Feasibility, potential and environmental impacts of ocean alkalinity enhancement for removing CO_2 from the atmosphere and counteracting seawater acidification

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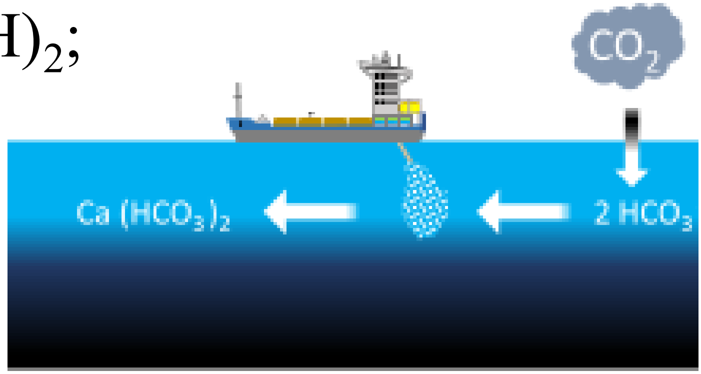
Artificial Ocean Alkalinisation (AOA)/ Ocean Alkalinity Enhancement (OAE)

- consists in spreading by means of ships alkaline material, e.g. $Ca(OH)_2$;
- enhances ocean CO_2 uptake, storing CO_2 as HCO_3^- ;
- increases locally pH addressing ocean acidification.



Outcomes:

1. Limestone world availability

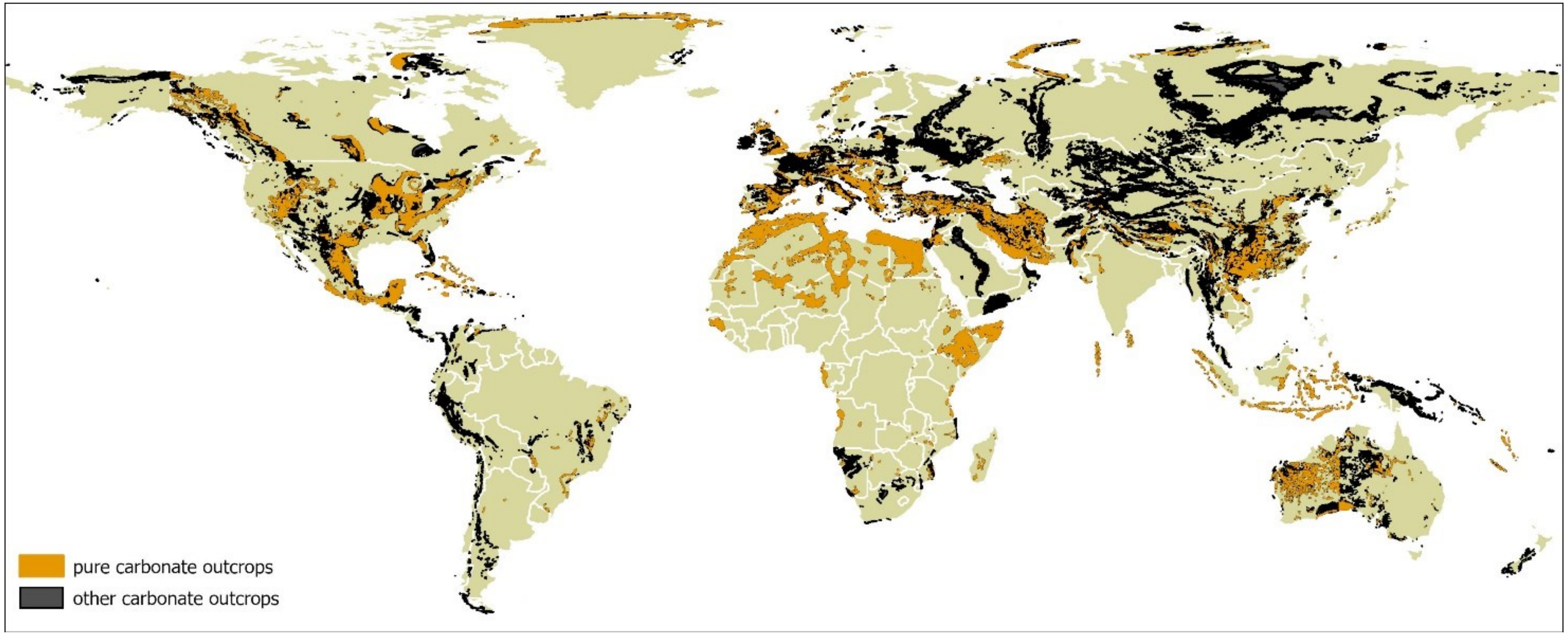
2. Potential environmental impacts of producing decarbonized $Ca(OH)_2$

3. Feasibility of 2 logistic scenarios for discharging $Ca(OH)_2$ into seawater

Limestone world availability

- For achieving Paris Agreement temperature goal in 2100: 500-1,000 Gt CO_2
- Pure carbonates (<10 km from the coastline, below bare ground or scrub/shrub): 5,000 Gt
- Lower potential of olivine resources (in the order of a few hundred Gt)
- Annual production of limestone: 6.6 Gt/y ≈ annual coal production 7.3 Gt/y (2017)

Caserini, S., Storni, N., Grosso, M. (2022) The Availability of Limestone and Other Raw Materials for Ocean Alkalinity Enhancement. Global Biogeochemical Cycles



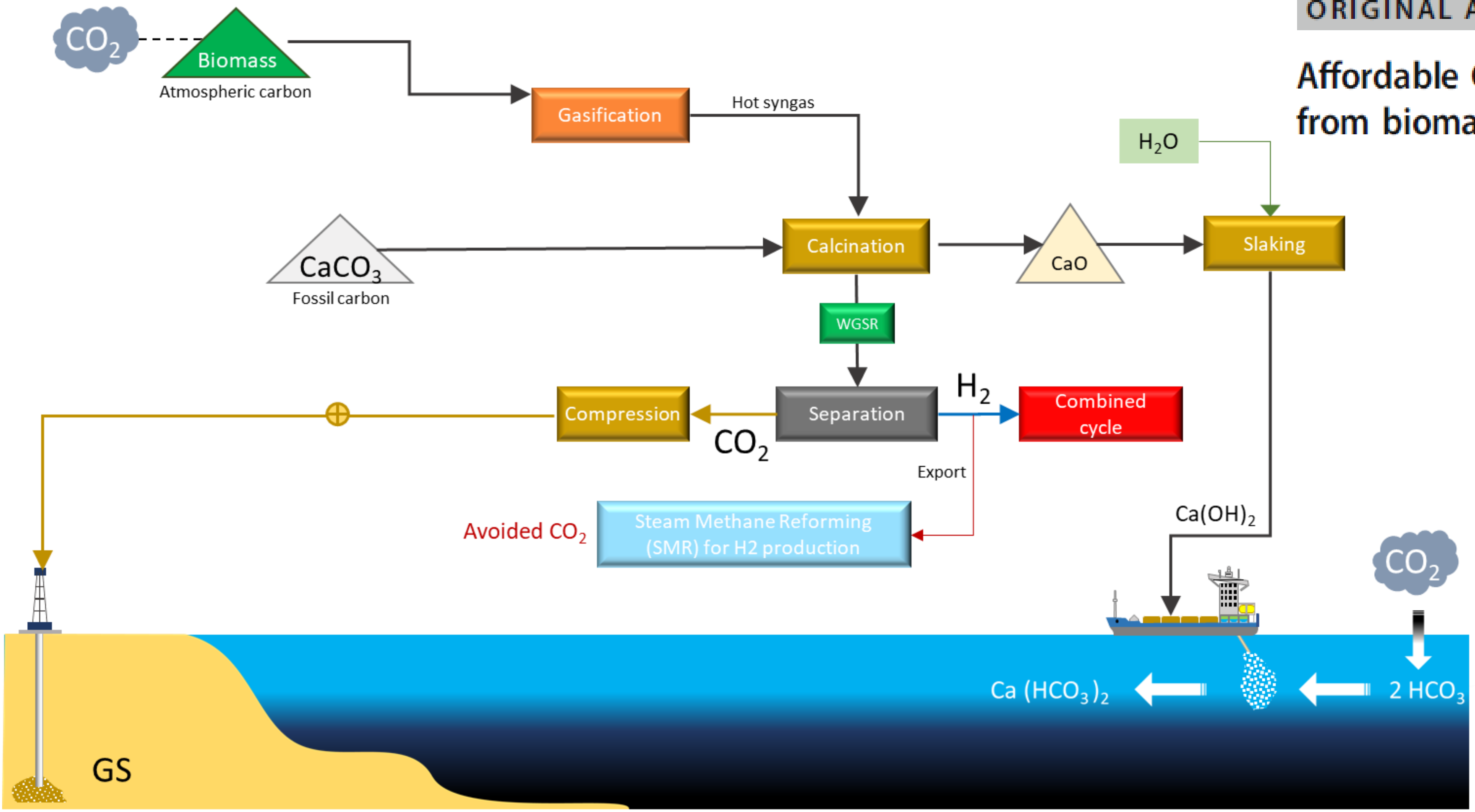
Pure carbonate and other carbonate rocks outcrops in the world data from: Hartmann, J., Moosdorf, N., (2012) The new global lithological map database GLiM: A representation of rock properties at the Earth surface, Geochemstry Geophysics Geosystems, 13, Q12004.

Desarc – Maresanus CDR process for decarbonized Ca(OH)2

Mitigation and Adaptation Strategies for Global Change
https://doi.org/10.1007/s11027-018-9835-7

ORIGINAL ARTICLE

Affordable CO_2 negative emission through hydrogen from biomass, ocean liming, and CO_2 storage



Life Cycle Assessment – goal and scope

Goal: assess the **overall greenhouse gas emissions** and the other potential environmental impacts for the CDR technology and comparing the different configurations.

Scope

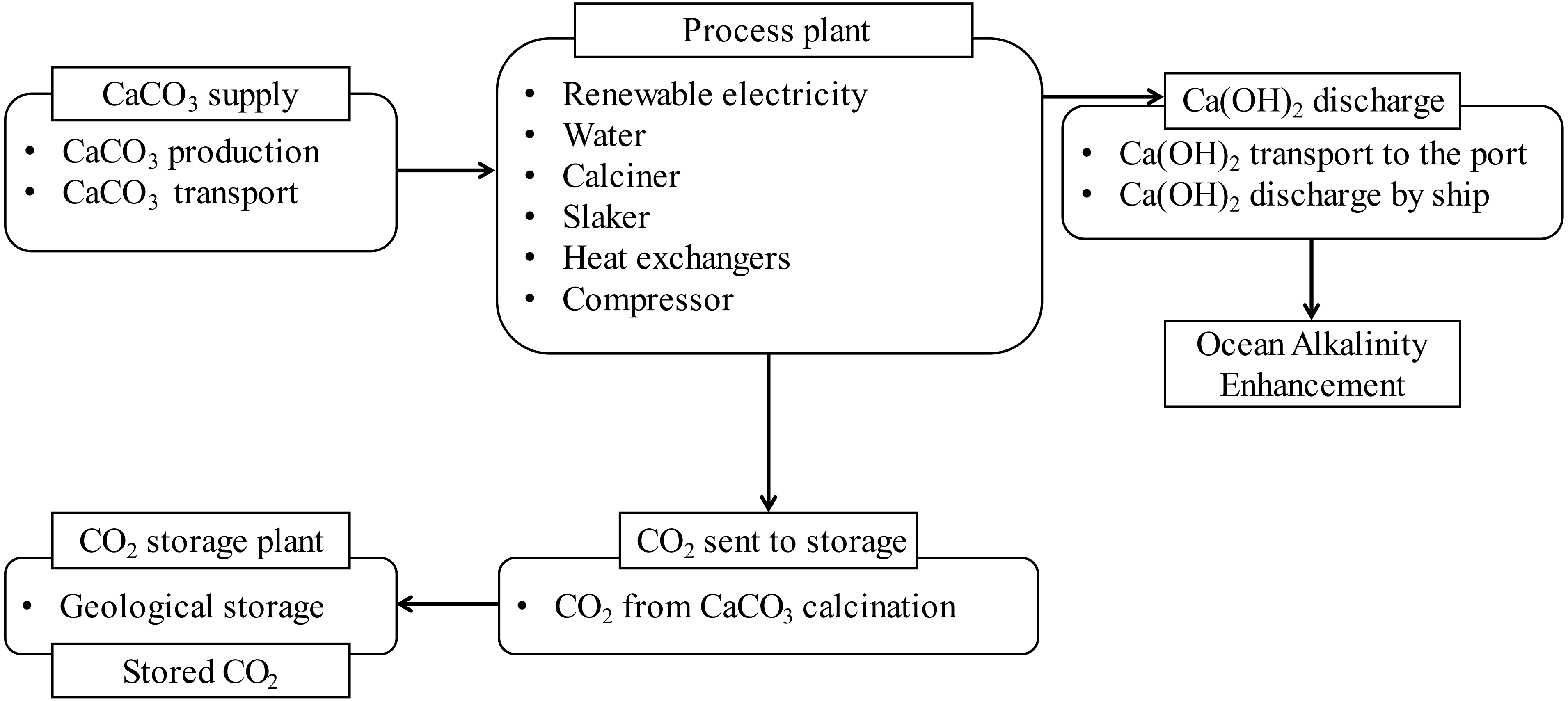
Functional Unit (FU): 1 kg of slaked lime - $Ca(OH)_2$ produced and discharged

16 categories considered: 1) **Climate change** 2) Ozone depletion 3) Ionizing radiation HH 4) Photochemical ozone formation 5) Respiratory inorganics 6) Non-cancer human health effects 7) Cancer human health effects 8) Acidification terrestrial and freshwater 9) Eutrophication freshwater 10) Eutrophication marine 11) Eutrophication terrestrial 12) Ecotoxicity freshwater 13) Land use 14) Water scarcity 15) Resource use, energy carriers 16) Resource use, mineral and metals (EF method 1.0)

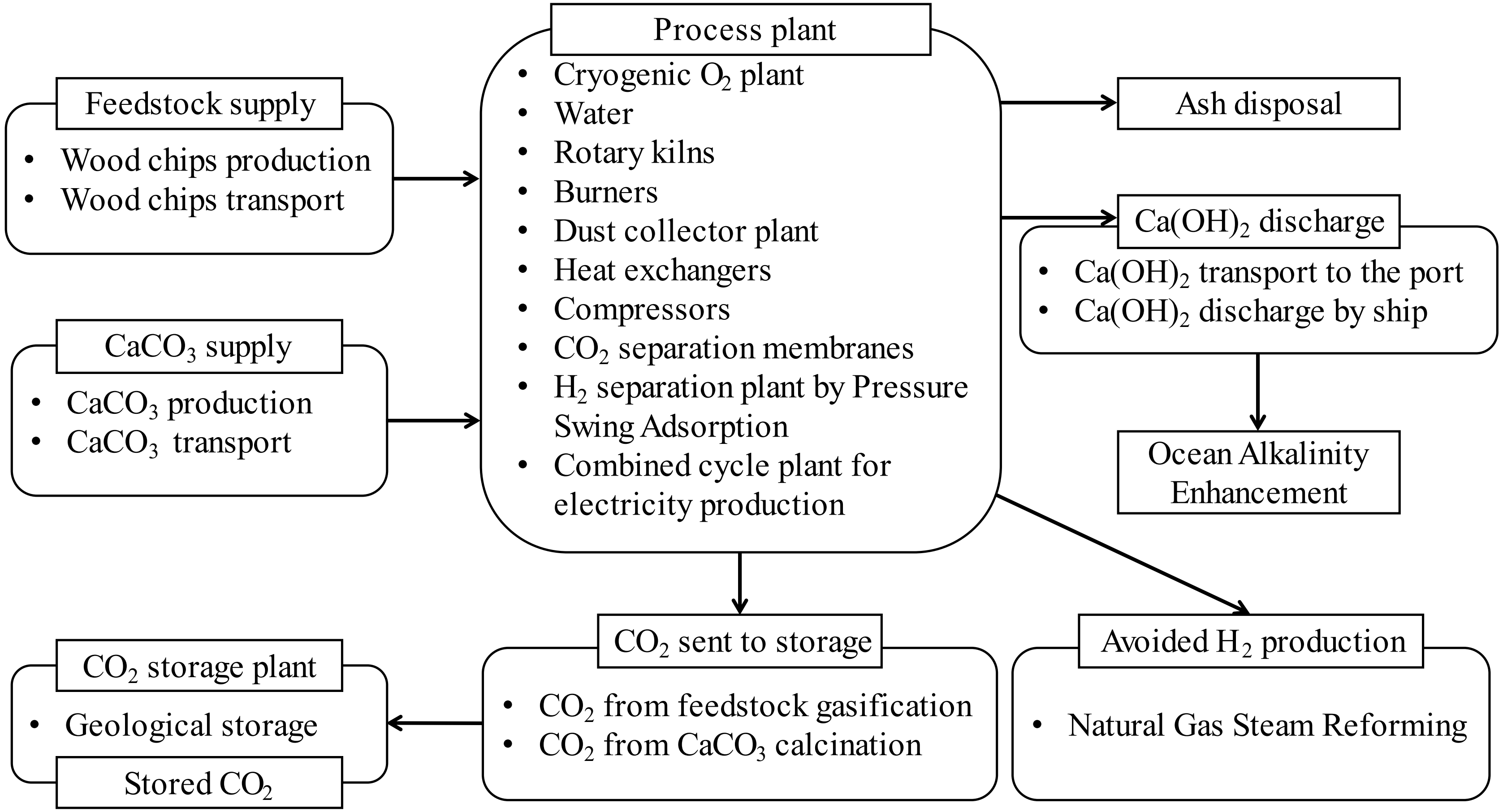
Data: process designers, scientific literature and ecoinvent 3.5

Software: SimaPro 9.0

System boundary of renewable electricity scenario

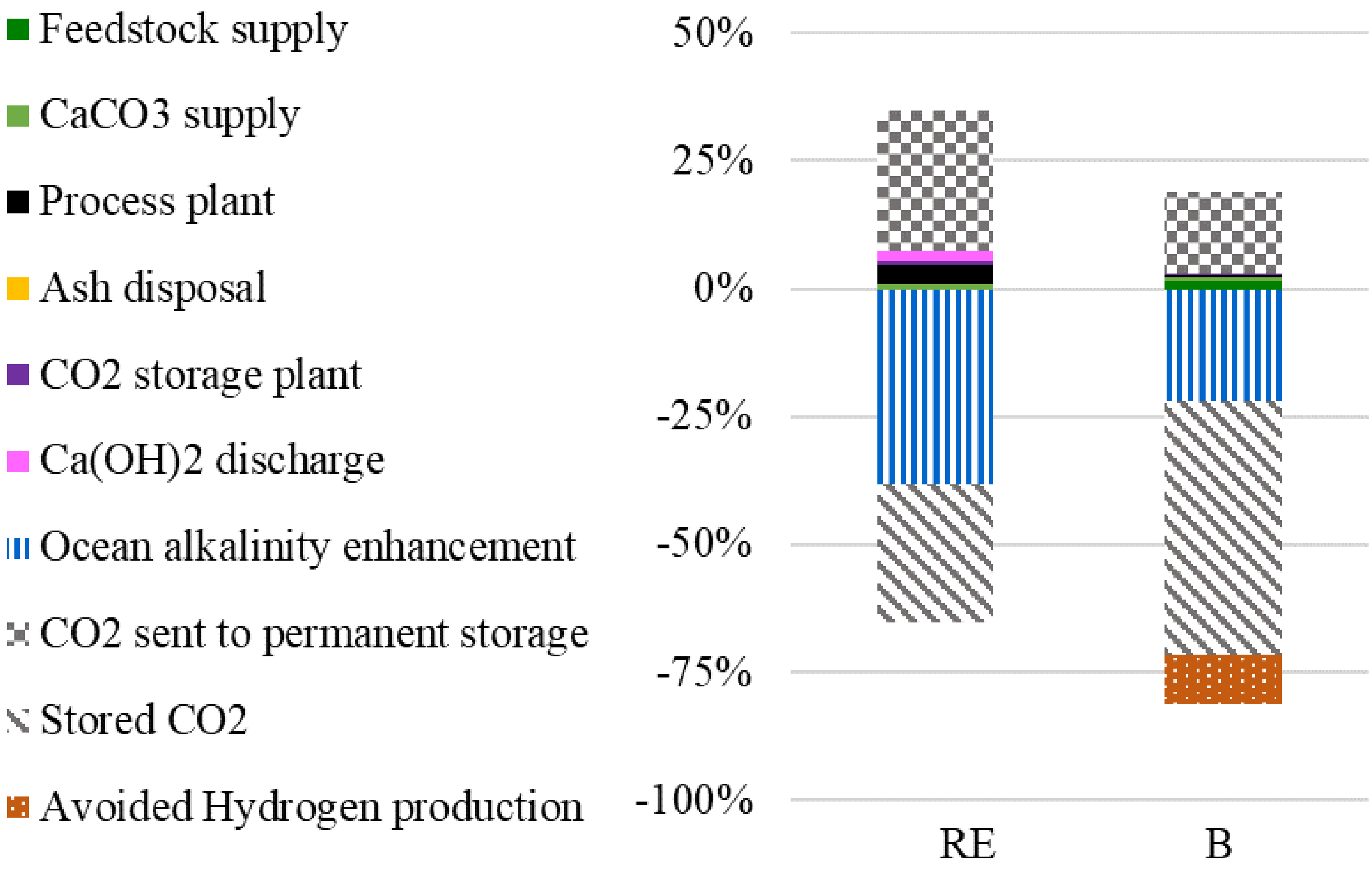


System boundary of biomass scenario



Climate change impact (kgCO_2eq/kg$Ca(OH)_2$)

RE	Biomass
-0.67	-2.3



Climate change impact ($kgCO_2eq/kgCa(OH)_2$)

RE	Biomass
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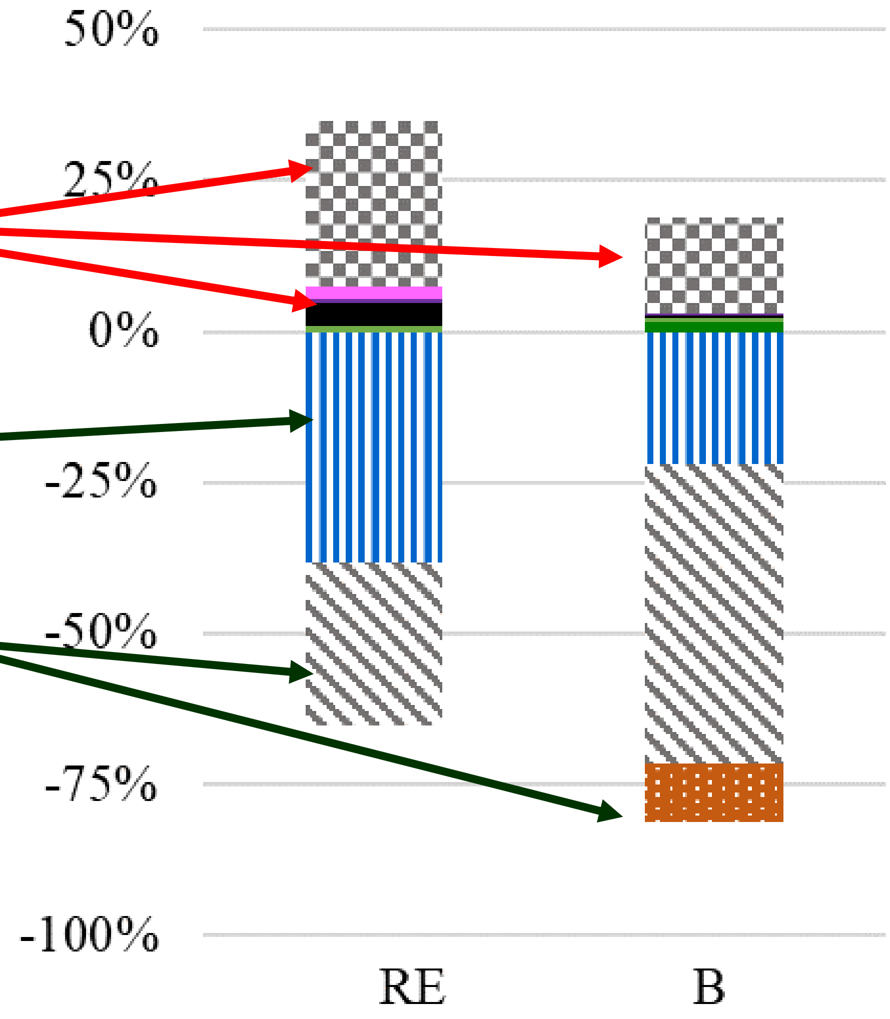
The system gives a carbon benefit in all scenarios.

The **potential CO_2eq emissions** are **lower** than the **potential negative emissions** (sum of removed CO_2, stored CO_2, avoided CO_2).



CO2 sent to permanent storage

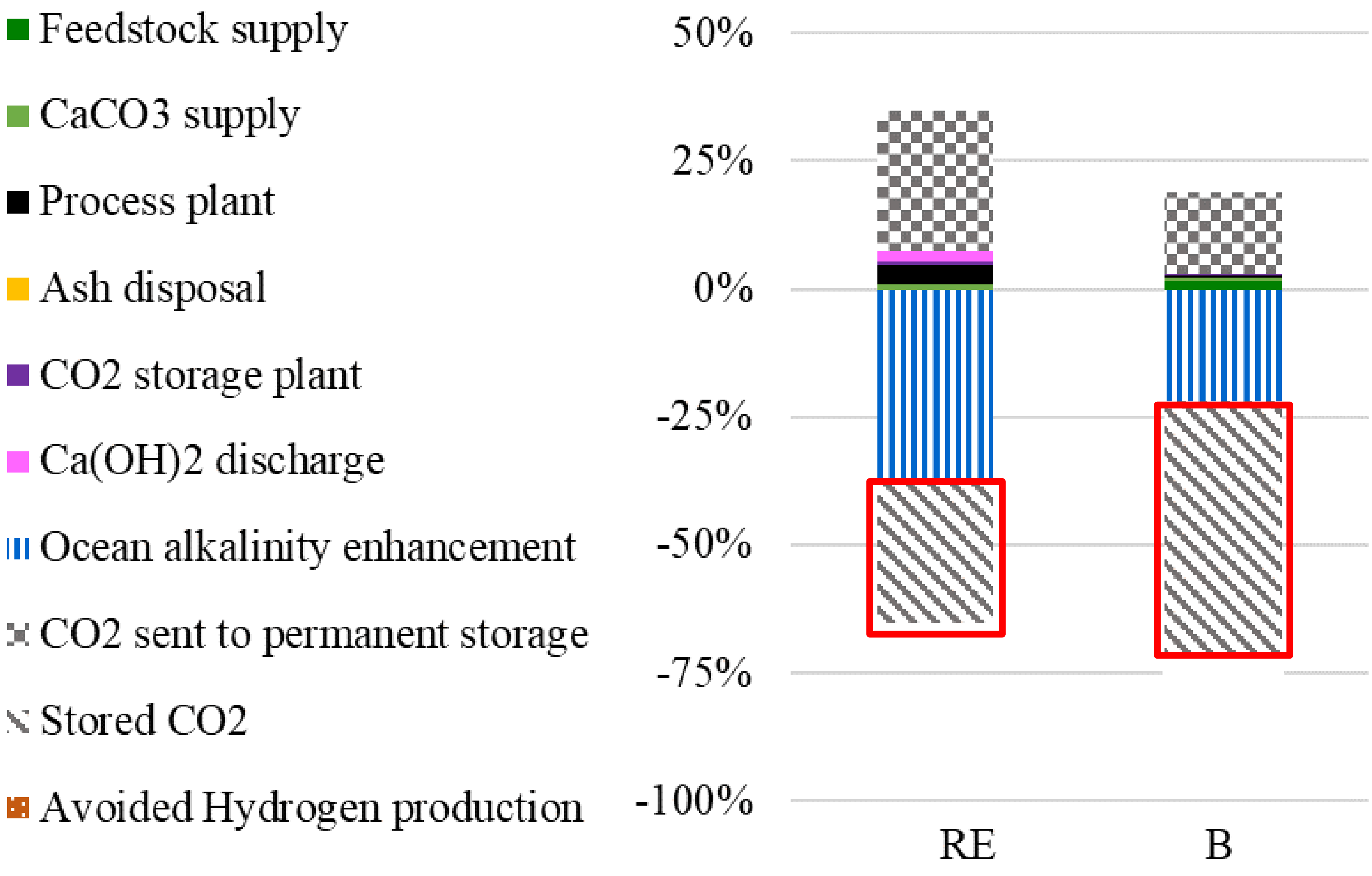
Stored CO2

Avoided Hydrogen production

Climate change impact ($kgCO_2eq/kgCa(OH)_2$)

RE	Biomass
-0.67	-1.9

- **Carbon removal also without considering avoided impacts from H_2 production surplus**
- **Essential CO_2 storage to achieve negative emissions**



Total impacts

Impact categories	UOM	Renewable electricity scenario RE (UOM/FU)	Biomass scenario B (UOM/FU)	Scenario with lower impact / higher benefit
Climate change	**kg CO2 eq**	**-0.67**	**-2.30**	B
Ozone depletion	**kg CFC11 eq**	2.32E-8	3.06E-8	RE
Ionising radiation, HH	**kBq U-235 eq**	1.31E-2	1.23E-2	B
Photochemical ozone formation, HH	**kg NMVOC eq**	1.33E-3	1.16E-3	B
Respiratory inorganics	**disease inc.**	1.16E-8	8.84E-9	B
Non-cancer human health effects	**CTUh**	5.12E-8	1.44E-7	RE
Cancer human health effects	**CTUh**	7.05E-9	4.05E-9	B
Acidification terrestrial and freshwater	**mol H+ eq**	2.30E-3	1.60E-3	B
Eutrophication freshwater	**kg P eq**	1.24E-4	2.58E-5	B
Eutrophication marine	**kg N eq**	4.39E-4	4.08E-4	B
Eutrophication terrestrial	**mol N eq**	4.86E-3	4.62E-3	B
Ecotoxicity freshwater	**CTUe**	2.30E-1	2.93E-1	RE
Land use	**Pt**	6	300	RE
Water scarcity	**m3 depriv.**	0.126	0.477	RE
Resource use, energy carriers	**MJ**	2.1	-3.6	B
Resource use, mineral and metals	**kg Sb eq**	3.51E-6	4.42E-7	B

Total impacts

Scenario RE best performance in 5 IC
Scenario B best performance in 11 IC (2 negative)

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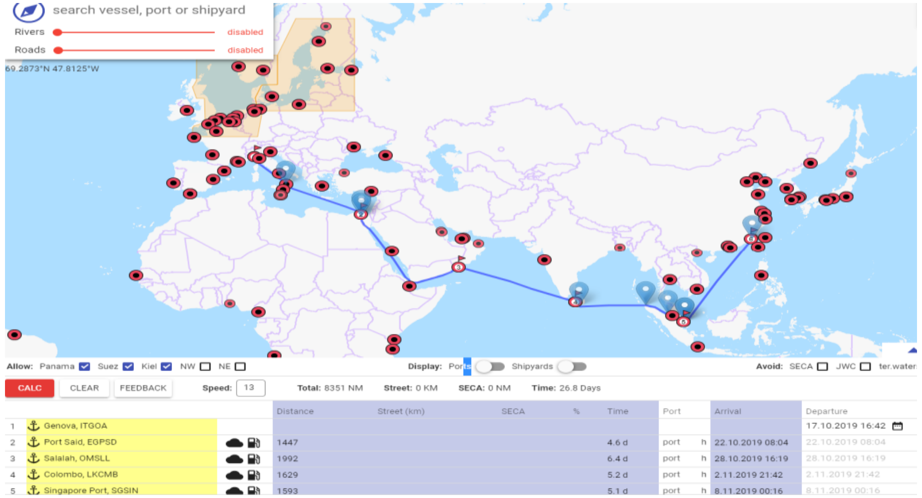
Logistic scenarios for discharging $Ca(OH)_2$ into seawater

1. **New dedicated ships**
2. **Existing ships using part of the cargo**

Objectives

- Keeping discharge rate range as low as possible
- Limiting water volume used
- Efficient management of $Ca(OH)_2$
- Maximize the amount discharged



Caserini et al. (2021) Potential of Maritime Transport for Ocean Liming and Atmospheric CO_2 Removal. Frontiers in Climate, 3, 575900.

Scenario 1: new dedicated ships

Advantages

- Enhanced flexibility in the choice of discharge parameters
- High efficiency of water use
- Higher amount of $Ca(OH)_2$ discharged
- Better logistic management
- Dedicated routes

Disadvantages

- Higher capital costs
- Longer project execution times

Total potential discharge with 1000 ships :
1.3 Gt $Ca(OH)_2$ /year

Scenario 2: partial cargo of the existing ships

Bulk carriers and container ships: only 17% of total fleet, but 53% of total active tonnage of the global commercial fleet (IMO - International Maritime Organization, 2014).

Advantages

- Minor modifications of the ships for the purpose
- Lower operative costs
- Bulk carriers: long journeys allow low discharge rates
- Container ships: intermediate stops exploitable to reload the $Ca(OH)_2$

Disadvantages

- Need of dedicated $Ca(OH)_2$ loading facilities in ports
- Additional time for vessel loading and unloading in the ports for the reload

Total potential discharge with only 1 load: 1.7 Gt $Ca(OH)_2$ /year

Total potential discharge with 2 or more reloads: 4.0 Gt $Ca(OH)_2$ /year

Thank you for your attention

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