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Views & Comments

Fitting on the Earth: Challenges of Carbon and Nitrogen Cycle to Preserve the Habitability of the Planet

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Our small planet is now vulnerable to the cumulative effects of our normal activities. There are two specific grand challenges associated with sustainability that are worth our attention—the global carbon cycle and the global nitrogen cycle.

Human beings are disrupting the carbon cycle by releasing carbon, dug out of coalmines and oil fields, into the atmosphere. Mainly due to human beings' activities, the concentration of carbon dioxide in the atmosphere has increased by more than 30% over the last 250 years, with an annual increase of about 0.5%. Two-thirds of the rise has occurred during the past 50 years. Fossil fuel accounts for 85% of the world's energy system, and has been the principle agent of interference with the natural cycle for carbon. Such a disrupted carbon cycle, with a high carbon dioxide concentration, is posing tremendous challenges, including wide-spread global warming, rising sea level, significant threats to human health, more frequent extreme weather, and harmful disrupted ecological systems, and so on. Unless there is a change, the world will see much higher concentration of carbon dioxide, and it is thus a must for the world to redesign its energy system to become much less dependent on fossil fuels and less harmful to the carbon cycle.

Besides the carbon cycle, the nitrogen cycle is another fundamental feature of life on the planet. The nitrogen cycle is also being disrupted by human beings. Organisms on this planet require nitrogen to survive, but the nitrogen in the atmosphere must be modified to be useful. The nitrogen needed by life is produced by "nitrogen-fixing bacteria" that break the triple bond of atmospheric nitrogen (N_2, or N≡N) and produce "available" nitrogen. Only a few bacteria can act as "nitrogen-fixing bacteria." Additional nitrogen fixation is accomplished by lightning. However, for the past hundred years, human beings have been able to produce available nitrogen from atmospheric nitrogen industrially, using the Haber-Bosch process. The most important product, globally, is nitrogen fertilizer, which has enabled a great expansion of the world's food supply. The world is now more and more dependent on fertilizers to fix nitrogen. And now, more nitrogen is fixed in fertilizer factories than by the bacteria of the world.

Another new source of available nitrogen comes from combustion of fossil fuels, which produces nitrogen oxides ("NO_x," which subsumes NO, NO_2, N_2O_5, and other oxides of nitrogen). Significant increases in NO_x emissions could occur over the next several decades due to both population growth and per capita increases in fossil-fuel use, although there are many technologies that can reduce NO_x emissions.

The extra nitrogen fixation today will seriously affect many environment systems—changing the balance of species, producing unwanted biological growth (eutrophication) in aqueous systems, and increasing the emissions of nitrous oxide (N_2O, a greenhouse gas) to the atmosphere. International attention to the nitrogen cycle has gradually increased and focuses on the complexity of human alteration of the nitrogen cycle.

Coordinated management of the nitrogen and carbon cycles is desirable. Engineering can provide remedies to disrupted ecosystems and has managed to achieve partial successes.

There are many reasons to be optimistic that much can be accomplished, the world still has a terribly inefficient system for using carbon and nitrogen, and there is so much room to improve our energy system, food system, and agricultural system. The word "smart" is a key word to describe what engineers can contribute—smart buildings, appliances, infrastructure, vehicles, and food systems, with a core aim to achieve better efficiency. In order to achieve that, we can use a carbon price and a nitrogen price to promote efficient use. Also, we have an enormous amount of global infrastructure still to build, especially in the developing world (Table 1). Crucially, young scientists and engineers now find the challenges of carbon and nitrogen management exciting.

As a main engineering method to protect the carbon cycle, carbon dioxide can be captured at a coal plant, then compressed and sent into porous rocks deep below ground. Someday all coal plants may separate the burning of coal from the emission of carbon dioxide. The already existing network of carbon dioxide pipelines in the USA shows that such a route for a low-carbon future

Table 1
Parallels between carbon and nitrogen.

	Carbon	Nitrogen
Industrial sector	Fossil fuel	Fertilizer
Fundamental activity	CO_2 to the atmosphere	Nitrogen fixation: N≡N⟶NH and NO
Quantitative measure	$[CO_2]_{atm}$ is rising 0.5% per year	Fertilizer factories fix as much N as bacteria
Engineering opportunity	Efficient use	Efficient use

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is real. These pipelines help bring additional oil out of formations, through "enhanced oil recovery." However, many related technologies are still at an experimental stage, which generates much uncertainty.

Engineering solutions have also been introduced to reduce nitrogen emissions and can be used worldwide with few variations. A big opportunity for decreases of both carbon dioxide and nitrogen emissions involves a "technology leap" through adoption of advanced technologies such as electric propulsion vehicles and zero emission-distributed power. Further efforts must be made to increase nitrogen efficiency in both the food product systems and the transportation systems. Altogether, the most benefit will come from an integrated system optimizing nitrogen management in the whole society while decreasing detrimental environmental impacts.

Besides engineering treatments of carbon and nitrogen, we must also deal with many social challenges. Among them, poverty is an immense challenge and can be addressed by the cooperation between developed and developing countries. It used to be that rich countries were expected to take the lead role, but now a developing country, like China, is also expected to be involved in the search for solutions. There are new solutions, and one does not need to depend only on old solutions. It is possible to do something for the first time—to leapfrog—with new technologies and new international partnerships. Everyone can participate in sustainability collaborations: environmentalists, technologists, economists, public citizens, and governments around the world can improve the global management of the nitrogen and the carbon cycles. Furthermore, in the near future, sustainability collaborations will be needed to find a way to deal with "unburnable" fossil fuel, which is the fuel that we will voluntarily leave in ground; this is a new and difficult problem that will soon occupy center stage.

However, every "solution" has a dark side, and each "solution" we use can potentially bring new, serious problems of its own. We therefore should demand risk management, taking into account the risks of disruption both from climate change and from mitigation. To achieve better carbon and nitrogen management, especially young generations need to learn some relevant science and strive to be the leaders needed in this critical new area where environmental and engineering issues come together.