# Carbon capture and sequestration: The roles of agriculture and soils

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**Abstract:** Renewable energy as a replacement for fossil fuels is highly desirable, but the reality is that fossil fuels (especially coal and petroleum) will be major sources of global energy for many decades to come. Therefore, carbon capture is vital to reduce release of carbon emissions and other GHG's to the atmosphere thereby mitigating global warming. This presentation is a review of the role of agriculture and soils in carbon capture. Carbon sequestration in soils is the process of transferring $CO_2$ from the atmosphere into soils through crop residues. Soil carbon sequestration increases with practices long recommended to increase yields, such as no-till, manure application, agroforestry and cover cropping. It is a Win-Win-Win strategy—advancing food security, improving the environment, and mitigating global warming. Carbon enrichment in greenhouse culture is in widespread use and has been adopted by many commercial producers. It results in remarkable increases in yields of flowers and vegetables. Research has shown the same increase in yields of trees and field crops with higher $CO_2$ concentrations. The question is, how can $CO_2$ be applied to field crops to increase yields? Restoration of desertified lands would improve soil quality, increase the pool of C in soils and forests, reduce $CO_2$ emission to the atmosphere, and improve soil quality. Sequestration of additional carbon in soils would reduce $CO_2$ emissions to the atmosphere thus mitigating global warming. Reforestation of forests is important, but real trees have ecological limits. Artificial trees could be used to absorb $CO_2$ from the air any place on the planet, from any source—power plants, vehicles, and all industrial applications. Addition of $CO_2$ in irrigation water could reduce the pH and help restore alkaline soils. Research is needed to further clarify the cost and benefit of many agriculture technologies for capturing and storing carbon.

**Keywords:** carbon capture, sequestration, soils, agriculture, parasitic cost of carbon capture and sequestration
**DOI:** 10.3965/j.ijabe.20160901.2280

**Citation:** Stout B, Lal R, Monger C. Carbon capture and sequestration: The roles of agriculture and soils. Int J Agric & Biol Eng, 2016; 9(1): 1−8.

## 1 Introduction

### 1.1 The emissions problem, global warming

Coal and petroleum are widely used as fossil fuels that emit large quantities of greenhouse gases (GHG). Although there is disagreement among scientists and engineers, the overwhelming majority believe that manmade emissions are the main cause of the rise in global temperature in recent years. Consequences of the rising global temperatures have been the subject of numerous publications. This paper focuses on $CO_2$, a predominant GHG and the role of agriculture and soils in limiting $CO_2$ release to the atmosphere, thus mitigating global warming.

The increase in atmospheric $CO_2$ has been well documented (Figure 1).

What can be done to limit the net $CO_2$ release to the atmosphere? A vast number of publications have dealt

**Received data:** 2015-12-12 **Accepted data:** 2016-01-10
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with the development of non-carbon (C) renewable energy and the authors fully support this move. The importance of energy efficiency and conservation has also been widely recognized. But non-carbon renewable energy currently provides a small part of overall global energy, perhaps only 13%-16%[2]. Renewables will certainly grow, but so will energy demand. Thus, the question is: are there options other than renewables and increased energy efficiency that can reduce the net anthropogenic emissions? The answer is, yes—Carbon Capture and Sequestration (CCS, deep storage of carbon)[3]; that is, limiting the net release of C and other GHG to the atmosphere. The cost of storing carbon using agricultural processes and soils needs to be determined through further research.

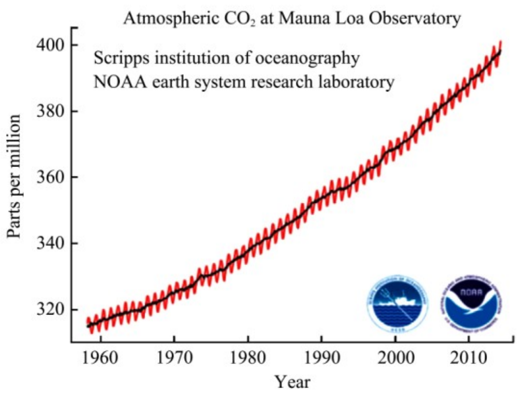


Figure 1 Increase in atmospheric $CO_2$[1]

### 1.2 Carbon capture and sequestration

Can $CO_2$ release to the atmosphere be controlled? Yes! One of the early publications on C release to the atmosphere was published 37 years ago[4].

Many publications on both deep CCS and near-surface carbon capture using agriculture and soils have been published recently[5-7] and many more. Currently, much research is underway dealing with deep CCS (Figure 2)[8].

Critics say that deep CCS is a move in the wrong direction; that is, techniques to continue using coal, petroleum and other hydrocarbon fuels. They say, we should focus on weaning ourselves from fossil fuels[9,10]. But Steven Chu, Nobel Prize winning Physicist and former US Secretary of Energy, who strongly supports solar, wind, and other renewables says---for decades to come, fossil fuels will be very important and we will need CCS[11,12]. Deep storage CCS is currently considered too expensive for widespread commercial adoption[13]. The parasitic load may be as high as 30% of a power plant output. But Shiffman[14] says, "The biggest challenge is not technical, but rather economic". Are we willing to pay more for electricity in order to implement CCS and mitigate global warming?

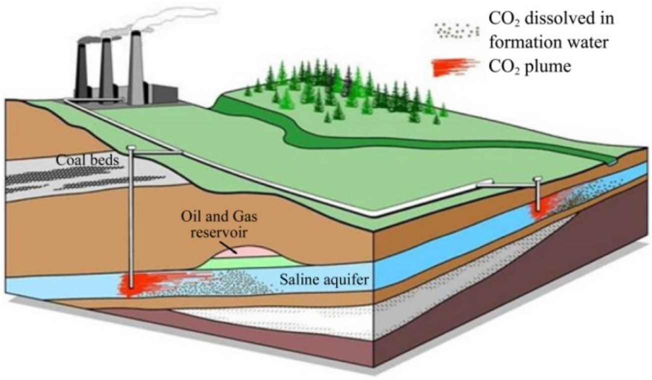


Figure 2 Deep storage of $CO_2$ (Princeton University)

The reality is that dependence on coal to generate electricity is not ending anytime soon. Although renewable energy is expected to boom in future decades, coal will remain by far the top global power[12,15].

There is a strong movement to improve current $CO_2$ deep storage technology and reduce the cost. The Global CCS Institute[16], registered in Australia, with members from over 40 countries, states its mission—"to accelerate development, demonstration, and deployment of CCS globally". They host an annual "Carbon Capture, Utilization and Storage" conference in Pittsburg, USA. The conference in 2015 was the 14th.

### 1.3 China's energy flow

Since China has surpassed the US as the world's greatest $CO_2$ emitter and that China is responsible for almost of 1/3 of the global GHG output, it is instructive to study China's energy use and flow and look at the increase in energy use over a 20 year period. In 1987, China's total energy use was about 880 million tons of coal equivalent (mtce) (Figure 3). Coal was by far the greatest energy source, about 663 mtce (75% of the total) followed by oil (about 20%). Note that agriculture was a tiny energy user (about 4%).

Twenty years later (Figure 4), because of the enormous population and rapid economic growth, China's total energy input grew from about 880 to 2500 mtce (2.8 times) and coal use increased accordingly from 663 mtce to 1804 mtce (2.7 times). Note that agriculture's energy use during this 20 year period increased from about 34 mtce to 61 mtce (about 1.8 times)[18].

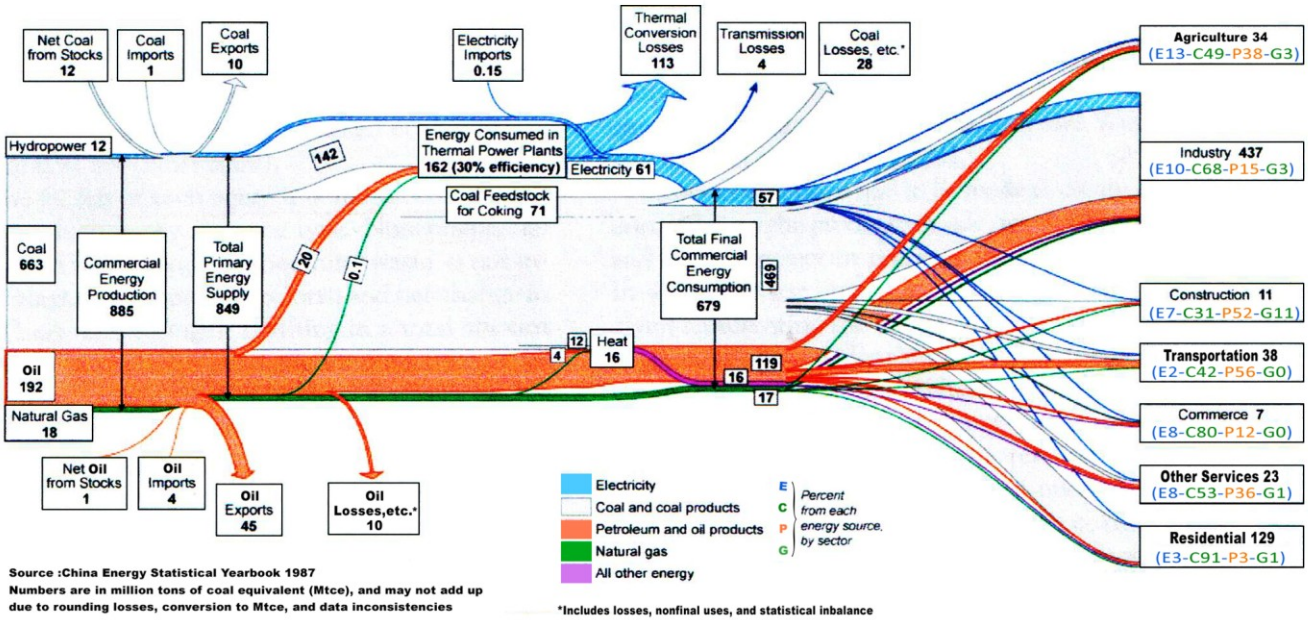


Figure 3 China energy flow---1987 (China Energy Statistics Yearbook)[17]

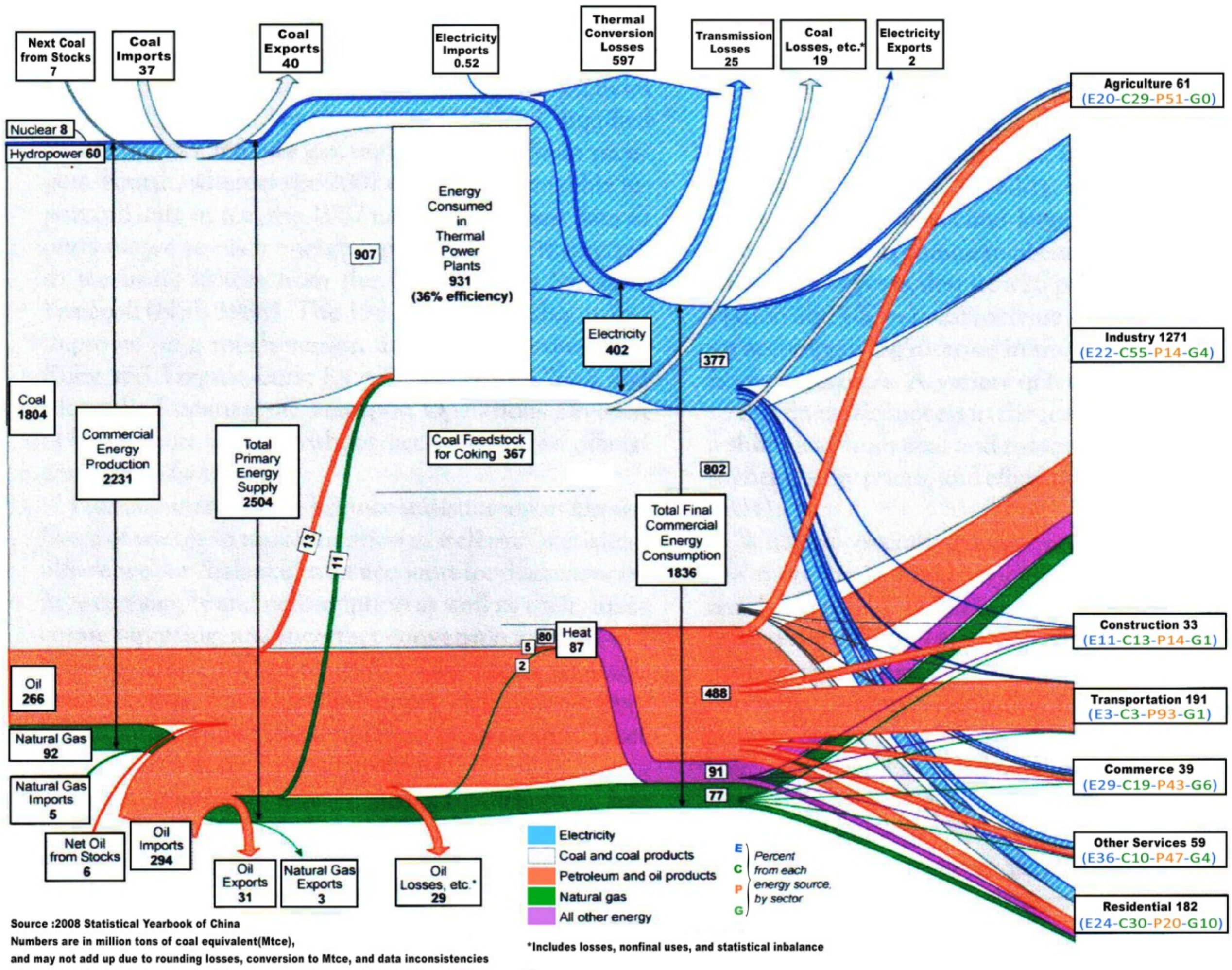


Figure 4 China energy flow-2007[18]

China recognizes that it has an environmental crisis[19]. Air pollution is a major problem caused mainly by combustion of coal and oil. But China is not likely to reduce consumption of coal and oil anytime soon, despite the agreement signed by Presidents Xi and Obama November 11, 2014 (US White House Press Release, Nov

11) and the Paris Agreement of December 2015 (Paris Agreement, December 2015, European Commission, Climate Change, EU Action)[20]. The Xi/Obama agreement commits both countries to start reducing peak $CO_2$ emissions by the year 2030 (14 years in the future), earlier if possible and to increase the non-fossil fuel share of all energy to around 20% by 2030. The Paris Agreement was approved by 195 countries and seeks to slow the rise of GHG so the world temperature rise would be limited to 2 degrees Celcius or less. These are hopeful goals, but there are many sceptics that question the significance of these political agreements.

For example, here are some comments from the respected journal, Scientific American, November 12, 2014[21]. Biello wrote, the Xi/Obama agreement does not mean the problem of climate change is solved. The US and China are on a pace to release billions of tons of $CO_2$ into the atmosphere. The world still has a long way to go to combat climate change. Lets hope for positive outcomes from these agreements, but continue the search for practical, cheaper technologies for reducing $CO_2$ emissions into the atmosphere and thereby mitigating the air pollution and global warming problems.

## 2 The role of agriculture and soils in carbon capture and climate change

"Considerable opportunity and growing sophistication can make terrestrial C sequestration both practical and effective." (Figure 5)[22].

Figure 5 Example of terrestrial carbon sequestration－tropical rain forest

The amount of C in soils represents a substantial portion of C found in terrestrial ecosystems of the planet, about 2500 GT, nearly 80% of the total. The soil C pool is about 3 times larger than the atmospheric pool[6,23].

Soil carbon sequestration is the process of transferring $CO_2$ from the atmosphere into soils through crop residues (Figure 6)[24,25].

Figure 6 Crop residues sequester $CO^2$[24], No-till farming can increase C sequestration in surface layers[6]

Some benefits of C storage in soils include increased soil organic matter (SOM) leading to increased crop yield and farmer incomes leading to global food security, improved water quality as a result of reduced runoff and soil erosion, increased soil biodiversity, and soil resilience against extreme events such as heavy rainfall and flooding[26].

Soil carbon sequestration increases with cultural practices long recommended to increase crop yields and insure global food security[27].

Movement of $CO_2$ from the atmosphere into land via photosynthesis and root respiration, the subsequent formation of bicarbonate in the soil, and its storage in groundwater or precipitation as $CACO_3$ in dryland soils are major processes in the global C cycle. Together, inorganic C as soil carbonate and bicarbonate in groundwater surpass soil organic C as the largest terrestrial pool of C. Yet, despite the general agreement about its huge size, controversy about the potential of inorganic C to sequester atmospheric $CO_2$ remains unresolved[28].

At the Climate Summit in Paris from 30$^{th}$ November to 12$^{th}$ December, 2015, the French Government (Mr Stephane Le Foll, the Minister of Agriculture and Forestry) presented the "4 pour Mille" proposal of sequestering C in soils (40 cm depth) of the world at the rate of 0.4% per year. With a total C pool of 800 Gt to 40-cm depth, an annual increase of 0.4% implies off-set of 3.2 Gt/yr. Being a natural and a cost-effective option, this proposal has numerous co-benefits. Implementation of the proposal will be discussed at the COP22 scheduled to be held in Marrakech, Morocco in 2016[20].

### 2.1 How about $CO_2$ fertilization?

In field tests, young trees exposed to double the current atmospheric $CO_2$ concentration grew much faster and translocated more carbon. Growth rate of agricultural crops and grassland was accelerated by elevated atmospheric $CO_2$ concentration[29].

$CO_2$ enrichment in greenhouses is in widespread use and has been adopted by many commercial producers. The result is remarkable increases in yield of all flowers and vegetables. It may permit an additional crop each year. There is no question about the benefits of $CO_2$ enrichment. The optimum concentration of $CO_2$ is about 1000 ppm (2 1/2 times normal atmosphere) (Figure 7)[30].

A challenge for Agricultural and Biological Engineers and other scientists is---how to apply $CO_2$ enrichment to field crops (Figure 8)? Good management practices for agriculture and soils may be the tools. "The talents of engineers and biologists must be consolidated to develop ways to control enhanced levels of $CO_2$ in the production of all economic crops". Note this quotation was published 46 years ago in the ASAE Transactions![30]

Figure 7 $CO_2$ enrichment in greenhouses, a common commercial practice

Figure 8 Field crops, how to increase $CO_2$ concentration?

Actually, a great deal of research is underway to determine the benefits and to develop practical and cost efficient technologies for $CO_2$ enhancement of field crops. A review of FACE (Free Air $CO_2$ Enrichment) containing 54 references was published by Elsevier in 2014[31]. And research is underway at the University of Illinois to evaluate the cost and benefit of FACE (Figures 9 and 10---photos by B. Stout).


Figure 9 Study of FACE (University of Illinois)


Figure 10 Liquid $CO_2$ to be applied to field crops (University of Illinois)

It must be noted that there are constraints to $CO_2$ fertilization. For example, other plant requirements such as lack of available water or short supply of N and other nutrients may be limiting factors in crop production[32].

### 2.2 Restoration of desertified land

Restoration would improve soil quality, increase the pool of C in the soil, and induce the formation of carbonates in the soil leading to reduction of C emissions to the atmosphere[33,34]. The concept of zero net land use degradation and adopted by UNCCD is very pertinent to sequestering C by restoring desertified lands and ecosystems[35].

### 2.3 Promoting carbon sequestration in soil

Potential of C sequestration is largest and the challenges the greatest in severely eroded, degraded and desertified ecosystems. Resource-poor small landholders of the tropics lack the financial capability to invest in soil restoration. However, carbon capture and sequestration is another income stream for farmers through payments from ecosystem services[6,36]. Assessing the societal value of soil C and developing a mechanism for payment to land managers are important to implementing this concept[37].

### 2.4 Cap and trade system

Any country that has a surplus quota can sell it to other countries under the cap and trade system. This is truly Win-Win, while sequestration in the soil mitigates climate change, it also increases biodiversity, improves the environment and advances food security[6,36].

### 2.5 Carbon sequestration in soils

The soil carbon sink capacity, is estimated at 10-60 mg/hm$^2$. Principal strategies for soil organic carbon (SOC) sequestration involve: (i) restoration of degraded/desertified soils through conversion to perennial land use, and (ii) adoption of recommended management practices (RMPs) such as no-till farming (Figure 10), manuring, agroforestry, and use of biochar as a soil amendment[6].

Soil C sequestration is a Win-Win-Win strategy because it advances food security, improves the environment and mitigates global warming[6].

### 2.6 Offsetting China's $CO_2$ emissions by soil carbon sequestration

China's soils have lost have lost 30%-50% of SOC. Some of the depleted SOC pool can be sequestered through restoration of degraded soils[34]; that is adoption of recommended management practices[38]. Reforestation and permanent grasslands are other options (Figure 11).

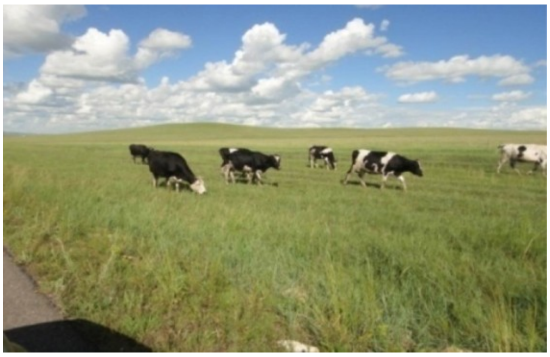

Figure 11 Example---grasslands in Inner Mongolia

### 2.7 Air extraction strategy, artificial trees

Why can't we just suck the $CO_2$ out of the atmosphere? In fact, we can! Much research is underway on air extraction technology; that is, absorbing $CO_2$ from the air at any place on earth—from any source, power plants, airplanes, all industrial operations, etc.[39]

Real trees have ecological limits, but how about artificial trees? (Figure 12) They use sodium hydroxide (lye) to absorb $CO_2$[40]. Is there a role for ABE's and other scientists? We think so.

Figure 12 Artificial trees---they look like posts with venetian blinds along the top, a means of extending forests

### 2.8 Restoration of alkaline soils

A pH of 6.0-8.0 is optimal for plants. Alkaline salts are not soluble in water. But $CO_2$ is soluble in water producing carbonic acid[41].

If the soil pH is above 8.0, some action may be needed to reduce the pH. Could addition of $CO_2$ to irrigation water lower the pH and help restore alkaline soils? (Figure 13).

Figure 13 Alkaline soils with low productivity

### 2.9 CCS---general comments, cost

Power plants account for about 40% of global manmade carbon emissions. The biggest challenge is not technical, but economic[14]. Are we willing to pay more for electricity in order to limit emissions and mitigate global warming.

As pointed out earlier, the parasitic load for deep CCS applied to coal-fired power plants is reported as about 30%, too expensive for widespread commercial application[13]--or is it? Compare the 30% parasitic load of CCS with the thermal efficiency of internal combustion engines. For spark ignition (gasoline) engines, the thermal efficiency, i.e. conversion of fuel energy to mechanical work may be as high as 60% (probably less). Thus, the parasitic load for spark ignition engines is in the range of 40%. Yet internal combustion spark ignition (gasoline) engines have been widely adopted since the Otto cycle was invented in 1876.

Diesel engines (compression ignition) are more efficient than gasoline engines (spark ignition), with thermal efficiencies as high as 65% and have been widely used since the early 1900's. Consumers have accepted the parasitic load of perhaps 35%.

So if consumers are willing to pay more for electricity and accept the parasitic loss of around 30% (much less than internal combustion engines that are widely accepted without question), perhaps deep CCS could now be applied to reduce $CO_2$ emissions from the burning of coal and petroleum and thereby mitigate global warming. Think about it! Further research is needed to establish the costs and benefits of carbon capture and sequestration using near-surface agriculture and soils applications.

Government intervention may well be needed. Mechanisms for paying such as carbon capture and trade will need to be strengthened. Perhaps energy companies might be required to purchase "Certificates of Sequestration". Carbon Capture needs to be made into a profitable venture, making clean air more attractive than fouling it[14].

## 3 Closing comments

Energy is vital for human welfare and economic growth. The long-term solution to the emissions problem and global warming is carbon free renewable energy. But fossil fuels (coal, oil, N-gas, etc) will be major world energy sources for many decades to come. Thus, Carbon Capture and Squestration (CCS) are technologies whose time has come! Let's explore the opportunities for ABE's and other engineers and scientists and help mitigate global warming. Carbon sequestration in soils and vegetation, especially those of degraded and desertified ecosystems, is a win-win option. It buys us time and is a bridge to the future until low-C or no-C fuel sources take effect.

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