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Response to reviewer comments

David R. Morrow et al.

Author comment on "GCAM-CDR v1.0: enhancing the representation of carbon dioxide removal technologies and policies in an integrated assessment model" by David R. Morrow et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2022-125-AC1, 2022

Response to reviewers

Thanks to the reviewers for their thorough and helpful feedback, which we have used to improve the paper and the model. We have made minor changes to the main text and significant changes to the Supplemental Information (SI) to address these comments. We have also fixed some minor errors in the model that the reviewers identified. The updated version, GCAM-CDR 1.0.2, is now available on Github and Zenodo.

Here we summarize how we have addressed the reviewers' comments.

- **On costs of CDR technologies.** Both reviewers suggested reporting the costs of the various CDR technologies. We have added a lengthy discussion of costs to the SI, but for the reasons we explain in that discussion, *we have deliberately de-emphasized the per-ton costs of CDR in the paper*. In that discussion, however, we do give an illustrative snapshot of CDR costs in a specific year for a specific region in a specific scenario.
  To summarize the discussion from the SI: we de-emphasize costs because GCAM-CDR reports per-ton costs of CDR that are higher than in the CDR literature, but a cost decomposition analysis reveals that this is a model artifact resulting from different assumptions about long-term energy costs between GCAM 5.4 and the CDR literature. *Forced to choose between fidelity to energy requirements and fidelity to projected costs, we chose fidelity to energy requirements*. Because we do not take this to be a strong reason to think that CDR will be more expensive than the literature projects, we have mostly avoided reporting costs here. As we explain in the SI, what matters for GCAM-CDR, given the way it sets demand for CDR, is the cost of CDR technologies relative to one another, which vary from region to region, year to year, and scenario to scenario.
- **On the "placeholder technology" used to constrain growth in CDR.** We have clarified the explanation in the main text and added a section in the SI on constraining the growth of CDR. Briefly, our approach is an adaptation of the modeling technique used in GCAM 5.4 to constrain the growth in DAC. The placeholder technology is a "dummy" technology that does nothing but is parameterized to capture market share from the "real" CDR technologies to limit their growth to an exogenously specified level in each period. *In other words, the placeholder technology is a technical modeling trick that has no analog in the real world. We use this approach because the real-world constraints on growth are not tractable in GCAM.*

- **On variants of CDR technologies.** As we now emphasize in the main text, GCAM-CDR 1.0 includes only a handful of proposed CDR technologies, leaving out many interesting variants, such as heat pump-based solid sorbent DAC (which GCAM 5.4 includes), hydrogen-fueled DAC (which GCAM 5.4 does not include), ocean liming using a fleet of purpose-built ships, and so on. *The point is to understand the basic dynamics of CDR in GCAM, including technologies with endogenous limits to deployment.* Users who are familiar with GCAM can fairly easily add new technologies to explore topics of interest.
- **On the choice and presentation of I/O parameters.** One reviewer wondered about the choice of energy input-output coefficients for DAC and ocean liming. We used the lower-end energy estimates for DAC from Realmonte et al. because the fast-moving nature of technology development in DAC makes us optimistic that energy costs will end up closer to the lower end of their range than the higher end. Users can easily substitute less optimistic assumptions. For ocean liming, the range from Renforth's paper reflects a variety of different technologies. We use the specific values given for oxyflash calcination with CCS, adjusted to reflect the way in which some components of the ocean liming process, such as carbon sequestration, are modeled in other parts of GCAM.

  We have also modified the SI, as one reviewer suggested, to give I/O coefficients in terms of GJ of energy per metric ton of CO_2, rather than EJ per metric ton of carbon.
- **On the competition between BECCS and other CDR technologies.** We have edited the text to clarify several points here. We agree that BECCS would likely compete directly with DAC, etc., in a general CDR market, and we see its inability to do so in GCAM 5.4 as a limitation to be overcome. *The default configuration files that we provide for GCAM-CDR make it so that BECCS does compete directly with other CDR technologies.* A lack of competition is the "default" for GCAM only in the sense that because of how GCAM works, the model must be run with specific input files to make that competition possible.
- **On the rate of growth of CDR.** The growth rate for CDR is highly uncertain, and any modeling assumption about it is going to be fairly arbitrary. *We now discuss the growth rate in more detail in the new section in the SI on constraining the growth of CDR. It is worth emphasizing, in the context of the main figures, that not much would change with a different growth rate:* the output of CDR would rise more or less sharply over the first half of the century, and temperatures and CO_2 concentrations would be slightly higher or lower, but the main differences between scenarios are driven by difference in final demand for CDR, not by the choice of growth rate. GCAM-CDR 1.0 includes files for faster and slower growth rates as well, and users exploring scenarios in which that growth rate plays an important role can easily adapt these for their own research.
- **On weighting regional output of CDR in international trade.** We have clarified that the regional weighting is simply an initial weighting, after which *the model redistributes CDR output based on economic efficiency*. The point is that *some* initial weighing is inevitable, and that our weighting based on regional GHG output is better than the "default" in which each region receives equal weight, regardless of size, GDP, etc.
- **On bioliquids as industrial feedstocks.** In principle, we agree that bioliquids could be used to produce industrial feedstocks. However, GCAM 5.4 is not currently equipped to handle carbon accounting well in the chemicals industry. *Given the current limits and internal dynamics in GCAM, allowing bioliquid feedstocks causes unrealistic and misleading model behavior*.
- **On waste heat for DAC.** The SI now *explains our method of modeling and pricing waste heat in the detailed description of the solid sorbent DAC technology*. We have also fixed the labeling for that technology, which incorrectly indicated that it used oxyflash. None of the substantive modeling decisions involved any assumption that oxyflash was being used. Rather, the labeling resulted from an overly broad find-and-replace in the input XML, which still isn't as bad as the time Aprilynne Pike's British publisher did a find-and-replace on the word "pants" that resulted in her book

Spells going to press containing the word "occutrousers."

- **On TEW particle size and parameterization.** We assumed a *particle size of 10 μm,* which we have now clarified in the text and discussed in the technology description in the SI. *Reviewer 1 is correct that our input-output coefficient for basalt was way off. We have corrected this, which forced a correction in the coefficient for the abstract "cropland" input*. We have verified that these changes have virtually no impact on the results reported in the main text, because the cost of TEW in those scenarios is dominated by other factors.
- **On shipping for ocean liming as a byproduct of international shipping.** As we now explain in the SI, modeling shipping for ocean liming as a byproduct of international shipping, rather than using international shipping as a direct input, *allows us to model the opportunity to use empty or nearly empty cargo vessels for dispersing lime*. Users could fairly easily add another technology that takes international shipping as a direct input.