Water necessary for slaked lime production calculated from stoichiometry
Construction materials	Oxygen plant	Oxygen, liquid {RER}| air separation	793 kg	Assumed Vacuum Pressure Swing Adsorption process
	Rotary kilns	Lime, hydraulic | production	6417 kg	Calculated on the basis of the slaked lime per FU considering all the machinery of the plant that are rotary kilns, i.e., gasifier, calciner and slaker.
	Pipeline	Polyethylene, high density, granulate	1.34E-3 kg	Assuming a commercial HDPE pipeline length 3 km, outer diameter 2500, inner diameter 2378
		Extrusion, plastic pipes	1.34E-3 kg	

Life cycle impact assessment

The potential impacts are calculated assuming current Norwegian energy mix because it is currently about 95% renewable and LIMENET process will use renewable energy. The results are shown in Table 3

Table 3. Total of all impact categories.

	Impact category	**Unit of measure (UOM)**	**UOM/FU**
1	Climate change	kg CO_2 eq	60.0
2	Ozone depletion	kg CFC-11 eq	1.01E-05
3	Ionising radiation, HH	kBq U_{235} eq	7.3
4	Photochemical ozone formation, HH	kg NMVOC eq	0.51
5	Particulate matter	disease inc.	6.36E-06
6	Human toxicity, non-cancer	CTUh	1.31E-06
7	Human toxicity, cancer	CTUh	1.01E-07
8	Acidification	mol H^+ eq	0.45
9	Eutrophication, freshwater	kg P eq	1.26E-02
10	Eutrophication, marine	kg N eq	0.14
11	Eutrophication, terrestrial	mol N eq	1.7
12	Ecotoxicity, freshwater	CTUe	7827
13	Land use	Pt	88107
14	Water use	m^3 depriv.	753
15	Resource use, fossils	MJ	823
16	Resource use, minerals and metals	kg Sb eq	9.44E-04

The carbon dioxide removal efficiency (E_{CDR}) expressed as percentage is defined as the following equation.

$$E_{CDR}(\%) = \frac{(Climate\ change\ total\ impact) - CDR}{CDR} \times 100$$

Where *Climate change total impact* is the total impact in that category, i.e., life cycle GHG emission of LIMENET combined with biomass gasification, and *CDR* is the amount of atmospheric CO_2 removed by the plant, i.e., 1 tonne of CO_2. As results, E_{CDR} of LIMENET combined with biomass gasification is about 94%. Thus, only 6% of the removed CO_2 has to be used for compensating life-cycle emissions of the LIMENET process.

In Figure 2, the contribution of each process unit for Climate change impact category is reported. Biomass supply contributes for about 50% (30.9 kgCO_2eq per 1 tonne of CO_2 removed) of the emissions of the process. Biomass supply includes biomass production and its transport to the LIMENET plant. Then, the second most impacting process unit is the limestone supply.

From the contribution analysis, where the contribution of the process unit to each impact is reported in Figure 3, the biomass supply is the most impacting process unit in Climate change, Ozone depletion and Land use.

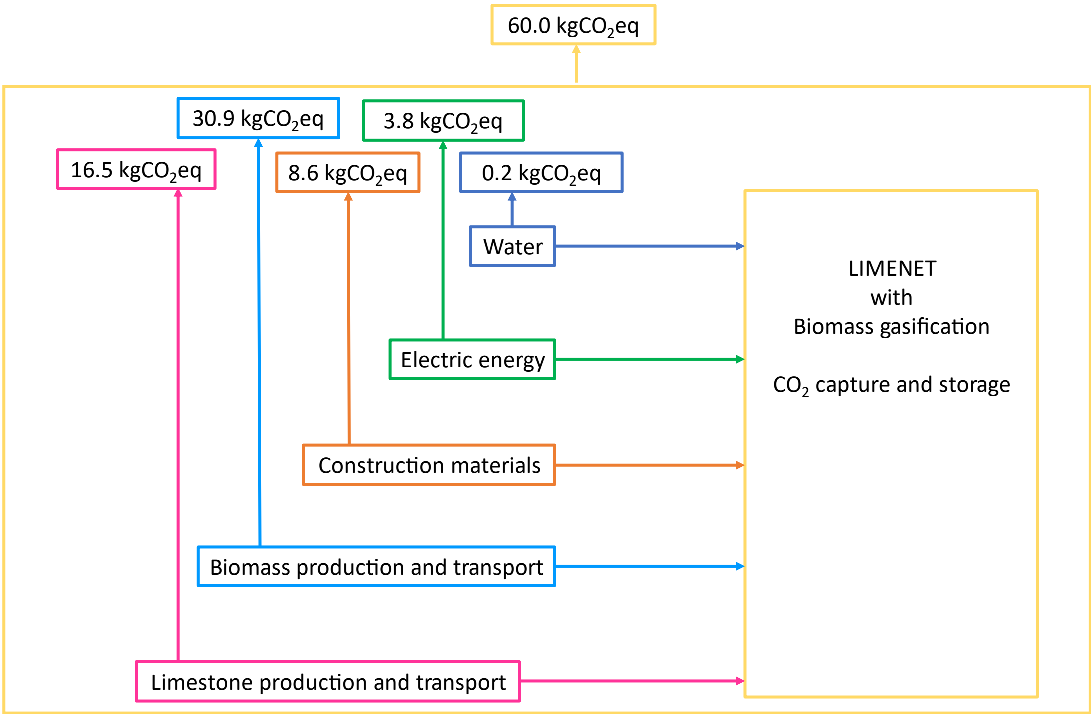

Figure 2. Process units contribution for Climate change impact category.

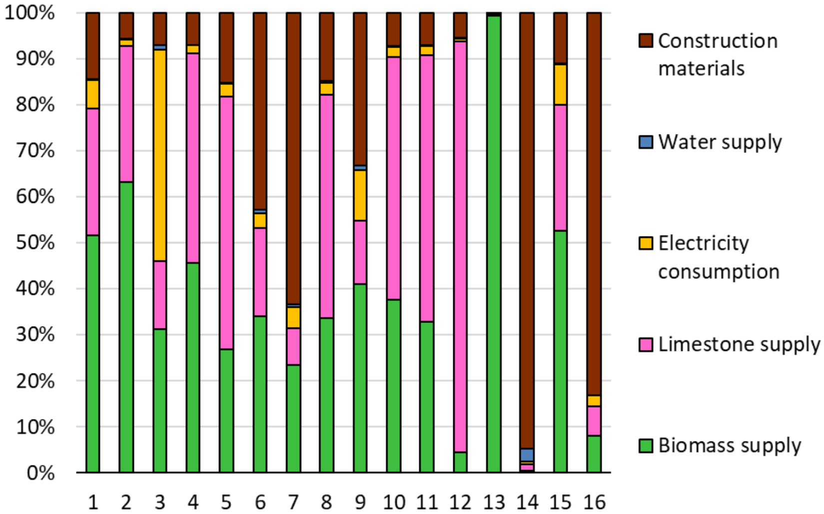

Figure 3. Contribution analysis of the LIMENET process combined with biomass gasification. On the x-axis the impact categories numbers referred to Table 1.

Conclusions

This LCA study evaluates the potential environmental impacts of LIMENET combined with biomass gasification process that removes CO_2 from the atmosphere and stores it in the sea as bicarbonate (Caserini et al., 2021).

The results show that the LIMENET process combined with biomass gasification produces negative emissions. The rate of carbon dioxide removal efficiency is equal to 94%, i.e., only around 6% of the removed CO_2 is necessary to offset life cycle GHG emissions of the process. This high rate of efficiency is already feasible in Norway where about 95% of the electricity is currently produced from renewables.

References

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