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News and opinions

Putting carbon nanomaterials on the carbon cycle map

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ABSTRACT

The large-scale production and spread applications of carbon nanomaterials in the past few years have led to a very high proportion of carbon store in these materials worldwide, which may be imported into the carbon cycle. Carbon nanomaterials can enter living organisms, the atmosphere, soil, water and sediments, without being unchanged or degraded during their transfer. Here, we show that there is a scientific basis for researchers and policy-makers to be concerned about the potential impact of carbon nanomaterials on the carbon cycle and integrate them into the map of carbon cycle.

Carbon nanomaterials possess unique physical-chemical properties and have been applied in numerous areas [1–9]. Significant commercial interest has stimulated an increase in production capacity of carbon nanomaterials, and demand is still continually increasing [10,11]. Given that the main component of carbon nanomaterials such as carbon nanotubes, graphene and fullerene is carbon, a high proportion of the Earth's carbon has been moved into these materials. Until now, however, they have not been considered as a potentially important part of carbon cycle because they are new emerging materials. The specific issue that we are addressing is whether carbon nanomaterials will play a role in carbon cycle. Herein, we provide three pieces of scientific evidence that demonstrate their potential role in carbon cycle:

The first issue is that the carbon amount in carbon nanomaterials will become very large as the production of carbon nanomaterials continuously increases. It has been reported that the estimated production capacity of carbon nanotubes in 2011 was >4.5 kiloton/year, which is about 10 times more than that in 2006 [3]. For graphene films and small graphene sheets, the annual production capacity in China was reported to be more than 110,000 m^2 and 0.4 kiloton, respectively [5]. The estimated annual U.S. production of fullerenes was 0.002–0.080 kiloton/year [7]. Adding up all types of carbon nanomaterials for decades at a global scale, the carbon amount stored in these materials would become very considerable. Mass production and wide applications of carbon nanomaterials give rise to the possibility that they find their way into the carbon cycle. Thus, we cannot ignore the role of carbon possessed by carbon nanomaterials when exploring the carbon cycle (Fig. 1).

The second piece of scientific evidence is that carbons derived from carbon nanomaterials can transfer in the environment and widely distribute in the world. They are able to move via food chains or physical-chemical processes [12], increasing the complexity to investigate carbon-transfer routes. The carbon from carbon nanomaterials faces two fates: remain unchanged or decompose. Some microbes can utilize carbon nanomaterials as a carbon source [13,14], generating CO_2 that can enter the atmosphere [15]. Although the degradation rate of carbon nanomaterials is often low [16], the carbon arising from this process is considerable due to the large volume of carbon nanomaterials being generated in the world. It is noteworthy that carbon nanomaterials can also interact with environmental substances, which can become an obstacle to quantifying them accurately [12]. It is not easy to track carbon movement associated with carbon nanomaterials in the environment. Carbon transfer routes for carbon nanomaterials and how these integrate with the whole carbon cycle now need to be investigated.

The third issue is that carbon nanomaterials have a direct influence on the carbon cycle because of the adverse effect they have on fungi and bacteria [17]. Thus, the environmental release of carbon nanomaterials will affect carbon transport and balance.

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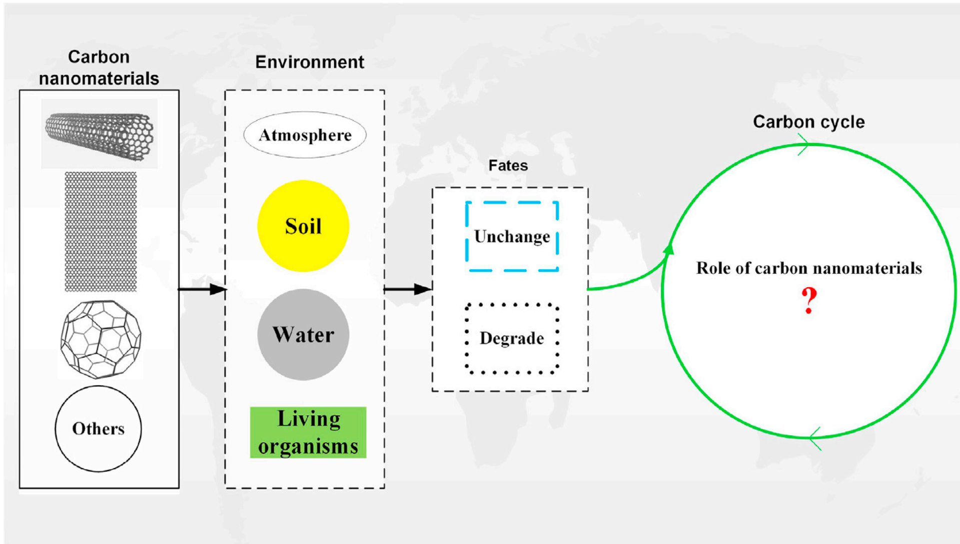

Fig. 1. Integrating environmental carbon nanomaterials (carbon nanotubes, graphene, fullerene and others) into the global map of carbon cycle. The question mark indicates that the role of carbon nanomaterials is still unclear. The world map is used as the background.

Given the above three pieces of evidence, carbon nanomaterials have been in contact with carbon cycle. We thus suggest that the researchers and policy-makers should consider their roles in the carbon cycle and make reasonable policies to cope with the potential impacts of carbon nanomaterials on carbon cycle in the near future. However, this problem is not easily solved due to the unique properties of carbon nanomaterials. For example, the nanoscale size of carbon nanomaterials results in that it is very difficult to trace them in the environment. A systemic approach that includes new equipment or technologies such as numerical modeling technology with high accuracy on current basis is needed.

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References

[1] A. Dasgupta, L.P. Rajukumar, C. Rotella, Y. Lei, M. Terrones, Nano Today 12 (2017) 116–135.
[2] M. Chen, X. Qin, G. Zeng, Chemosphere 163 (2016) 217–226.
[3] M.F. De Volder, S.H. Tawfick, R.H. Baughman, A.J. Hart, Science 339 (2013) 535–539.
[4] M. Chen, X. Qin, G. Zeng, Nano Today (2017), http://dx.doi.org/10.1016/j.nantod.2017.1009.1001.
[5] W. Ren, H.-M. Cheng, Nat. Nanotechnol. 9 (2014) 726–730.
[6] M. Chen, G. Zeng, P. Xu, Y. Zhang, D. Jiang, S. Zhou, Environ. Sci. Nano 4 (2017) 720–727.
[7] C.O. Hendren, X. Mesnard, J. Dröge, M.R. Wiesner, Environ. Sci. Technol. 45 (2011) 2562–2569.
[8] M. Chen, G. Zeng, C. Lai, C. Zhang, P. Xu, M. Yan, W. Xiong, Chemosphere 184 (2017) 127–136.
[9] M. Chen, G. Zeng, P. Xu, M. Yan, W. Xiong, S. Zhou, Environ. Sci. Nano 4 (2017) 1954–1960.
[10] D. Jariwala, V.K. Sangwan, L.J. Lauhon, T.J. Marks, M.C. Hersam, Chem. Soc. Rev. 42 (2013) 2824–2860.
[11] M. Chen, G. Zeng, P. Xu, C. Lai, L. Tang, Trends Biochem. Sci. 42 (2017) 914–930.
[12] C. Larue, M. Pinault, B. Czarny, D. Georgin, D. Jaillard, N. Bendiab, M. Mayne-L'Hermite, F. Taran, V. Dive, M. Carrière, J. Hazard. Mater. 227 (2012) 155–163.
[13] M. Chen, X. Qin, G. Zeng, Trends Biotechnol. 35 (2017) 836–846.
[14] M. Chen, X. Qin, J. Li, G. Zeng, RSC Adv. 6 (2016) 3592–3599.
[15] L. Zhang, E.J. Petersen, M.Y. Habteselassie, L. Mao, Q. Huang, Environ. Pollut. 181 (2013) 335–339.
[16] D.X. Flores-Cervantes, H.M. Maes, A. Schäffer, J. Hollender, H.-P.E. Kohler, Environ. Sci. Technol. 48 (2014) 4826–4834.
[17] D.F. Rodrigues, D.P. Jaisi, M. Elimelech, Environ. Sci. Technol. 47 (2013) 625–633.

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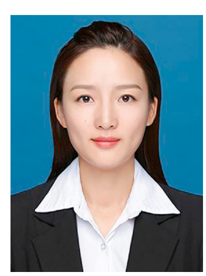

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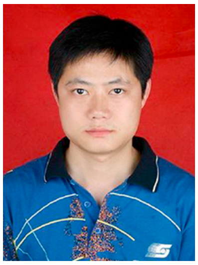

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