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A new novel solution to grow diatom algae in large natural water bodies and its impact on CO_2 capture and nutrient removal

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Abstract:

The accumulation of CO_2 in atmosphere as a result of fossil fuel combustion is the primary cause for global climate change. Although it has potential to harm it also has value as a source of carbon for photosynthesis. Using CO_2 as a feed stock for photosynthetic microorganisms can provide a large sink for carbon assimilation. Microalgae have enormous potential because of their rapid growth and tolerance to varied environmental conditions. To meet the nutrient and land requirement for large scale micro algae cultivation using waste water rich in N and P and growing algae in large water bodies and sea shores adjacent to big cities and CO_2 sources can be a sustainable option. Main challenge in growing algae in open waters is to trigger growth of a desirable type of algae. Diatom Algae are responsible for about 50% of all primary production in waterways and are the natural food for shrimp, other crustaceans and finfish. Diatoms are unique since they have a silica shell so in this article we explore the potential of diatom algae as efficient tools for CO_2 assimilation and effect of nano silica based nutrient mixture called Nualgi in triggering diatom growth in open waters and it s impact on CO_2 mitigation and nutrient removal from polluted water bodies.

Key words: Diatoms, Nualgi, Biofuels, Carbon capture, Climate change.

Introduction:

Climate change models worldwide have highlighted the importance of carbon neutral fuels and efficient CO_2 capture and storage (CCS) strategies [1]. A reduction in CO_2 emissions by 25-40% by 2020 and 80-90% by 2050 is predicted to limit global temperature increase to less than 2ºc. With the predicted global population increase from 6.6 billion at 2008 to 9.2 billion by 2050 [2-3] and the resultant increase in fossil fuel energy demands of rapidly expanding economies of China and India will further reduce fossil fuel reserves and subsequent CGH emissions. So there is an urgent need to develop technologies for sustainable, cost effective renewable energy generation and also CO_2 capture methodologies to address pressing constraints of climate change. CCS is capture and secured storage of CO_2 that would otherwise be emitted to atmosphere. With many nations investing to increase their share in renewable energy generation, addressing climate change concerns will require significant efforts for efficient CCS.

Use of microalgae for biological CO_2 fixation has been actively explores as an ecofriendly carbon mitigation strategy. Photosynthesis will release O_2 while fixing CO_2 into biomass. Microalgae can also remove Nitrogen, Phosphorus and heavy metals from waste water. Microalgae are diverse in nature with an estimated 200,000-800,000 species of which about 35,000 have been described [4]. Microalgae especially diatoms are primarily responsible for biological uptake of CO_2 in Oceans. Major portion of CO_2 absorbed by Diatoms are transferred into deep Oceans which acts as Carbon sink this process is known as "Biological Carbon pump" remaining CO_2 is converted to fish biomass. This deep sea burial of CO_2 brought about by Diatom algae is one of the main natural CO_2 mitigation strategies.

Microalgae CO_2 capture can also be coupled with waste water treatment and nutrient recycling which provides additional benefits by reducing energy consumption and cost compared to traditional processes. The concept of CO_2 capture by microalgae grown in sewage water was already proposed half century ago by Oswald [5-6]and has been researched upon in US by Sheenan [7] and Hamasaki [8-9] in Japan.

The goal of this paper is to explore the potential use of Diatom Algae as Carbon capture tool and to develop a technology for efficient algae based CCS mechanism for large water bodies.

Limitations in Algae based Flue gas related CCS strategies:

Relative large land area, ability to capture only 25-30% CO_2 in one go from flue gas, cost of pumping flue gas and underdeveloped state of this technology are limiting factors [10-12]. 1MW power plant produces 2269 Metric tons of carbon which would require about 16 hectare algae bioreactor facility yielding 80g DW m^{-2} day^{-1} or 64 hectare algal facility yielding 20g DW m^{-2} day^{-1}. Ability of algae to capture CO_2 at fast rate to avoid acidification of medium resulting in culture crash is a main limiting factor in high CO_2 sources like flue gas.

CO_2 sequestration by algae:

To have a good impact on green house gas mitigation CO_2 must not only be captured but also sequestered. Direct injection into geological formations and chemical conversion are some options. Another strategy is to bury it as biomass. This strategy is attractive because solar energy is used for biomass generation. One of the main efforts in studying this strategy was to fertilize open oceans to trigger phytoplankton growth [13]. Fertilizing with nutrients like Iron that limit algae growth can exponentially enhance algal growth and CO_2 capture but ecological impacts of this strategy is unknown.

An alternative strategy to open ocean fertilization is controlled production of algal biomass in open ponds, large enclosed water bodies, rivers and coastal waters. Direct burial of biomass is simple technology and it is very efficient and cost effective. If we can implement this strategy in water bodies with fish, the fish which consume zooplankton which in turn consume phytoplankton so the CO_2 sequestered by fish can be converted to fish biomass.

Advantages of diatoms over other algae:

Diatoms are among most productive and environmentally diverse on planet. They are estimated to be responsible for 40% of global carbon fixation. They are highly diverse with estimates of over 100,000 species. According to Aquatic species programme recommended list of most promising species for biofuel production, 60% of selected strains are diatoms. This list is based on high growth rate, lipid yield, tolerance to harsh environment and performance in mass scale. Diatoms have shown greater carbon fixing ability than other co existing algae per unit of crop carbon [14]. Diatoms can even dominate under nutrient and light limited conditions [15-16] . In spite of having all these advantages over other algal species it is quite puzzling that diatoms are the least explored species in the fields of algal biofuels and CO_2 sequestration.

Use of diatoms for CO_2 sequestration:

Diatoms being most productive and more diverse have distinctive advantage over other algal species studied for CO_2 sequestration. Diatoms are largely responsible for CO_2 export to ocean depths. Diatom cell membrane is highly permeable to CO_2 resulting in efficient exchange between cell and external medium. Diatoms adapted to ambient high O_2 and less CO_2 concentration over geological times by the evolution of efficient carbon concentrating mechanisms (CCM). CCM helps diatoms concentrate CO_2 at the site of fixation by RubisCO for better utilization. It is not exaggeration to believe that today's atmospheric CO_2 concentration is largely influenced by efficiency of diatom CCM [17]. Diatom because of their silica cell wall exhibit very fast sinking rates compared to other algae. In nutrient rich fresh water systems surface dwelling cyanobacterial blooms reduce dissolved inorganic carbon (DIC) [18-19] leading to high pH which further facilitates BGA blooms. Diatoms with its efficient CCM which can work even at low DIC levels are the only competitors which can compete with BGA for nutrients if sufficient Si is present. Of the 10 ocean fertilization experiments 9 resulted in phytoplankton blooms dominated by diatoms [20-21] so diatoms respond very well to changes in nutrient concentration and grow rapidly even in open waters.

Mechanism to trigger diatoms in open waters:

Growing one type of algae in open waters is complicated process but diatoms have a distinctive advantage because of their absolute requirement for silica. So using this advantage we can trigger diatoms in open waters especially in fresh water ecosystem were silica concentration is less. Taking this advantage in to consideration we have developed a nano silica based micronutrient mixture called "Nualgi" which has Nano silica as its major constituent along with iron and 9 other trace metals. The silica becomes both the carrier for other nutrients and the nutrient by itself. It is in a water dispersible particulate form. Nualgi because of its nano size is able to pervade very small spaces in the subsurface and remain suspended in water, allowing the particles to travel farther than larger, macro-sized particles there by increasing the bioavailability of the nutrients for easy absorption by micro algae and achieve wider distribution. In water Nualgi causes Diatom Algae to bloom, though any pond, lake, estuary or coastal water has many species of organisms, only Diatoms require silica and they consume Nualgi rapidly and bloom. In lab experiments with pure marine diatom cultures highest biomass concentration and biomass productivity was attained in both *C. clostridium* and *C. fusiformis* in cultures grown in Nualgi containing medium these values were almost double than in the popular f/2 medium (fig.1) [22].

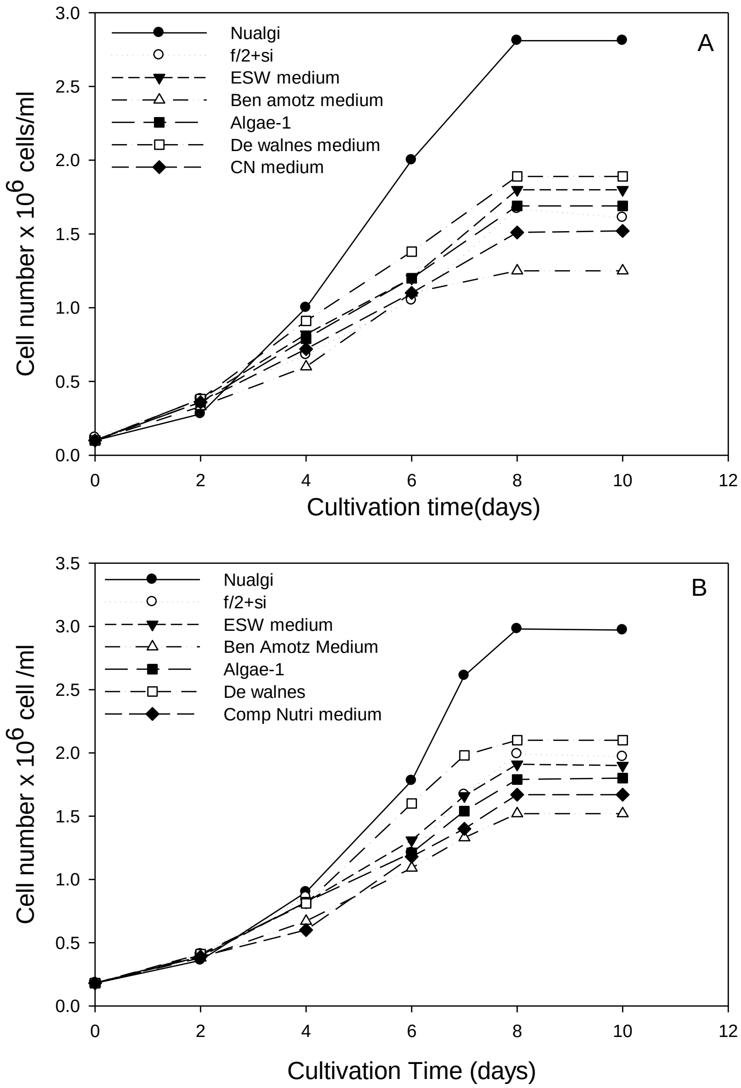

Fig.1. Effect of six different mediums on growth of *Cylindrotheca clostredium* (A) & *Cylindrotheca fusiformis* (B) when compared with Nualgi containing medium

From Lab trails with eutrophic fresh water from Hussain sagar Lake Nualgi triggered diatom growth by not only trigerring increase in number of diatom cells but also in increasing diatom diversity. In samples without nualgi six different species of diatoms were identified in which *Cyclotella meneghiniana*, *Gomponema lanceolatum* and *Nitzschia palea* were the abundant species were as in samples with nualgi addition *Achnanthidium exiguum*, *Navicula crytocephala*, *Cymbella tugidula*, *Navicula gracilis* and *Pleurosigma elongatum* were the dominant species with a total of 30 different diatom species. The dominant species in samples with no Nualgi addition were identified as pollution tolerant species and in Nualgi added samples dominant species are less pollution tolerant species this change in diatom species diversity clearly indicates the effect of Nualgi addition in nutrient reduction. In field conditions with Nualgi, N removal percentage was 95.1% and P removal of 88.9% was achieved over a period of 10 days. COD and BOD reduction was also significant with 91 and 51% respectively (Thomas, unpublished). Nualgi as an efficient tool to trigger diatom growth is well proven in both lab and field trials. So by using this product we want to propose a new strategy to mitigate CO_2 by growing diatom algae in large fresh and brackish water bodies.

Description of the proposed technology:

Our proposed technology harnesses the enormous potential of diatom algae in Sequestering large amounts of CO_2 in open waters. If we can convert this diatom biomass to fish biomass as diatoms being the primary producers in the food chain, their biomass will be consumed by Zooplankton which are in turn consumed by fish so the carbon captured by diatoms will be incorporated in to fish biomass (Fig.2). As triggering only diatom algae in open waters is a challenge we are able to solve this by developing an efficient nutrient mixture called Nualgi which can be used in any type of water body to consistently trigger diatom growth. We want to use open water bodies as majority of them are nutrient rich with sewage and agricultural runoff so lot of them are dominated by Blue green algae (BGA) which grow on top of the water layer stopping gaseous exchange and light which in turn stops other beneficial algae and aerobic bacteria to grow leading to hyper eutrophic condition. Diatoms which can dominate BGA in presence of sufficient silica concentration can help in BGA control and they can help in restoring the water quality by nutrient reduction, increase in fish biomass and enhanced oxygen production. BGA are not consumed by zooplankton and fish so the Carbon captured cannot be sequestered but Carbon in diatom biomass will be incorporated in to the food chain and the remaining biomass will rapidly settle to the bottom as diatom cells are made up of silica leading to efficient CCS.

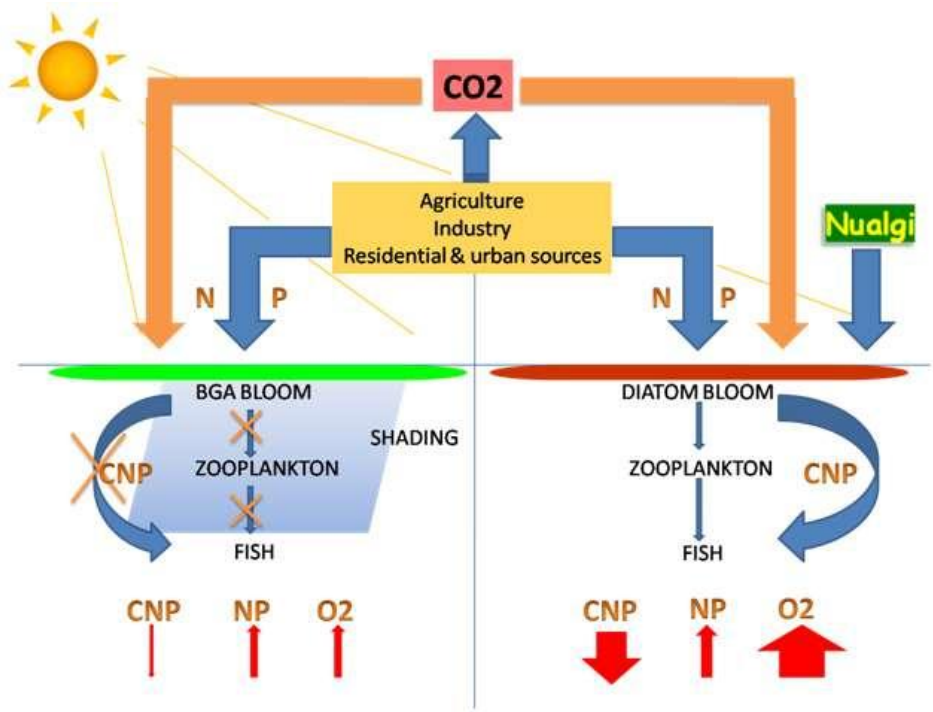

Fig.2. Schematic diagram showing the mechanism of CO_2 sequestration from diatom algae triggered by Nualgi

Advantages of proposed technology:

Huge land requirement, cost of CO_2 capture from flue gas, Cost of N and P and limitations like medium acidification in small volume cultures bubbled with flue gas are the main draw backs of the present algae based CO_2 capture technologies by growing diatom algae in large water bodies adjacent to sources of CO_2 emissions we can counter all the major draw backs. If we grow algae in open water bodies the land required for sequestration can be countered. As the atmosphere adjacent to flue gas emissions is high in CO_2 the water bodies also contain high CO_2 concentration so by utilizing this CO_2 we can reduce the cost of CO_2 capture from flue gas. By growing diatom algae we can generate fish biomass which can be sold to offset the cost. In any algae mass culture facility input cost for major nutrients N and P is significant so if we can grow diatoms in water bodies which are already rich in N and P due to anthropogenic discharge from adjoining human habitations we can offset the cost of Nutrients. In large waterbodies acidification is not a problem because of large surface area. This technology is cost effective as we don't need any huge infrastructure and high man power requirement.

In India there are many urban water bodies in and around cities which are polluted with excess nutrients and are in eutrophic condition which can be used to grow algae. So by growing algae in these large water bodies and sea shores adjacent to big cities we can utilize these excess N and P and it can become a viable option to meet the requirement of land and nutrients required for large scale CO2 sequestration strategies.

Conclusion:

For algae to be used as a carbon capture technology and energy alternative, the process must be able to compete on a cost basis with other chemical and geological technologies. It should also be sustainable and if deployed global scale the land and water use must be minimized to preserve nature and to eliminate conflict over these resources with other users. Current CCS technologies are energy intensive and expensive often requiring optimized and controlled conditions. Algae can be a good alternative to competing technologies like Non-biological carbon Capture, Hydrogen production from fossil fuels and storage of CO_2 from fossil fuels if overall running costs are less and implementation at scale can be achieved. By using large water bodies which are nutrient rich to sequester CO_2 using algae which are well adapted for efficient CO2 sequestration can emerge as a sustainable alternative to available technologies. The proposed technology has potential for future research, which may assist in the remediation of problems associated with water pollution and green house gases.

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