Wood burial is currently the only fast and effective method of carbon neutrality

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Abstract

In this study, we analyzed the feasibility of various carbon neutral methods based on the first principles of biogeochemistry, namely energy use efficiency and elemental stoichiometry. We believe that wood burial is the only currently feasible carbon neutrality method because this method has no theoretical uncertainties, can be implemented immediately on a large scale, has a long sequestration time, low cost, low technical requirements, and relatively little impact on agriculture.

Keywords: CO_2, carbon neutrality, elemental stoichiometry, energy use efficiency, first principle, sink enhancement.

1. The feasibility of carbon neutral methods

Carbon dioxide (CO_2) is one of the most important greenhouse gases and the main target for carbon neutrality. The major increment of atmospheric carbon dioxide comes from the use of fossil fuels, so there are two pathways to reach net-zero emissions, the so-called carbon neutrality: emission reduction and sink enhancement. Carbon neutrality is an international route that will last at least a century. Currently, the annual carbon increment to the atmosphere is about 5×10^{15} g C [1, 2]. Therefore, a viable carbon neutrality program must be large in scale and capable of long-term implementation, and this program is essentially in long-term competition with the industrial capacity of human civilization. If the effect of a program is two orders of magnitude lower than emissions, it is of little practical significance; if it is three orders of magnitude lower, it is almost meaningless; if the effect of a program can reach 10% of emissions, it is highly feasible. Carbon neutrality involves several disciplines, but the research field of individuals is getting narrower and narrower, and the information explosion leads to the inability to judge the advantages and disadvantages of various carbon neutrality methods. Here, we analyzed the feasibility of several major carbon neutrality methods based on the first principles of biogeochemistry, namely energy use efficiency and elemental stoichiometry (Fig. 1).

2. Economic pressure to emission reduction

New energy sources such as solar energy, wind energy and nuclear energy still have many drawbacks and limitations, which lead to fossil fuels being the world's main energy source at present and in the coming decades. Emission reduction means reduce the use of fossil fuels; therefore, it will certainly affect the economy. Differences in national circumstances and differences in the implementation of reduction actions will put enormous pressure on the countries that reduce emissions first, leading to conflicting policies, wasted time, and increased costs. In many countries, the conflict between emission reduction and livelihood electricity consumption has attracted widespread attention. Therefore, there is an urgent need for viable sink enhancement programs to save time for the development of new energy technologies.

3. Analysis and comparison of sink enhancement methods

Sink enhancement is the conversion of gaseous CO_2 into other types of inorganic or organic carbon and long-term storage. This long-term means that the stored carbon will not return to the atmosphere for at least a century, which is arguably the minimum standard for internationally recognized sink enhancement programs. For example, wood burial is a biological method of sink enhancement, referring to carbon sequestration through the production and long-term storage of dry wood. One popular inorganic method for sink enhancement is to liquefy CO_2 and inject it into the ground. However, after more than 40 years of development, this inorganic method remains highly controversial and more than 80% of commercial projects have failed [3]. Of particular note: liquid CO_2 at –20°C and 5 Mpa has a density of 1059 kg/m^3 which is very close to the density of water. A simple calculation shows that the carbon content per cubic meter of liquid CO_2 is 0.29 tons, which is very close to that of dry wood. But the former is obviously much more expensive to produce and store. If the product of some inorganic method has a lower carbon content per unit volume than dry wood and a higher cost than wood production, then it is not as good as wood burial. Of course, sequestration of liquid CO_2 has unique advantages over biological methods of sink enhancement, for example, it does not consume nitrogen, phosphorus and potassium nutrients.

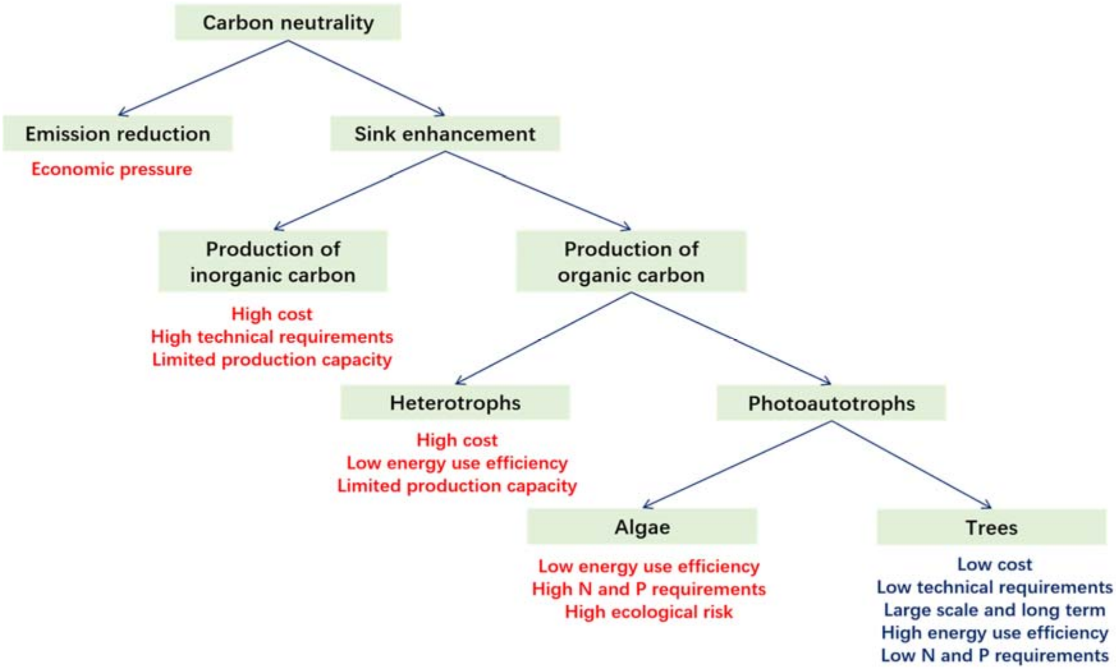

Fig. 1 Feasibility analysis of several major carbon neutrality methods based on the first principles of biogeochemistry.

CO_2 is a weakly acidic gas, thus alkalizing seawater with the addition of alkaline minerals would help the seawater absorb more CO_2, but this approach would require worldwide agreement and concerted action to make it work. Large-scale changes to the marine environment would have a huge impact on marine ecology and would most likely attract a lot of opposition.

The organic method for sink enhancement is to produce and store organic matter for a long-time using CO_2 as a feedstock. The industrial synthesis of organic matter is obviously not yet available for large-scale sink enhancement, and the production of organic matter through cultivation of organisms is the only way to go at present. The energy transfer efficiency between trophic levels is quite low due to the large amount of energy that would be lost, suggesting that photoautotrophs have a much higher sink

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enhancement potential than other organisms.

Natural organic matter consists mainly of six elements: carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur, which account for more than 95% of living organisms [1, 4]. Natural organic matter contains mainly four major classes of macromolecules, among which proteins are rich in nitrogen, nucleic acids and lipids are rich in nitrogen and phosphorus; while carbohydrates are very low in nitrogen and phosphorus. Therefore, the production of the first three organic matters for carbon neutrality will consume a large amount of nitrogen and phosphorus fertilizers, which will impact agricultural production causing food shortages and will cause a new round of competition for nitrogen and phosphorus resources. Among major photoautotrophs (Table 1), the carbon: nitrogen: phosphorus (C:N:P) molar ratio of trees is as high as 1360:8.5:1, which is much higher than seagrasses (550:30:1), macroalgae (550:30:1), and microalgae (106:16:1) [1, 5, 6]. If the product of an organic method has a higher nitrogen and phosphorus contents than wood, then it is no better than wood burial for sink enhancement in terms of nutrient requirement. If the production of certain organic matter needs to be involved with heterotrophs, then the energy use efficiency will be much lower than wood production.

Organisms mainly compete for food rich in nitrogen and phosphorus nutrients, which result in proteins, nucleic acids, and lipids being eaten or decomposed very quickly in natural environment. Wood is a solid and its main component is carbohydrates, these physical and chemical properties make it very easy to sequestrate carbon in the form of wood for more than 1000 years [7]. Even simple and low-cost techniques can significantly increase the time to carbon lockup. Due to the low C:N:P ratio of macroalgae and microalgae, they will be quickly utilized and decomposed, and most of the organic carbon fixed by photosynthesis will be turned back to CO_2.

All the organic carbon pools on the Earth surface are originated from photoautotrophs. Both marine microalgae and terrestrial plants contribute about half of the global net primary production (NPP), but the former accounts for only about 0.2% of the biomass of the latter [8]. It seems that marine microalgae have a great potential for sink enhancement. About 80% of the total marine NPP come from marine microalgae in open oceans, but at least 80% of the marine NPP is decomposed directly into CO_2 in surface seawater, with less than 20% remaining sinking to the deep ocean, and about 98% of the sinking

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organic carbon is decomposed into CO_2 [1]. Thus, for marine microalgae in South China Sea, only about 2.5% of NPP is long-termly sequestered in the deep ocean with the involvement of bacteria and other microorganisms [9]. These data suggest that the efficiency (as a percentage of NPP) of carbon sequestration via microalgae cultivation is extremely low. Similar, but better, about 13% of NPP of marine macroalgae is long-termly sequestered [10]. The plant carbon pool contains mainly terrestrial trees, and about 70% of plant biomass is wood [1, 4, 7, 11]. Thus, the carbon sequestration efficiency of wood burial can be as high as 70%, which is much higher than that of algae cultivation (Table 1).

Table 1 Carbon sequestration efficiency (%) and nutrient requirement (%) as a percentage of industrial production for biological sink enhancement methods. To simplify the calculation, it is assumed that nitrogen and phosphorus exported to the deep sea can be completely reused for carbon sequestration.

Photoautotrophs	C:N:P ratio		Carbon sequestration efficiency (%)	Nutrient requirement (%)		
	Body	Sequestrated organic matter		N	P	K
Trees	1360:8.5:1	1360:8.5:1	70%	24.3%	27.9%	149.7%
Macroalgae, Seagrasses	550:30:1	200:14:1	13%	272.2%	189.9%	0
Microalgae	106:16:1		2.5%			

Marine microalgae mainly distributed in the surface seawater of open oceans where the concentrations of available nitrogen, phosphorus, iron and silicon are normally very low [3, 12]. The organic matter buried in marine sediments is the major form of long-term carbon sequestration in the ocean, with a C:N:P ratio of 200:14:1 [1]. Theoretically, microalgae biomass can be increased by fertilization in the oceans, which would then increase the size of the carbon pool derived from microalgae. However, since (1) The ocean is too deep and too wide, the diffusion effect causes fertilization to increase the nutrient concentration of surface seawater only for a short time, which is bound to cause great waste; (2) The number of microalgae per unit volume is very low, which leads to the fertilization concentration cannot be too high, otherwise the fertilizer cannot be fully utilized; (3) The nitrogen and phosphorus content of microalgae is much higher than that of wood [5], which has a large demand for fertilizer and brings a large (relative to humans but very small to the ocean) amount

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of valuable nitrogen and phosphorus (especially phosphorus) to the deep ocean. It is worth noting that the cycle of marine nitrogen and phosphorus is not under human control; (4) It takes years to test and confirm the effect of fertilization on sink enhancement; (5) Fertilization in the open oceans requires a unified global opinion and may cause disputes in ecology and environmental protection; (6) Carbon sequestration by microalgae cultivation is very inefficient because it requires the participation of other organisms. As a result, large-scale ocean fertilization projects are not only difficult to implement, but also have uncertain consequences. One idea to combine inorganic and organic methods is to put alkaline inorganic minerals into the ocean to promote the absorption of carbon dioxide by the ocean on the one hand, and to burial organic matter on the seabed to reduce decomposition on the other. This idea faces the same problems described above.

Zeng [7] summarized three advantages of wood burial: (1) The plant carbon pool is comparable to the atmospheric carbon pool, thus wood can be preserved on a large scale; (2) Wood burial has the advantages of long-term sequestration, low technical requirements, low cost and easy management; (3) By scientific management of global forests and wood production, forest fires can be reduced, which then reduces carbon emissions. Here, we given three additional advantages of wood burial compared with other biological method for sink enhancement from the perspective of elemental stoichiometry [1, 11, 13, 14]: (1) The dry wood has a high carbon content, about 45% by weight; (2) Compared with cultivation of other photoautotrophs, the production of wood consumes less nitrogen and phosphorus nutrients and has less impact on agricultural production (Table 1); (3) About 70% of plant biomass is wood. These advantages make wood burial the only feasible method for carbon neutrality at present.

In total, human activity emits 350×10^{15} g of carbon into the atmosphere, about two-thirds of which comes from the burning of fossil fuels (origin from ancient plants) and one-third from tropical deforestation [4]. Wood burial can return carbon to its original form. Organic carbon is the basis of human civilization as well as the Earth's ecosystem, and wood far exceeds other forms of carbon in terms of integrated use and is most likely to be a scarce resource in the future. Thus, developing the use of wood can encourage wood burial to enhance carbon sequestration.

4. Wood burial program

Zeng [7] discussed many technical details of wood burial, and here we would like to discuss the feasibility in terms of nutrient requirements. The average density of dry wood is about 0.65 tons per cubic meter, with a carbon content of about 45% by weight [13, 14]. Global annual net carbon emissions are about 5×10^{15} g C [2], equivalent to 17 billion cubic meters of dry wood. In addition to nitrogen and phosphorus, trees also have a high demand for potassium (K), with a C:N:K:P molar ratio of about 1360:8.5:4:1 [1, 13]. USGS data show that global annual industrial productions of nitrogen, phosphorus and potassium fertilizers are about 150×10^{12} g N, 34×10^{12} g P and 32×10^{12} g K, respectively [2]. Assuming that all of the nitrogen and phosphorus absorbed by trees is used for wood production, then at least 24.3%, 27.9%, and 149.7% of global annual industrial nitrogen, phosphorus, and potassium fertilizer production, respectively, would need to be used to tree planting to achieve carbon neutrality.

Based on C:N:P molar ratio, the nitrogen and phosphorus requirements for wood burial are significantly lower than for other biological methods in achieving carbon neutrality (Table 1). Even so, a conflict between carbon neutrality and agriculture is already inevitable, and the world will face a severe shortage of nitrogen, phosphorus and potassium resources. Nutrients such as nitrogen, phosphorus and potassium are mainly enriched in the soft (active growth) parts, such as, leaves and shoots, thus these parts need to be recycled for wood production. Potassium can be extracted and obtained from seawater by biological (e.g., farming macroalgae, seagrasses, mangroves, etc.) or chemical methods. We can also use the nutrient-rich non-agricultural land with net carbon emissions for tree planting. The soil organic carbon pool is about twice as large as the atmospheric carbon pool, and soil contain much more nitrogen and phosphorus than wood [1, 4, 15], so the potential for use in wood production is very high.

5. Summary

The key to achieving carbon neutrality is to be able to implement it at low cost and large scale. In this study, we analyzed the feasibility of various carbon neutral methods from the perspective of elemental stoichiometry, and found that wood burial may be the only fast and effective method of carbon neutrality at present. Wood burial can be implemented immediately and on a large scale, with long sequestration time, low cost and technical requirements, and no theoretical uncertainties and relatively little impact on agriculture. However, it is clear that the implementation of carbon neutral methods requires a globally integrated management of resources.

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Conflicts of interest

The author reports no potential conflicts of interest.

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