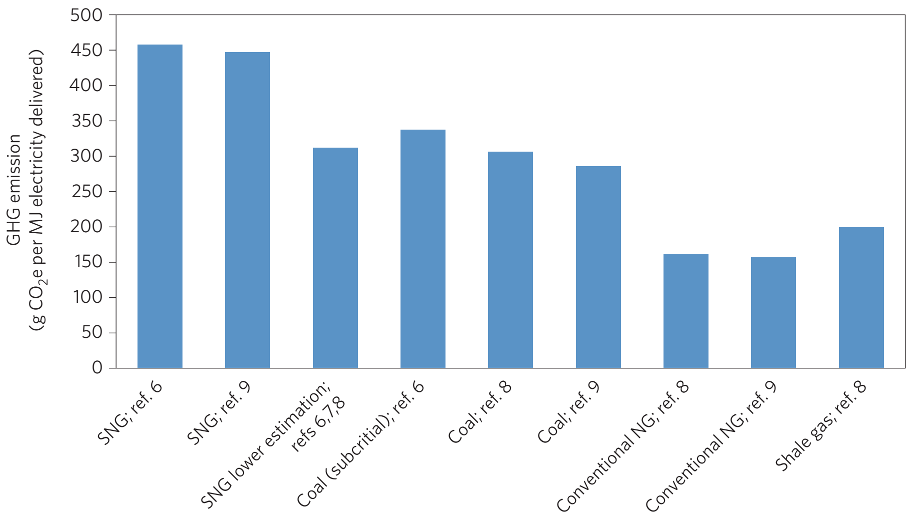

Figure 2 | Comparison, using revised data, of the life-cycle GHG emissions associated with the coal-to-SNG, coal-to-electricity, conventional natural gas and shale gas pathways. The SNG lower estimate is based on coal-to-SNG (refs 6,7) and natural gas combined cycle (ref. 8).

Following ref. 2, Yang and Jackson[1] assumed a relatively low energy efficiency of the existing coal-to-SNG process of 50%. The above corrected calculations of the life-cycle GHG emissions of the coal-to-SNG pathway are also based on existing, more efficient technologies.

Although China remains highly dependent on coal for energy, its use of gas increased from 5.6% in 2008 to approximately 29% in 2012[5]. If the efficiency of the coal-to-SNG pathway could be improved to approximately 60–65%[6,7], the life-cycle GHG emissions would be reduced and would be comparable to those associated with current coal-to-electricity pathways. Moreover, in coal chemical plant that emit high concentrations of CO_2 (such as coal-to-SNG plant), it is possible to capture CO_2 with relatively low energy consumption and cost penalties. Therefore, the life-cycle GHG emissions from the coal-to-SNG process can be further mitigated if CO_2 capture is applied.

China faces climate mitigation, energy efficiency, and energy security challenges and thus must and will develop a new generation of clean coal technologies because China's energy structure will be highly coal dependent for a long time. ❐

References

1. Yang, C-J. & Jackson, R. B. *Nature Clim. Change* **3,** 852–854 (2013).
2. Ding, Y., Han, W., Chai, Q., Yang, S. & Shen, W. *Energy Policy* **55,** 445–453 (2013).
3. Fulton, M., Mellquist, N., Kitasei, S. & Bluestein, J. *Comparing Life-cycle Greenhouse Gas Emissions from Coal and Natural Gas* (World Watch Institute, 2011).
4. Jaramillo, P., Griffin, W. M. & Matthews, H. S. *Environ. Sci. Technol.* **41,** 6290 (2007).
5. National Bureau of Statistics of China; http://data.stats.gov.cn/english/easyquery.htm?cn=C01
6. Department of Energy *Cost and Performance Baseline for Fossil Energy Plants Volume 2: Coal to Synthetic Natural Gas and Ammonia* (National Energy Technology Laboratory, 2011).
7. Li, S., Ji, X., Zhang, X., Gao, L. & Jin, H. *Appl. Energ.* **136,** 98–109 (2014).
8. Siemens Gas turbine SGT5–8000H; http://go.nature.com/GMaWpK
9. IPPC National Greenhouse Gas Inventories Programme *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (eds Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K.) Vol. 2 (Institute for Global Environmental Strategies Japan, 2006).
10. Xie, P., Sun, J., Wang, J., Li, X. & Sha, Y. *Energ. Conserv. Technol.* **24,** 181–184 (2006).

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Additional information

Supplementary information is available in the online version of the paper.

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Reply to 'Greenhouse gas emissions from synthetic natural gas production'

Yang and Jackson reply — Sheng and Gao[1] correctly point out a mistake we made in our original calculations in our Commentary[2], attributable to our misinterpretation of the units used in the work by Ding and colleagues[3]. Here, we revise our calculations, which lower the estimate of CO_2 emissions associated with the production of synthetic natural gas (SNG) but do not alter the broad conclusions of our Commentary.

The revised calculations indicate that the life cycle of SNG has 3.3–3.9 times more CO_2 emissions than natural gas does, but not 7 times more as originally stated[2]. We revised the function unit to that of electricity, assuming that all these fuels are used to generate electricity. Because wet cooling is banned in China's arid regions, we assume dry cooling in power generation. The revised figure 1 from our Commentary[2] should then look like Fig. 1 here.

In our Commentary[2] we correctly stated "If SNG is used to generate electricity, its life-cycle GHG emissions are ~36–82% higher than pulverized-coal-fired power." This finding is consistent with Gao and Sheng's finding[1] that the coal-to-SNG-to-electricity pathway produces 1.35 to 1.6 times the CO_2 emissions of the coal-to-electricity pathway. In contrast, Sheng and Gao also argue that future improvements in SNG technology will reduce the emissions of coal-to-SNG-to-electricity to a level that is comparable to the conventional coal-fired electricity. However, even if the carbon footprint of coal-to-SNG-to-electricity might someday become comparable to coal-to-electricity, it remains a technology of relatively high CO_2 and water footprints.

Sheng and Gao[1] correctly point out that the life-cycle GHG emissions from the coal-to-SNG process can be further mitigated if CO_2 capture is applied. However, none of China's SNG projects plan to capture CO_2. Based on a recent review of experiences at the Great Plains Synfuels Plant[4], even with current carbon capture and storage practices, the carbon emissions from SNG are still more than twice as high as for natural gas.

Another major conclusion in our original paper[2] concerned the high water consumption of SNG. A recent analysis of China's first SNG demonstration project suggested a number of shortcomings for water use and water pollution[5]. The Correspondence from Sheng and Gao[1] does not address or mention the many important water issues or other environmental impacts created by SNG.

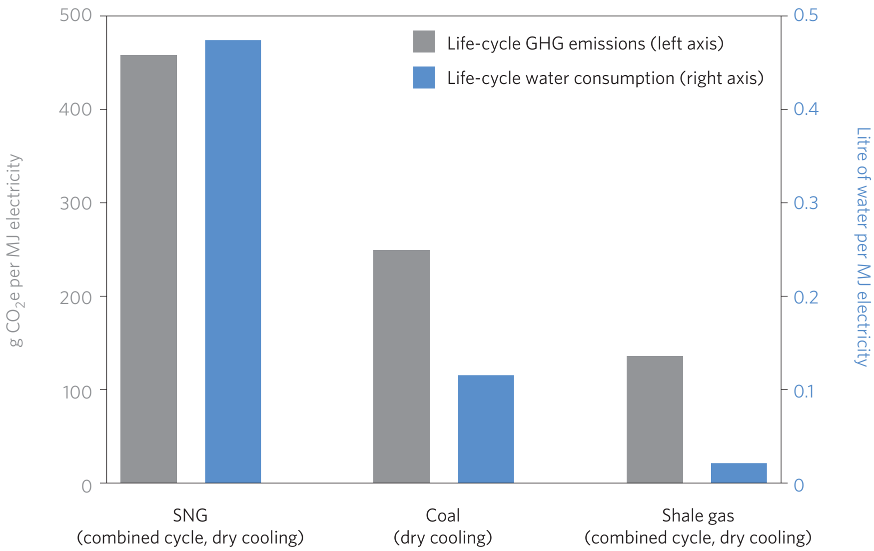

Figure 1 | Life-cycle GHG emissions and water consumption for SNG, coal and shale gas (revised from figure 1 in our Commentary[2]). Note that the water consumption used previously only accounts for that used during the fuel production process, while the values used here include both fuel production and power generation.

We thank the authors for correctly pointing out the revision needed for our calculation. Because of its substantially higher greenhouse gas emissions and water requirements, however, SNG is not a clean technology and, in our view, should not be advocated. ❐

References
1. Sheng, L. & Gao, L. *Nature Clim. Change* **6,** 220–221 (2016).
2. Yang, C-J. & Jackson, R. B. *Nature Clim. Change* **3,** 852–854 (2013).
3. Ding, Y., Han, W., Chai, Q., Yang, S. & Shen, W. *Energy Policy* **55,** 445–453 (2013).
4. Yang, C.-J. *The U. S. Experiences in Coal-Based Synthetic Natural Gas and its Lessons for China* (Greenpeace East Asia, 2014); http://go.nature.com/BQywtO
5. *Coal-to-Gas Project Investigation Report* (Greenpeace East Asia, 2014); http://go.nature.com/QZjURz

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COMMENTARY:

1.5 °C and climate research after the Paris Agreement

Mike Hulme

The Paris Agreement contains an ambition to limit global warming to no more than 1.5 °C above pre-industrial levels, changing the context for policy-relevant research and extending a challenge to the IPCC and researchers.

To some commentators' surprise, the Paris Agreement reached in December 2015 under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC) included the explicit intention to "pursue efforts to limit the [global] temperature increase to 1.5 °C above pre-industrial levels". Given that countries' stated ambitions, in the form of the Intended Nationally Determined Contributions (INDCs), fall well short of limiting warming to 2 °C[1], let alone to 1.5 °C, one might wonder whether negotiators were whistling in the dark.

Accompanying the Agreement, however, was an invitation from the Conference of the Parties to the IPCC. It requested the IPCC to "provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways". In inviting this report, governments are effectively asking the IPCC to explain some of the implications of what they have already agreed.

The significance of this invitation from the world's governments to the IPCC is twofold. First, the IPCC is being asked to 'identify a level' to which annual emissions should be reduced by 2030 to offer the prospect of just 1.5 °C of warming, a level presumably well below the 40 $GtCO_2$ that is deemed necessary for securing 2 °C with reasonable likelihood. Second, the impacts of a 1.5 °C warming identified by such an IPCC report would be important for discussions about the Warsaw International Mechanism for Loss and Damage. The scale of these prospective climate change-induced damages would act as a minimum baseline against which potential flows of adaptation support and finance might be judged.

Such a request raises important questions about the relationship between knowledge and policy, highlighted here. Specifically, the UNFCCC's invitation raises the issue of whether the IPCC is in a position to deliver such a report in 2018, and if so, whether its assessment would be useful and robust. More generally, the invitation refocuses attention on the function and status of