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Cost of Carbon Capture: Can Young People Bear the Burden?

James Hansen[1,*] and Pushker Kharecha[1]

Near-universal recognition of the threat of human-caused global warming, tragically, has not been accompanied by comprehensive quantitative assessment of technological options for mitigating climate change. In this issue of *Joule*, David W. Keith and co-authors describe a process of capturing CO_2 from the air and provide a much-needed empirical cost estimate based on results from a pilot plant. Estimated costs, exceeding \$100 per ton of CO_2 without including the cost of CO_2 storage, are lower than some prior estimates, yet are so high as to strongly support the need for rapid reduction of fossil fuel emissions.

It feels as if the world is almost sleepwalking into a tragedy for humanity and many other species on our planet. Estimates for the dangerous level of global warming have declined, as recognized in the United Nations Paris Agreement,[1] which aims to "strengthen the global response to the threat of climate change by keeping global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C." Yet global fossil fuel emissions, the principal cause of global warming, continue at a high level, even rising (Figure 1).

The Intergovernmental Panel on Climate Change,[4] in response to continued high emissions, began assessing so-called "negative emissions" in its climate scenarios. Indeed, extraction of CO_2 from the air is now almost surely required if global temperature is to be stabilized at a level avoiding disastrous consequences.[5] Are such negative emissions a plausible assumption? Will today's young people be able to afford the cost of negative emissions?

Keith et al.[6] built a pilot plant capturing CO_2, which provides the best basis so far for estimating the cost of CO_2 extraction. Their estimated cost range is \$94–\$232/tCO_2, where tCO_2 is metric tons of CO_2. This cost appears to be much lower than estimates in an earlier study.[7] However, it would be a grave misconception to think that the Keith study provides hope for a "get out of jail free card" for the climate problem.

First, note that the \$94/tCO_2 estimate applied only to a case in which CO_2 was processed to a point of being ready for use in production of a carbon-based fuel. That use of the CO_2 does not result in negative emissions when the fuel is burned. Keith's cost estimate for cases in which extracted CO_2 is prepared for storage is \$113–\$232/tCO_2.

Second, note that Keith does not include the cost of CO_2 storage, which has been estimated[7] as \$10–\$20/tCO_2. Inclusion of storage makes the cost estimate for carbon capture and storage (CCS) \$123–\$252/tCO_2.

Finally, note that costs are often discussed in units of \$/tC, where tC is tons of carbon. A ton of CO_2 is 44/12 times heavier than a ton of C. Thus, the Keith study implies a removal cost of \$451–\$924/tC.

Hansen et al.[5] used an optimistic cost estimate of \$150–\$350/tC for CO_2 extraction. Even that lower rate results in a removal cost of \$89–\$535 trillion over the next 80 years for a growth rate of emissions ranging from 0 (constant emissions) to +2 percent/year.

Global costs may be difficult for individuals to grasp. In Figure 2A we show the cost of extraction per person for national emissions, based on the lower limit of Keith's estimated cost \$123//tCO_2. The current annual cost to extract all of the annual emissions is of the order of \$1,000 per person per year in developed countries, about \$600/person/year on global average. Extracting all current emissions is a realistic approximation of the need, as the allowed carbon budget to keep warming in the range specified by the Paris accord is nearly exhausted.

Climate change is proportional to cumulative emissions.[9,10] The average citizen in developed countries such as the United States, the United Kingdom, and Germany has a debt of over \$100,000 to remove their country's contribution to climate change via fossil fuel burning (Figure 2B).

Political leaders celebrated the Paris Agreement, as they did the 1997 Kyoto Protocol. Yet these are precatory agreements, wishful thinking, which do almost nothing to address the fundamental problem summarized so clearly in Figure 1. The world is using a tremendous amount of energy,

[1]Climate Science, Awareness and Solutions, Columbia University Earth Institute, New York, NY, USA

*Correspondence: jeh1@columbia.edu

https://doi.org/10.1016/j.joule.2018.07.035

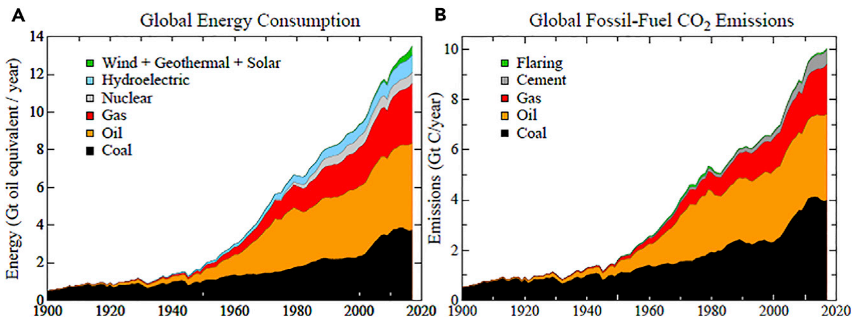

Figure 1. . Global Energy Consumption and Fossil Fuel Emissions
(A and B) BP[2] data are used for 1965–2017. Boden et al.[3] data for earlier years are adjusted by factors near unity to match BP data at 1965. (A) Global energy consumption. (B) Global fossil fuel CO_2 emissions.

over 85% of which is provided by fossil fuels. Even more energy is needed to raise standards of living globally, which is an underlying requirement for global fertility rates to decline to a sustainable level.

The urgency and scope of the climate issue is not new. Major alteration of global energy use or carbon capture can occur only on a timescale of decades to a century. In view of our long-standing knowledge of the threat posed by climate change, we find it morally repugnant and reprehensible that we, the older generations, have not developed, tested, and costed the known technological options for addressing climate change, so that today's young people and future generations will have viable options for addressing climate change.

Instead we placed all of our eggs in a single basket, renewable energies, with almost unlimited subsidies through renewable portfolio standards. Carbon capture is one of the technologies that should be thoroughly explored, and the Keith study is a welcome step in that direction. Advanced generation nuclear power is another, as it is a good candidate for providing the huge requirements for power and process heat in countries such as China and India.

Unless such technology options are developed rapidly, young people and future generations likely will be forced into extensive geoengineering, purposeful intervention in nature, which will raise many practical and ethical issues. Scientific analysis of all options is appropriate, but so saying should only increase the incentive to reduce CO_2 emissions rapidly, thus reducing human-made climate interference and minimizing deleterious consequences.

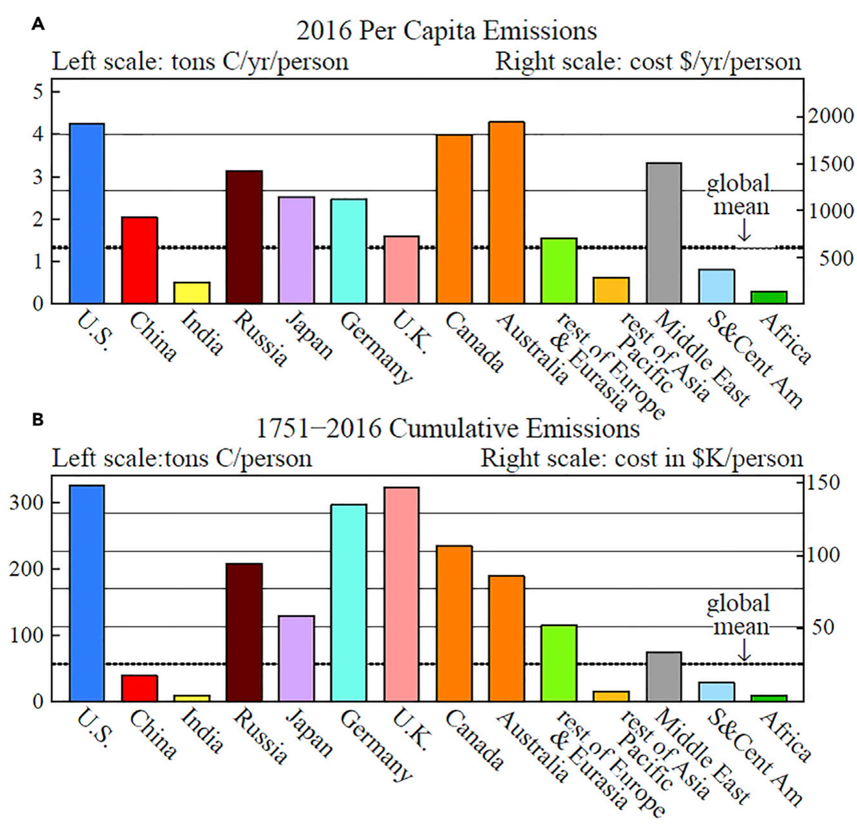

Figure 2. Per Capita Annual and Cumulative Fossil Fuel Emissions
(A and B) Update of Figure 6 of Hansen and Sato.[8] Per capita cost for extraction of the emitted CO_2 (right scale) assumes an extraction cost of \$123/tCO_2. (A) 2016 per capita emissions. (B) 1751–2016 cumulative emissions.

ACKNOWLEDGMENTS

The authors thank Makiko Sato for the figures.

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Preview

Fossil Fuel Assets May Turn Toxic

Klaus Hubacek[1,2,*] and Giovanni Baiocchi[1]

Stranded assets might lead to an overvaluation of companies and contribute to a carbon bubble with potential negative effects to the economy in the future. Mercure et al. find that even in the absence of stringent climate change policies, current trends in renewable diffusion and increased energy efficiency could lead to stranded assets resulting in substantial global wealth loss and wealth redistribution.

Stranded assets are assets that have stopped earning sufficient economic returns or even turned into liabilities well before their expected economic end-of-life. Stranded assets are considered an inevitable consequence of the normal dynamic economic structural change driven by technological innovation and diffusion but have more recently taken central stage in the sustainability debate as climate change policies and the occurring transition toward competitive renewable technologies have raised questions on value and long-term profitability of fossil fuel companies. Bursting the "carbon bubble" could not only affect fossil fuel companies and industries that use fossil fuels as inputs, but might also impact the entire global economy. In 2017, global investment in new renewables (i.e., renewables excluding large hydro) net additional capacity for power generation was approximately twice as large as in fossil fuel generation for the sixth consecutive year, due in large part to sharp cost reductions especially for solar photovoltaics and wind power.[1] It is worth noting that in 2016 the monetary value of new investments decreased compared to previous years, but capacity still increased mostly because of better energy capacity "bang" for the investment "buck" with lower costs for solar photovoltaics, onshore wind, and offshore wind.[1] Similarly, from 2012 to 2017, global sales of electric cars grew at an annual rate of 66%. China is leading the way with almost half of all new sales in 2017.[2] Altogether, this is not enough to currently displace a significant amount of liquid fuels, but it shows the potential to strand oil-related assets.

This problem of technological obsolescence may be further compounded by social and political pressures leading to fossil fuel divestments of institutional investment funds, such as pension funds, faith groups, foundations, charities, and university endowments, in an attempt to decarbonize portfolios and respond to stakeholder pressure. These divestment initiatives are designed to delegitimize companies' business models still investing in fossil fuel technologies and exploration of new sources that might not safely be burnt under more stringent climate regulations. Yet, according to the International Energy Agency, the global share of fossil fuels, including thermal power generation, in total energy supply investment increased for the first time since 2014, to 59% up slightly from a minimum of 57.1% reached in 2016.[3,4] On the other hand, return on investments for oil and gas companies has been lower than investments in clean energy stocks, providing another indicator for an accelerating transition.[5]

Another important component in potentially fast-forwarding this transition is governmental carbon regulations such as cap and trade, carbon taxation, and clean air policies, which received another impetus through the

[1]Department of Geographical Sciences, University of Maryland, College Park, MD 20742, USA

[2]Department of Environmental Studies, Masaryk University, Jostova 10, 602 00 Brno, Czech Republic

*Correspondence: hubacek@umd.edu

https://doi.org/10.1016/j.joule.2018.07.014