U.S. DEPARTMENT OF ENERGY

PNNL-19547

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Response to: "Long-term effectiveness and consequences of carbon dioxide sequestration" by Gary Shaffer, published in *Nature Geosciences*, 27 June 2010.

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July 2010

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Abstract: Shaffer's (2010) article reports on the long term impact of less than perfect retention of anthropogenic carbon dioxide (CO_2) stored in deep geologic reservoirs and in the ocean. The central thesis of Shaffer's article is predicated on two deeply flawed assumptions. The first and most glaring is the implicit assumption that society has only one means of reducing greenhouse gas emissions, carbon dioxide capture and storage (CCS). Secondly, there is absolutely no geophysical nor geomechanical basis for assuming an exponential decay of CO_2 stored in deep geologic formations as done by Schaffer. Shaffer's analysis of the impact of leakage from anthropogenic CO_2 stored in deep geologic reservoirs are based upon two fundamentally flawed assumptions and therefore the reported results as well as the public policy conclusions presented in the paper need to be read with this understanding in mind as far less CO_2 stored below ground because society drew upon a broad portfolio of advanced energy technologies over the coming century coupled with a more technically accurate conceptualization of CO_2 storage in the deep subsurface and the important role of secondary and tertiary trapping mechanisms would have yield a far less pessimistic view of the potential role that CCS can play in a broader portfolio of societal responses to the very serious threat posed by climate change.

Key Words: carbon dioxide capture and storage; deep geologic formations; retention; climate change

Shaffer's (2010) article reports on the long term impact of less than perfect retention of anthropogenic carbon dioxide (CO_2) stored in deep geologic reservoirs and in the ocean. The central thesis of Shaffer's article is predicated on two deeply flawed assumptions which combine to grossly overstate the impacts associated with society using carbon dioxide capture and storage (CCS) as a part of a broader portfolio of responses to climate change.

The first and most glaring is the implicit assumption that CCS is the only means that society has to reduce greenhouse gas emissions (GHG). Even the most cursory reading of any of the assessments published by the Intergovernmental Panel on Climate Change's (IPCC) Working Group III over the past decade or more (e.g., IPCC, 2007) would reveal that there is a broad portfolio of energy technologies that society currently draws upon and there is a vast literature that points to society's ability to expand the deployment of large elements of this portfolio in order to reduce GHG emissions. Chapter 8 of the IPCC's Special Report on Carbon Dioxide Capture and Storage (IPCC, 2005) reports that across a broad literature of Integrated Assessment (IA) research, CCS comprised between 15% to 54% of all emissions mitigation over the course of the century, depending upon the model used and the stringency of the modeled greenhouse gas constraint. In all published mitigation scenarios using IA models, CCS is only one of many technologies that are introduced to reduce greenhouse gas emissions: spread of non-emitting energy generation technologies, spread of end-use efficiencies, and land-use changes all also play a role.

The assumption that CCS is the only mitigation technology available is therefore highly questionable as a simplifying assumption as it leads to a dramatic overestimation of the amount of CO_2 required to be sequestered. This significant overestimation of CO_2 stored leads directly to the enormous volume of leakage and the resulting harm from imperfect retention reported by Shaffer.

In addition, the assumption in Shaffer's ASG scenario that non-CO_2 emissions continue to rise as in they do in the SRES A2 scenario, so it is only CO_2 that is controlled skews the results even further. The work summarized by De la Chesnaye and Weyant (2006) makes it clear that the majority of other mitigation scenarios in the literature, and especially those used in IPCC, do not make this unrealistic assumption. Because only CO_2 is being controlled in this analysis, CO_2 emissions must be reduced further and since CCS is the only emissions mitigation option available that leads to more CO_2 stored and more leakage. The unrealistic nature of the simplifying assumptions employed here in large measure drives the reported results.

Secondly, Shaffer's application of an exponential decay function to model leakage of CO_2 stored in deep geologic formations has no basis in the science nor engineering of CCS systems. Schaffer cites the (IPCC, 2005) report's conclusion that for well maintained geologic CO_2 storage sites the amount of CO_2 retained "is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years." However, the author fails to note that the very next sentence in this report's Summary for Policy Makers states that, "The vast majority of the CO_2 will gradually be immobilized by various trapping mechanisms and, in that case, could be retained for up to millions of years. Because of these mechanisms, storage could become more secure over longer timeframes." Benson (2008), IPCC (2005), Hovorka et al, (2006), Juanes et al., (2006) and others have all shown that the security of deep geologic CO_2 storage should increase over time and that secondary and tertiary trapping mechanisms will reduce the chance of leakage from the first year of injection although it may take centuries to millennia for these processes to reach a new long-term equilibrium. Moreover, Dooley et al., (2010) have shown that there are a set of economic and regulatory structures and incentives that will be in place during the period of active injection and beyond which should also work to enhance the security of CO_2 storage.

Shaffer's analysis of the impact of leakage from anthropogenic CO_2 stored in deep geologic reservoirs is therefore based upon two fundamentally flawed assumptions and the reported results as well as the public policy conclusions presented in the paper need to be read with this understanding in mind. More reasonable assumptions would yield a far less pessimistic view of the potential role that CCS can play in a broader portfolio of societal responses to the very serious threat posed by climate change. The concerns over ocean injection appear valid in principle, although their quantitative nature will change if more reasonable emissions scenarios were used for analysis.

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