ACO2NE

Affordable CO_2 negative emissions through gasification, ocean alkalinization and CO_2 storage

Executive summary

The aim of the project is to achieve CO_2 negative emissions in an affordable manner. CO_2 concentration in the atmosphere is one of the important environmental problems of this era, as testified also by international treaties like the Paris agreement: the aim of the project is to take away CO_2 from the atmosphere combining different innovative processes.

The project starts with the study of an innovative chemical process that combines gasification and calcination, two well-known and established processes. Revenues are ensured by the hydrogen produced; other products are CO_2 and slaked lime.

To effectively achieve negative emissions, not only the CO_2 produced is stored, but this chemical process is followed up with ocean liming, i.e. the dispersion of slaked lime, one of the products, in the ocean.

The expected outcome of this study is a complete feasibility analysis of the process in its whole, from the plant to the CO_2 storage and the ocean liming, without neglecting the economical perspective.

Considering that the process can start using several fuels, ocean liming can be performed in several regions and the plant itself can be located in different parts of the world, multiple solutions have been explored.

After a thorough investigation of all the relevant points, the project ended with results about the best plant location, the ocean liming location and expected time period of ocean liming, the expected profitability of the process and the best combination of fuel and CO_2 storage to be used to achieve the goals.

Key Words

Ocean alkalinization, CO_2 storage, Negative Emissions, Gasification, Calcination

The group of ACO2NE the day of the final presentation

PRINCIPAL ACADEMIC TUTOR
Mario Grosso
DICA, Politecnico di Milano

ACADEMIC TUTOR
Stefano Caserini
DICA, Politecnico di Milano
Arianna Azzellino
DICA, Politecnico di Milano
Caterina Lanfredi
CoNISMa, DICA, Politecnico di Milano
Beatriz Barreto
DICA, Politecnico di Milano

EXTERNAL INSTITUTIONS
CO2Apps
CoNISMa

EXTERNAL TUTOR
Giovanni Cappello
Dennis Ross

TEAM MEMBERS

Mohamed Amr Aly, Petroleum Engineering, Politecnico di Torino

Alberto Bocchinfuso, Automation and Control Engineering, Politecnico di Milano

Matteo Bolognesi, Management Engineering, Politecnico di Milano

Sachin Nakkarike Aravinda, Mechanical Engineering, Politecnico di Milano

Davide Renda, Chemical Engineering, Politecnico di Milano

Gandolfo Scialabba, Aerospace Engineering, Politecnico di Torino

Project description written by the Principal Academic Tutor

Mounting research suggests that negative emissions technologies (NETs) have to play a major role in any global strategy to stabilize the climate, because a simple reduction of CO_2 emissions won't be sufficient to reach ambitious climate targets. Several published studies show that halting global warming at 2°C is likely to require CO_2 to be removed from the atmosphere on a large scale by the second half of this century.

Despite their significant mitigation potential, all of the known NETs have limiting factors, such as cost and energy requirements (i.e. for direct air capture), logistics of spreading materials over large areas (i.e. for enhanced weather technologies), and potential competition for land and freshwater (i.e. for afforestation and bioenergy with carbon capture and storage). Thus, there is an absolute need to find new solutions to reduce the CO_2 content of the atmosphere.

A new process is being developed, combining different technologies that address the CO_2 issue in terms of removing it from the atmosphere as well as decreasing its concentration in the oceans.

About 40% of the CO_2 released into the atmosphere by human activities is absorbed by the oceans. This helps slowing the rate of global warming but also increased ocean acidity, posing a serious threat to marine life.

The new technology includes coal gasification, CaO production, ocean alkalinisation, H_2 production and final CO_2 deep-water storage

The most critical aspects of the new proposed process need to be addressed, in order to come out with a feasibility study paving the road to a subsequent experimental stage, and later on to a pilot scale application.

This requires competences on the process design and optimization, on ocean chemistry, on mass and energy balances, on environmental assessment. Particular attention needs to be paid to the legislative and permitting issues, as well as to the acceptance of such an unconventional approach by the population and stakeholders. Communication then needs to play an important role.

Expected results are a preliminary validation of the feasibility of the technology, as well as some indications on possible sites where to apply it worldwide.

Team description by skill

Mohamed Amr Aly,

Alberto Bocchinfuso, Automation and Control Engineering, Politecnico di Milano: studied the ocean liming, in particular the ships that can be used.

Matteo Bolognesi, Management Engineering, Politecnico di Milano: studied the economic feasibility of the process.

Sachin Nakkarike Aravinda, Mechanical Engineering, Politecnico di Milano: studied the ocean liming process, ocean parameters in particular.

Davide Renda, Chemical Engineering, Politecnico di Milano: studied the technical feasibility of both the gasification and the calcination process for different configurations.

Gandolfo Scialabba, Aerospace Engineering, Politecnico di Torino: studied the ocean liming process, especially the mixing process in the wake of a ship.

Goal

CO_2 is a greenhouse gas which is causing the increase of the global temperature. Due to a rising attention from the public opinion, many nations signed an agreement in Paris setting a limit to the amount of CO_2 which can be emitted without causing any further increases of the global temperature. The aim of this project is not only to avoid any further emission but mainly achieving Negative Emission, i.e. the removal of part of the already existing CO_2 in the atmosphere.

As better explained later on, negative emissions are achieved through ocean liming, an innovative process still under active research. This process represents the core of the solution proposed, because it is the one that assures to achieve negative emissions, so particular attention is needed. Even though it is only theoretical, a deep study of its feasibility and potentiality are required. It is important to assess the potential environmental impact on the marine ecosystem due to ocean liming.

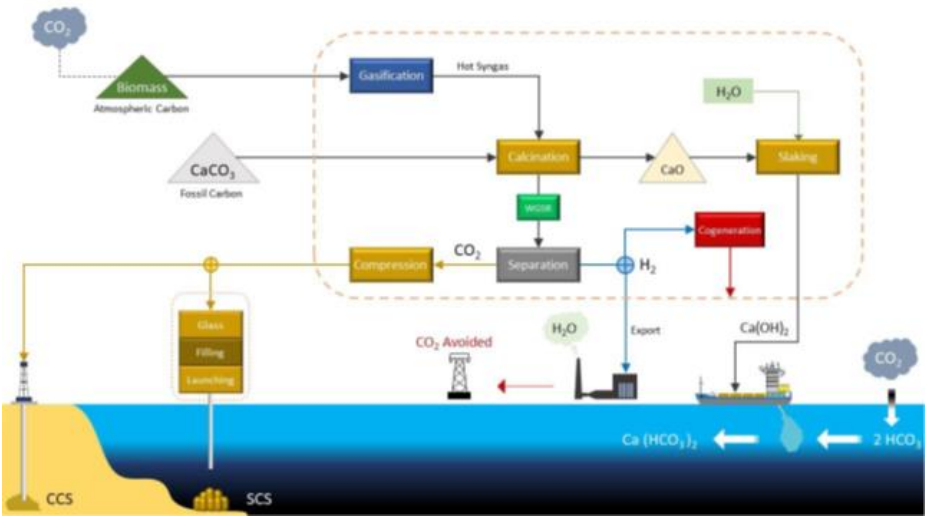
Furthermore, since removing large amount of CO_2 from the atmosphere requires this process to be carried out in a very large scale, the proposed solution do not want to aim only to governing institutions but also to the industrial sector. This is done by achieving negative emission in an affordable way, giving revenues to the investors.

To sum up, the aim of this project is to obtain a process which is both environmentally sustainable and economically feasible.

Understanding the problem

Our task is to study the feasibility of negative emissions technology, Ocean Liming. Since the starting point is a new chemical process, the first step is to study its potentialities; in parallel, the study the state of the art of ocean liming was carried out. The requirement was to evaluate the economic feasibility of the whole process.

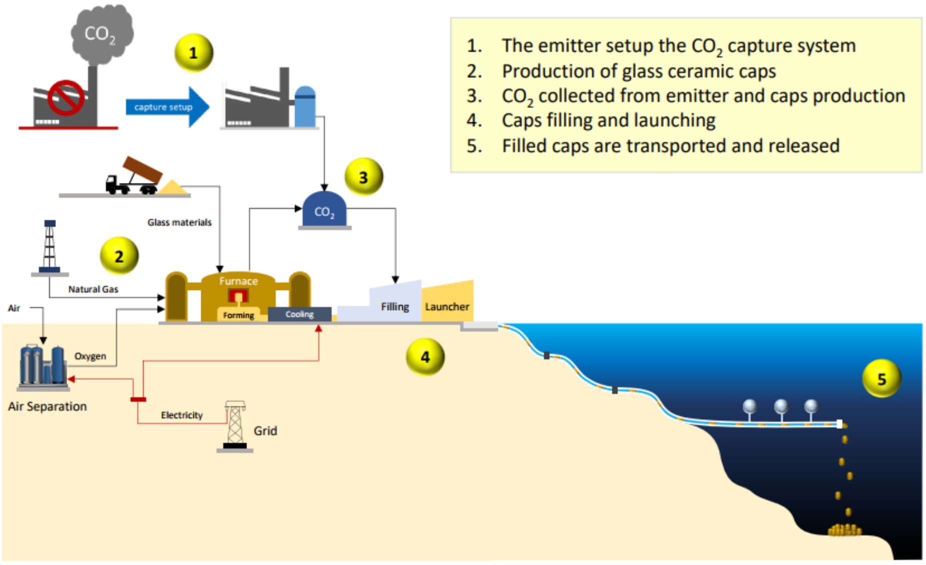
The principal subprocess is gasification, that is a chemical process which is used for producing syngas starting from organic matter, i.e. coal or biomass. Syngas can be used for a variety of production but, in this case it is used for producing hydrogen or ammonia. Both of them are highly valued compound with rising attention in these years and they represent the economical driving factor of the whole process.



Simplified version of the whole process

One of the drawbacks of the gasification process is that it also produces CO_2 as byproduct. However, since we want to achieve negative emission, we cannot emit CO_2 into the atmosphere. The solution is using a technology called Carbon Capture and Storage (CCS) where CO_2 is captured, instead of being emitted, and then stored in different formations. Here two different solutions were considered. The first is use CO_2 for Enhanced Oil Recovery (EOR) where it is used for increasing the productivity of depleted oil fields. The latter is to store it into glass capsule and then put them on the seabed in an innovative process called

Submarine Carbon Storage (SCS). While using CO_2 for EOR represents a revenue for the whole solution, its limited applicability needs to be considered for very large scale solutions. On the other hand, when EOR is not possible or already exploited, SCS represents a good solution since the seabed is a potential infinite sink of CO_2. However further studies are still required for assessing the best location and the real potential of this novel technology.



Carbon dioxide submarine storage in glass vessels

The combination of gasification and CO_2 storage allows to reach almost zero emissions. However, the aim of this project is to achieve negative emission and then removing CO_2 from the atmosphere. This is done through a process called ocean liming or ocean alkalinization.

Ocean is the biggest carbon sink where the carbon dioxide is constantly absorbed. The amount of carbon dioxide absorbed by the ocean depends on the ocean carbonate chemistry. When carbon dioxide is absorbed by the ocean, CO_2 dissolves to form carbonic acid. Carbonic acid further dissociates into bicarbonate and hydrogen ions. Artificial ocean alkalinization (AOA) or ocean liming is carried out to remove hydrogen ions (H^+) and trap more carbon as bicarbonate ions.

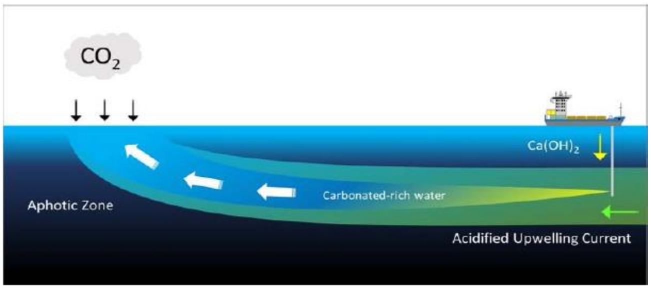
$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

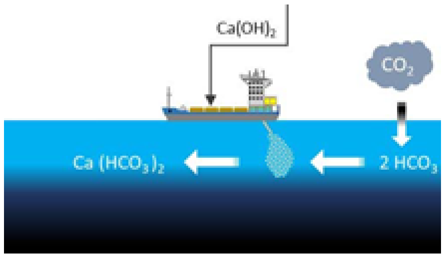
Slaked lime is used for ocean liming in this project. Discharging one mole of slaked lime ($Ca(OH)_2$) will result in sequestering 1.4 moles to 1.7 mole of CO_2 from the atmosphere. The impact of artificial ocean alkalinization (AOA) on the earth climate, ocean pH and carbonate saturation state in the long run has been investigated by different research groups and through different models. Adding 10 Gtons/year of $Ca(OH)_2$ for 80 years will remove 166 Gtons of carbon (602 Gtons of CO_2). This corresponds to a limiting value of only 1.4 moles of carbon dioxide per moles of slaked lime.

$$Ca(OH)_2 + 2CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$

An important factor of ocean liming is the effect of pH raising on ocean species and ecosystems by means of alkalinity addition. Discharge of slaked lime should not change the pH of the water too much, which can result in harmful environment to the life form in the ocean. According to the water quality guidelines of both U.S Environmental Protection Agency (1976) and the Canadian Council of Ministers of the Environment (1999), human activities should not result in a change in environmental pH of more than 0.2 pH units from normally occurring values. Another important factor is the increase in the calcite concentration should not cross the calcite supersaturation limit. Once the calcite supersaturation limit is crossed, there is precipitation of calcite and the whole process equilibrium is reversed resulting in CO_2 moving from the ocean to the atmosphere.

To estimate the discharge rate of slaked lime, the ocean parameters such as salinity, pH, Calcite supersaturation concentration, etc are required. Ocean parameters for this project is taken from the Global Data Analysis Project for carbon (GLODAP) data sets, January 2005 as reference. Slaked lime discharge can be mainly carried out using two ways. One is through discharging slaked lime on the wake of a ship and the second method is pointwise injection of slaked lime into the deep upwelling region. This project deals only with the concept of slaked lime discharge on the wake of the ship and calculating a safe discharge rate for the slaked lime slurry.

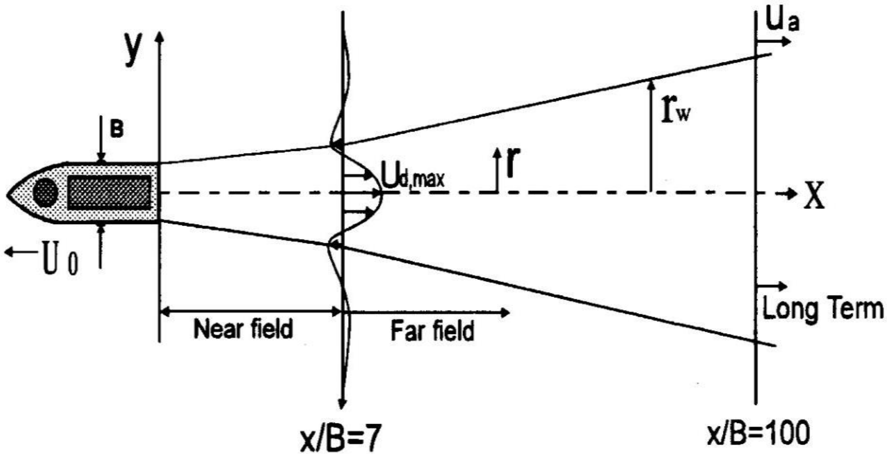




Upweling region Point wise injection (Wake)

Among the different possible methods to perform ocean liming, dispersal in the wake of a cruising ship was analysed.

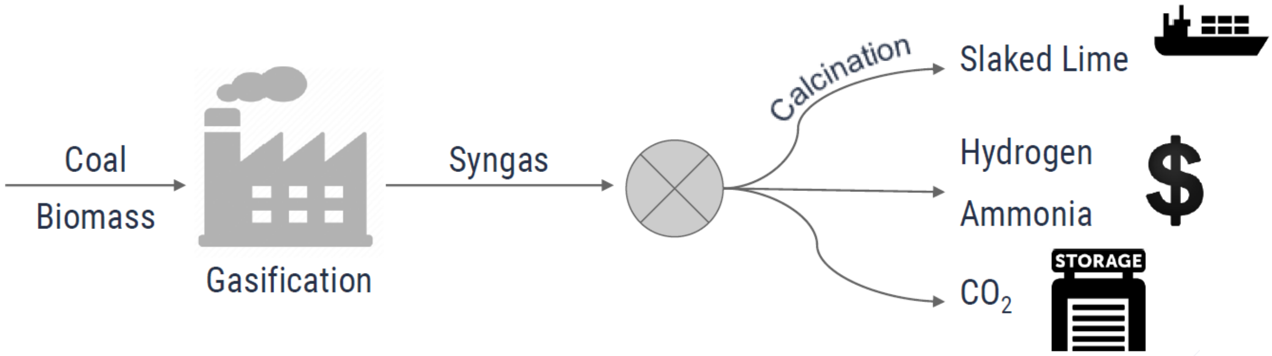
Turbulent motion in the flow region behind a cruising ship enhances the mixing process of slaked lime allowing a higher discharge rate. A momentumless homogeneous turbulent wake model has been considered, assuming a slurry of slaked lime and ocean water which is mixed on board and then dispersed. To keep the generality between different ships, the far field equation was considered for the whole region, since the near field is strictly depending on the ship geometry. Dilution rate is then defined as the ratio of initial concentration on board, which is assumed to be 10 times the supersaturation value for precipitation in the ocean, and the concentration level at a certain time. Subsequently the maximum discharge rate was computed as a function of ocean properties and time, in seconds, to reach a concentration value below the precipitation limit. Dilution rate of this model mainly depends on the speed velocity and width, other than the ocean properties and initial concentration, therefore three different sizes and two velocities for each of them were compared.



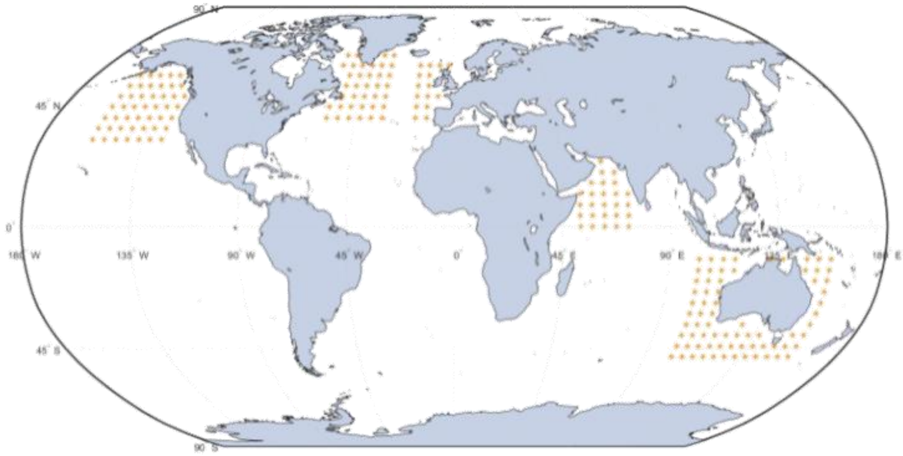
Schematic of the wake region subdivision

Exploring the opportunities

Our solution aims at combining the gasification process with the lime production, in a process called calcination, where limestone ($CaCO_3$) is decomposed thermally to lime (CaO). This represent a crucial part of the solution since this combination is never been done before and it allows to achieve both the production of lime, needed for the negative emissions through ocean liming, and hydrogen, the economically driving factor of the whole process.



Concerning ocean liming, in order to keep generality and study the possible different configurations, we select five different locations all over the world: Pacific Ocean, North Atlantic Ocean, Indian Ocean, European Atlantic Coast and Australian Coast.



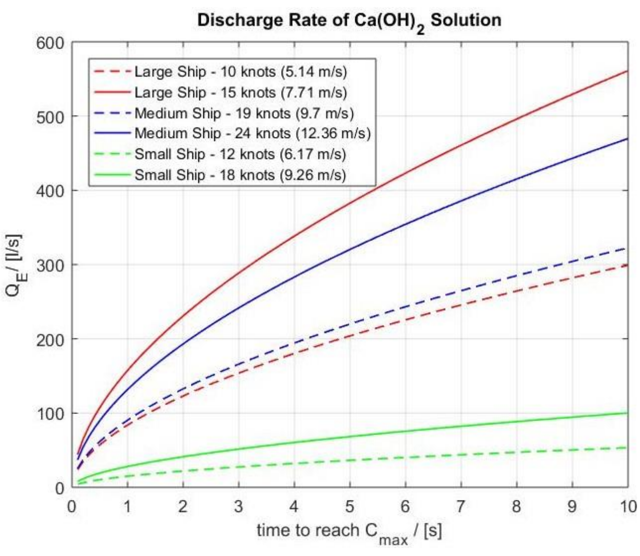
Size	Width\[m]	Speed\[Knots]	
		Maximum	Slow Steaming
Big	60	15	10
Medium	32	24	18.8
Small	15	18	12

Ships dimensions and speeds

Also, three different kinds of ships are selected, with different dimensions and two different speeds are chosen for every ship. In particular, it is worth mentioning the slow steaming speed, that is a speed used in order to reduce the emissions of the ships, so it is very relevant in the framework of this project.

Generating a solution

From the wake model different discharge rates were obtained for the five selected locations. In order to avoid long-time pH variation which could harm marine environment, the selected time intervals to reach a concentration value below precipitation were below 10 seconds. Ship sizes ranged from 15 to 60 meters and both cruising and slow steaming speeds were considered. In the sided graph results for the North Pacific Ocean are reported. For this situation, in case of a large ship (240.000 DWT) for a 5 seconds scenario and a slow steaming speed a total of 45 days would be needed for the total discharge time plus loading and traveling operations, with a discharge rate of 75,5 kg/s of Ca(OH)2.



For the chemical process, since many different fuels can be used, the productivity for each type of input was evaluated. Five different type of fuel, between coal and woody biomasses, were chosen in order to represent the wide range of possibility in a proper way. Through the writing and the solution of both the material and energy balances, the productivity of each configuration were studied. These results are very important for the following studies since they are needed for assessing the impact of the whole process (from gasification to ocean liming) for unit of input.

For understanding the best location for the plant, Italy, China and US have been considered. For each country, the different process configurations have been analysed both from an economic perspective and also for the amount of CO_2 that is removed. The best configurations is using biomass, producing hydrogen and storing CO_2 through EOR. A sensitivity analysis has been done to test the robustness of the results.
At the end of the project, the team is able to affirm that, even though this is a theoretical analysis, the process is able to achieve CO_2 negative emissions in and affordable way. The best location is California, since it can have the best configuration and it is close to the North Pacific Ocean, which has good properties for what concerns the ocean liming.

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