Algae-Based Carbon Sequestration

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Abstract: Our civilization is facing a series of environmental problems, including global warming and climate change, which are caused by the accumulation of greenhouse gases in the atmosphere. This article will briefly analyze the current global warming problem and propose a method that we apply algae cultivation to absorb carbon and use shellfish to sequestrate it. Despite the importance of decreasing CO\(_2\) emissions or developing carbon-free energy sources, carbon sequestration should be a key issue, since the amount of carbon dioxide that already exists in the atmosphere is great enough to cause global warming. Algae cultivation would be a good choice because they have high metabolism rates and provides shellfish with abundant food that contains carbon. Shellfish’s shells, which are difficult to be decomposed, are reliable storage of carbon, compared to dead organisms like trees and algae. The amount of carbon that can be sequestrated by shellfish is considerable. However, the sequestrating rate of algae and shellfish is not high enough to affect the global climate. Research on algae and shellfish cultivation, including gene technology that aims to create “super plants” and “super shellfish”, is decisive to the solution. Perhaps the baton of history will shift to gene technology, from nuclear physics that has lost appropriate international environment after the end of the Cold War. Gene technology is vital to human survival.

1. Introduction
Our civilization is facing a series of environmental problems, including global warming and climate change, which are caused by the accumulation of greenhouse gases in the atmosphere. Various possible methods have been proposed including industrial recycling, compressing it into the ocean floor, replacing fossil fuels with solar panels and land-based plant cultivation. However, the key way is carbon sequestration, which may not be accomplished by simply planting trees because carbon will be released again as the remnants of tree decay. Currently, the only way to permanently store carbon on a large scale is carbonates formation, which can be achieved by using shellfish to transform the carbon in the atmosphere into calcium carbonates.

2. Current environmental problems

2.1 Global warming and sea-level rise

2.1.1 Data from NASA
Currently, we are facing a severe global-warming problem. Based on research data from various research institutions, it can be concluded that global warming is indeed occurring, and that the increasing accumulation of greenhouse gases such as carbon dioxide in the atmosphere is causing the green-house effect to be more and more notable. The global temperature data provided by NASA\(^1\) (as shown in Figure 1) over the past few decades shows a growth of temperature of about 0.94 degrees Celsius, compared with that in 1880. Its global
temperature map also shows the global average temperature with a significant increase, especially the annual average temperature in the Northern Hemisphere. The diagrams below show that global warming is indeed occurring; it is not a hoax. This dramatic warming process has been happening over the past one hundred years, indicating the seriousness of the global warming problem that the earth is facing. The sea-level rise, which is at least partially caused by global warming, can be proved by the diagram provided by NASA [2] (as shown in Figure 2):

![Figure 1, Temperature Anomaly.](source: climate.nasa.gov)

![Figure 2, Sea Level Change.](source: climate.nasa.gov)

2.1.2 Data collection in Zhoushan
However, the data provided by NASA and IPCC is too far away from where I live—the melting icecaps are in Antarctica, thousands of miles away. In order to search more local sea-level data and make further proof of sea-level rises, I went to the Zhoushan monitoring center of National Maritime Bureau and asked for assistance (Figure 4). By looking up local sea-level measurements, which accumulated for decades, and comprehensive analysis of data sampling of observation points, a chart was drawn (Figure 3):

![Figure 3, Sea Level Change](source: climate.nasa.gov)
From 1980 to 2016, the average rising speed of the sea-level near Zhoushan was 4.5mm/year, which was close to the data provided by the fourth assessment of the IPCC. An increasing rate of 4.5mm per year seems very little, but with the accelerating melting speed of the glaciers in Antarctica and Greenland, the actual sea-level rise by 2050 will be considerable. According to the data, the sea level rise is consistent with global warming. Although the theory that the sea level rising should be completely attributed to global-warming is not proved, there is no doubt that global warming caused the melting and disintegration of glaciers and icecaps, and forced the sea-level to rise.

![Figure 4, Zhoushan Data Collection](image)

![Figure 5, CO₂ Emissions](image)

### 2.2 Carbon emissions

#### 2.2.1 Industrial carbon-dioxide emissions

Except for a tiny decline in carbon-dioxide emissions in the early 1980s, which was partially caused by the energy crisis, the world’s carbon-dioxide emission has increased by 46 percent in total. [3] (as shown in Figure 5)

The amount of carbon-dioxide in the atmosphere is increasing because the carbon cycle was broken by the emission of greenhouse gases, creating more carbon-dioxide than plants and the formation of calcium carbonate can absorb.

#### 2.2.2 CO₂ emissions from forest loss

G. R. van der Werf mentioned in his research report that “Within the science and policy communities, carbon emissions from deforestation and forest degradation have been estimated to account for about 20% of global anthropogenic CO2 emissions.”[4]

Forest loss greatly decreased the amount of carbon-dioxide that is absorbed and contributed 20% to the total carbon-dioxide increase. Though 20% is a relatively small percentage, compared with that caused by industrial emissions, this carbon emission illustrates the fact that plants are vital in controlling the green-house effect because they are one of the most important parts of the earth that transfers carbon-dioxide into organisms. Forest loss creates a greater gap between the production and the absorption of carbon-dioxide. Thus, based on current technology levels, the use of plants is a vital way to sequestrate carbon-dioxide in the atmosphere and fix the carbon cycle.

### 2.3 Brief analysis of global warming problem

In brief, the global-warming problem is caused by the inefficiency of modern day carbon-free energy sources like solar energy, wind energy, hydro-power and nuclear energy.

Solar energy is a prospective source, but the producing process of solar panels is not only costly, but also pollutes the environment with chemicals, including lead and cadmium.

The suitable areas for wind farms and hydropower stations are also limited. Bio-fuels and methane are regarded as “clean energy”, but they emit greenhouse gases, like CO₂ and CH₄. In some situations, using bio-fuels may be an irrational measure because a lot of grains would be consumed, which are needed by people who suffer from famine in South-Sahara regions.
Although nuclear energy comparatively produces little green-house gases and nuclear power stations can be built in many places, it causes political problems, in which no country can guarantee that those nuclear fuels are not used for military purposes. It is a difficult task to landfill nuclear waste without polluting local environments. Moreover, there are many legitimate objections from the public because of concerns that the consequence of a nuclear leak would be devastating. Thus, whether the global-warming problem would be successfully and completely solved depends on the technology developments of clean energy. However, based on technology, there are lots we can do in order to slow down the warming trend. In addition to expecting technological breakthroughs in nuclear fusion, we can sequestrate the carbon by using plants. Simply planting trees may not be an effective method because the carbon absorbed by trees will be released again after the trees die. There is not much land to grow extra plants on the continent, while there are huge amounts of water areas that remain uncultivated (Figure 6). So, it is possible to grow algae in some areas in which the growing algae is relatively easy to control (to prevent it from growing all around the world). In order to solve the problem of decay, we can let shellfish to sequestrate the carbon that is in the form of organic compounds into calcium carbonates.

![Figure 6. Uncultivated Water Areas](image)

### 3. Algae Cultivation

#### 3.1 Brief introduction

Algae cultivation aims to reduce the green-house effect in the atmosphere by using algae to absorb carbon-dioxide and letting algae sink into deep oceans. Carbon, together with the remnants of algae, would be stored in deep oceans, on the seafloor, for several centuries. Since algae is a fast-growing species, the effort we would need to spend to cultivate them is very little. It is widely known that the ability to grow fast is not a trouble, since some algae reproduce quickly and pollute water areas, causing “red tides”, but fast-growing is also a quality that can be used to absorb carbon-dioxide in a large scale. In addition to the fast-growing quality, algae that live on the ocean surface (such as plankton) can be controlled by adding and reducing the amount of nutrients in the ocean.

#### 3.2 Effectiveness of algae

Since each solution listed above has its insufficiencies, algae is outstanding, compared with the drawbacks of the other solutions. Carbon Recycling Process can only absorb a little amount of carbon-dioxide, while algae have a large potential to reduce carbon-dioxide from all around the atmosphere. Compressing carbon-dioxide into the seafloor is risky if we put exceeding amounts of green-house gases into it. Algae, however, can sink onto the seafloor as remnants of organisms, being prevented from being transformed into carbon-dioxide. Also, the costs of Tung trees’ cultivation on coastal deserts are also high, preventing this solution from coming true. In contrast, cultivating algae is cheap. Land-based plants contribute 52% of the total carbon-dioxide absorbed by the earth’s biosphere, while ocean-based algae contributed 45% to 50% of that, which means that despite their small size, algae can absorb carbon-dioxide efficiently because of their comparatively short life cycles. Algae can even reduce the amount of carbon-dioxide in the atmosphere more if we can support them with the appropriate environment, including temperature, nutrients (iron is one of the most important and
effective ones), sunlight and the number of animals that eat them. Thus, algae cultivation is a promising solution to reduce greenhouse effects.

The effectiveness of algae can be well illustrated by an experiment. A group of scientists from Alfred Wigner Polar Oceanographic Institute, claim that if we put extra iron into some water areas, algae is able to grow much more rapidly and absorb more carbon-dioxide. In February 13th, 2004, they sprayed 7 tons of FeSO$_4$ into acidic sea water, covering approximately 167 square kilometers of water area, and monitored the change of algae growth in the following five weeks. As they predicted, six species in diatoms grew rapidly. After that, researchers stopped adding iron and saw that the majority of diatoms died and sunk onto the seafloor, which proved that the growth of algae can be partially controlled. Its low cost is attractive because this method could be used extensively, in oceans all around the world, to absorb considerable amounts of greenhouse gases.

It is true that this method may show many drawbacks after being applied, but at least, the potential of algae is fully displayed.

John Martin, a marine scientist of the Marine Observation Station in California, said, “If you give me half a tanker of iron, I can return you an ice age.”

### 3.3 Cultivation in restricted areas and marine ranches

#### 3.3.1 Brief introduction

Despite the low price, problems, including the difficulty to control and the potential emission that will happen centuries later, will be caused if we apply iron fertilizers to open oceans. One way to avoid them is to cultivate algae in restricted areas, which means letting algae grow on ropes that extend into the ocean. Constructing pipes under the ropes that transport carbon-dioxide and releasing it for algae to use could also be a method. Algae can grow 1-2 centimeters per day, while they can grow much faster if they absorb extra carbon-dioxide. When the algae is bigger and longer, storing more carbon from the atmosphere and the gas we apply, we should harvest them. While in open sea areas, algae is difficult to collect and store, we just need to pull up the ropes and harvest them if algae is cultivated on ropes, which means it is restricted. After harvesting, we can either use it to generate electricity or sequestrate it.

![Figure 7, Red Tides](image1)

![Figure 8, Chlorella](image2)

While fertilizer could improve the productivity of farmlands, it can also increase the amount of harmful algae and form “red tides”. If we cultivate kelp in these areas, nutrients in the sea water would be largely absorbed and would not promote the growth of “red tides” (as shown in Figure 7 [6]) and harm fisheries. Thus, the bio-diversity in coastal would also be protected.

For a marine ranch that aims to sequestrate carbon, there are two possible choices of algae.

If we need to harvest algae for subsequent treatments, large algae, like kelp would be a better idea. Though small algae, such as chlorella (Figure 8 [7]), can grow rapidly, they are difficult to harvest and process because they distribute all around the surface of the water, forming a very thin layer of organisms and sinking quickly. In contrast, large algae can be controlled to grow on ropes.
However, if there is no need to harvest algae, single-cell algae would be a better choice because of its fast metabolism rate. They can also be easily absorbed by shellfish.

Through previous experiments, Martin J.H. and Fitzwater S.E. [8] proposed that in ocean areas with high nutrition content and low chlorophyll content, the limiting factor for algal growth is Fe, which means if enough amount of Fe is provided, algae growth can be greatly improved. Other fertilizers are needed to cultivate either single-celled algae or multicellular algae, which will not be introduced in this article.

3.3.2 Subsequent treatment

Subsequent Treatment is the key process to algae cultivation because the way we process the remnants of algae directly determines whether the whole process will make sense for carbon sequestration. The target is that we should not let the carbon kelp have an absorbed flow into the atmosphere, in other words, to store the carbon. Three sequestrating methods will be introduced in this passage.

3.3.2.1 Generating electricity

The most fundamental way to generate electricity is to burn combustibles, mainly fossil fuels, to generate steam, to rotate the steam turbine and to generate electric power (as shown in Figure 9[9]). However, the fundamental problem is that burning fossil fuels releases the carbon that was previously stored in the crust, and thus increases the amount of carbon-dioxide in the atmosphere. If what we burn is not fossil fuels and we burn plants instead, the carbon-cycle will be reestablished. The amount of carbon we emit by generating electricity will be the exact number those carbon plants absorbed. Then the question is what kind of plant should we burn? It is obvious that we cannot burn the trees, which was rejected by the United Kingdom in the 19th century because of the consumption of forest resources.

Figure 9. Generating Electricity

Compared with the disadvantages of burning trees, kelp seems a feasible idea. After being harvested and dehydrated, kelp can be used as fuel. The calorific value of standard coal is 29.27MJ/kg, while the average calorific value of dehydrated algae is 12.16MJ/kg, which means the potential heat that can be generated by kelp will be considerable.

However, if we want to completely fix the carbon cycle by simply using the remnants of kelp to generate electricity, the use of fossil fuels must be totally abandoned, which is currently impractical. The cycle itself, cultivating kelp and burning them, does not absorb any extra carbon in the atmosphere but consumes energy that needs to be used to manufacture fertilizers. It is clear that how much carbon it can sequestrate directly will depend on the amount of fossil fuels we are going to save. Unfortunately, the amount of fossil fuel that is going to be saved is limited because the cost of burning algae is apparently higher than excavating and using fossil fuels. Currently, using dehydrated kelp is not a practical idea.

3.3.2.2 Sequestration by shellfish

The only way that the earth itself permanently decreases carbon-dioxide in the atmosphere is to sequestrate it into calcium carbonates. The carbon absorbed by other methods, including photosynthesis and seawater dissolution will eventually be emitted into the atmosphere again. To
permanently store carbon, we not only need to use photosynthesis to change it into organic tissue, but must find a reliable way to store the organisms-- and storing it in shellfish’s shell, which mainly consists of calcium carbonates, is a good idea. Shellfish can transform the carbon from organisms into calcium carbonates by using this process:

\[
Ca^{2+} + 2HCO_3^- = CaCO_3 \downarrow + CO_2 + H_2O
\]

Since chlorella cannot be controlled by binding it on a rope, it needs to be restricted in an area by physical measures. Otherwise, the chlorella might float everywhere around the ocean with the tides and ocean currents. Dams are a possible choice for restriction, for the mature technology and good effect, which is greater than any of the chemical or biological restrictions. For the whole locked water area, the water inlet and the water outlet need to be designed in the middle of the dam, which looks like a tidal power station (as shown in Figure 10 [10]). However, the inlet and outlet water speed, especially outlet water speed needs to be small enough to not discharge too many organisms, or we cannot achieve the best results and will pollute nearby sea areas.

![Figure 10. Tidal Power Station](image)

The most significant drawback of dams which damages local bio-diversity, needs not to be of concern because the chlorella cultivation has already destroyed local ecosystems. Actually, if we want to keep local environments constant everywhere on the earth, not changing them in some way, it is impossible to achieve the sequestration of carbon-dioxide. Usually when we need to improve the environment in areas, we have to sacrifice others, though at a different intensity. Global Warming is more severe than local ecosystems. Thus, building dams is an acceptable method.

After the small algae that live on the surface of the water die, they sink into the water and can be absorbed by shellfish as nutrition. Carbon would be sequestrated in its shell as the shellfish grows. Other than the permanent storage of carbon, the most significant advantage is that shellfish has a high filtration efficiency, which enables them to use nearly all the organisms that distribute in seawater nearby and transform them into a part of their shells quickly. It has been proved that breeding shellfish on large scales has significant effects on regulating organisms in local water areas.

To absorb the remnants of algae that lives on the surface of the water and store them permanently, large amounts of shellfish need to be bred on the seafloor near coastlines. If it succeeds, unlike burying the remnants of kelp into ground, we do not need to do anything because calcium carbonates are extremely difficult to dissolve in seawater, creating a nearly permanent storage on the time scale of human civilization.

Some people may not desire to use biological methods because these methods do not appear as efficient as drilling a hole and compressing carbon-dioxide into seafloor. However, if the amount of shellfish is great enough, it would be the most efficient solution because of its low cost and high productivity. Zhang Jihong, a researcher in aquiculture ecology, announced that 1hm$^2$ of chlamys farreri (1125000 per hm$^2$) sequestrates 3.36 tons of carbon [11]. Though the chlamys farreri was not provided by intensive organisms as nutrition, it can still sequestrate 336tons of carbon per square kilometer. Thus, the carbon that can be sequestrated by shellfish is considerable.

It is believed that the white remnants on the Dover Cliff contribute to the climate significantly by storing carbon in the atmosphere. Those white cliffs display natural carbon sequestration process that happens near coastlines all around the world. As a species that is trying to make up for the environmental loss created by us, we can learn from nature and apply the process on a more concentrated scale to store the carbon.
4. More ambitious plans

4.1 Enlargement of cultivating scales
Since our civilization extremely relies on fossil fuels, it is impractical to suddenly quit using it or to greatly decrease the use. Otherwise, the global economy will collapse. In order to sequester the carbon on a much larger scale and cancel out the emission of green-house gases, we have to plant algae and shellfish on broad water areas, such as the Hudson Bay.

To cultivate algae on the surface of bay areas, the length of dams needed would be relatively short, compared to the broadness of water areas. It is true that the ecosystem in the bay would be destroyed by algae that cover the whole water surface, but the beneficial aspects would be more important than the drawbacks, which is the remission of the global warming problem.

4.2 Visions of “super plants” and “super shellfish”
Despite many of the advantages that algae cultivation may have, algae, including kelp, are still not the perfect species of plants that reduce the amount of carbon-dioxide in the atmosphere. There might be potential diffusion problems, and the cost will be high, too. All plants on earth have evolved in the way we see today because they need to compete with other organisms, rather than absorbing carbon-dioxide. In order to effectively mitigate the greenhouse effect, we must genetically modify the plant's genes and make "super plants" for our use.

An ideal “super plant” would meet these following conditions.
First, a “super plant” must have a high rate of photosynthesis to capture the energy in sunlight efficiently and grow quickly. This is the main reason why we expect to have a “super plant”-the photosynthesis efficiency of current plants, even including algae, is far below the demand, which is using them to change the amount of carbon-dioxide significantly.

Second, its Light Saturation Point(LSP) should be high enough to make full use of abundant tropical sunlight. Typically, a plant species with high photosynthesis efficiency would have relatively low LSP, being appropriate to high-latitude environments but unsuitable for tropical regions.

Third, although we could provide extra nutrients via fertilizers, the “super plant’s” demand of nutrients should not be too high. Otherwise, producing these fertilizers may cost a lot of energy (the total consumption of manufacturing 1 ton of CO(NH\textsubscript{2})\textsubscript{2} is 1555.49kg standard coal, including the raw material and fuel [12]). Plus, too much nutrients will allow plants and bacteria in this region to grow rapidly and pollute the local environment.

Since the subsequent treatment is the key issue of carbon sequestration in plant cultivation, there would be a huge demand for “super shellfish”. An eligible “super shellfish” may meet the following requirements.

The first is that “super shellfish” need to have high metabolism rates and good filtration ability to absorb organisms in the water quickly, which is the major goal of “super shellfish”. The shellfish we have needs tremendous amounts of seafloor to produce a notable decrease of carbon-dioxide in the atmosphere. The whole process will make little sense if the shellfish’s metabolism rate is low, even after “super algae” is developed because there would be much more organisms being produced than being absorbed.

Second, the “super shellfish” must be relatively easy to breed, in order to save costs. To cover vast marine areas, we need a tremendous amount of “super shellfish”, which leads to the demand that “super shellfish” need to be easy to breed and can reproduce quickly.

The third is that the shell much be thick and big, to increase the portion of weight that will not decay and can permanently store carbon.

It used to be supposed in the 1950s and 1960s, that the 21\textsuperscript{st} century would be an age of atomic energy and space colonization, so the environmental problems and energy crisis would not exist on Earth. Such estimations were reasonable, since the development of atomic technology and space technology were the fastest at that time. However, the energy problem has not been solved, and the development of atomic energy and space exploration is much slower than we once estimated. Until now, one of the major problems, which is the difficulty of using nuclear fusion to generate electricity, it is still several decades away from being solved. It is a shame that time estimations have remained constant for fifty
years. Instead of having breakthroughs in energy technology and spaceships, computer science and bio-technology are developing at an amazing speed now (Figure 11 [13]). Perhaps, the mission that remained incomplete in the 20th century, causing an energy crisis, global warming and sea-level rise, will be accomplished through “super plants”, which can be developed by computer technology and gene technology. Now, the baton of history has shifted to computer science and bio-technology, from nuclear physics and space technology that lost appropriate international environments after the Cold War. The consequence of “Transition Studies” depends on their performances.

![Figure 11, Gene Technology](image)

5. References

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