Core Model Proposal #388: Natural Gas Final Grade Cost and Miscellaneous Solution Improvements

Product: Global Change Analysis Model (GCAM)

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Related sector: energy, bugfix

Type of development: code, data

Purpose: In upcoming Core Model Proposals, we observed solution difficulty in some scenarios, particularly near the end of the century. These were traced to certain scenarios, such as SSP5, reaching the final grade of the natural gas supply curve which as an almost infinite slope. Since we were unable to trace this final extraction cost back to its original source, we increase the cost to a value which seems more reasonable. This change alone wasn't sufficient to deal with all solution issues, so some additional solver improvements are also included.

Description of Changes

Terminal Extraction Cost for Natural Gas

The final grade of our natural gas supply curves, which represents methane hydrates, has an enormous quantity of available energy. This is consistent with the original estimates from Rogner as well as more contemporary assessments of methane hydrate potential. However, the range of extraction costs which we are currently assuming is very narrow; currently the entire supply could be produced over a cost range from 6.5 to 6.6 1975$/GJ. The original Rogner source does not provide an upper bound price for this resource. Given the nature of the resource, which forms at differing depths beneath the sea floor and proximity to coast lines vs deep ocean, there is good reason to think there is a significant range of costs between the "first" unit of production and the "last".

Naturally, estimating what the cost of the "last" is difficult to do and highly speculative. In addition, given the very large quantity of resource available in the final grade (almost 10x the amount available in all lower grades) the final cost is not likely to change results much as the production will remain close the bottom of the grade. Thus, we (somewhat arbitrarily) increase to the final extraction cost to 16 1975$/GJ; just enough the give some slope and help the solver when it needs to find a solution in this range.

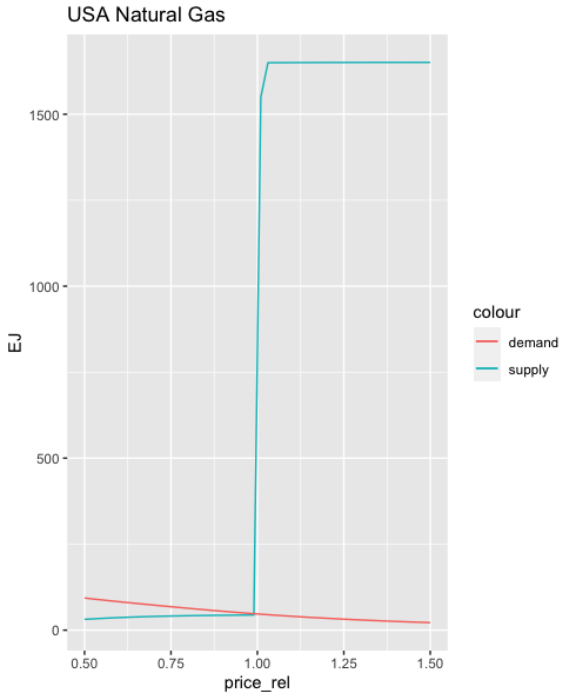
Additional Solver Improvements

Initial testing indicates the natural gas fixes alone are not sufficient to address solution issues we are seeing in recent GCAM core model proposals. In particular, we see failures in the first few model periods (i.e., in the 2025-2040 timeframe) for each dispatch of our target finder runs, which are unlikely to be related to methane hydrates. Upon inspection we notice nearly singular derivatives in these periods causing the Newton-Raphson / Broyden solution component to repeatedly make little to no progress. To address this, we tried:

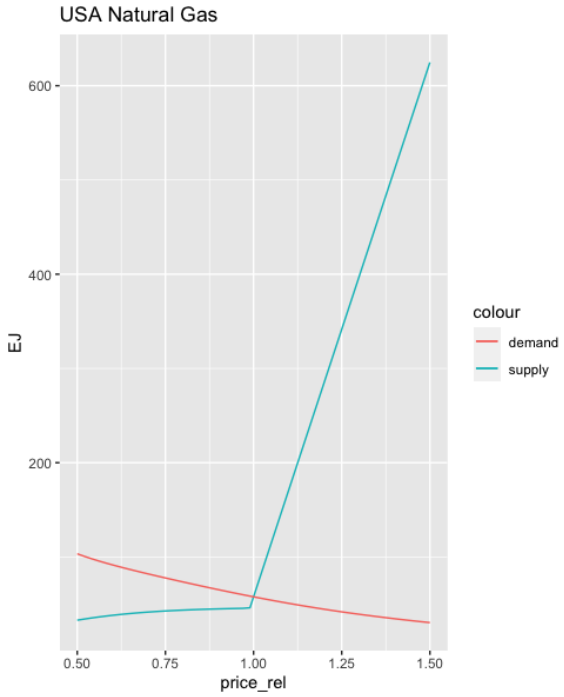
- Some fixes related to not using forecasted prices as our initial guess when that forecasted value significantly diverges from the previous period value.
- Apply a threshold on "large/small" derivatives which are usually just a result of discontinuous behavior. This lets us apply a reasonable threshold during SVD as well.
- Better heuristics in the pre-conditioner to quickly correct when the negative emissions budget constraint gets a price greater than 100%
    - It turns out the above wasn't sufficient to avoid issues as there is nothing to prevent solver components from trying a price > 100% and derailing the solution before the pre-conditioner has an opportunity to correct it. A better approach is to remove any caps in GCAM/CTaxInput. Doing so will create negative demands which does not make sense. However, given the supply will always be positive it could not solve to such a value. And more importantly, we will always have continuous behavior even at "invalid" prices.

Validation

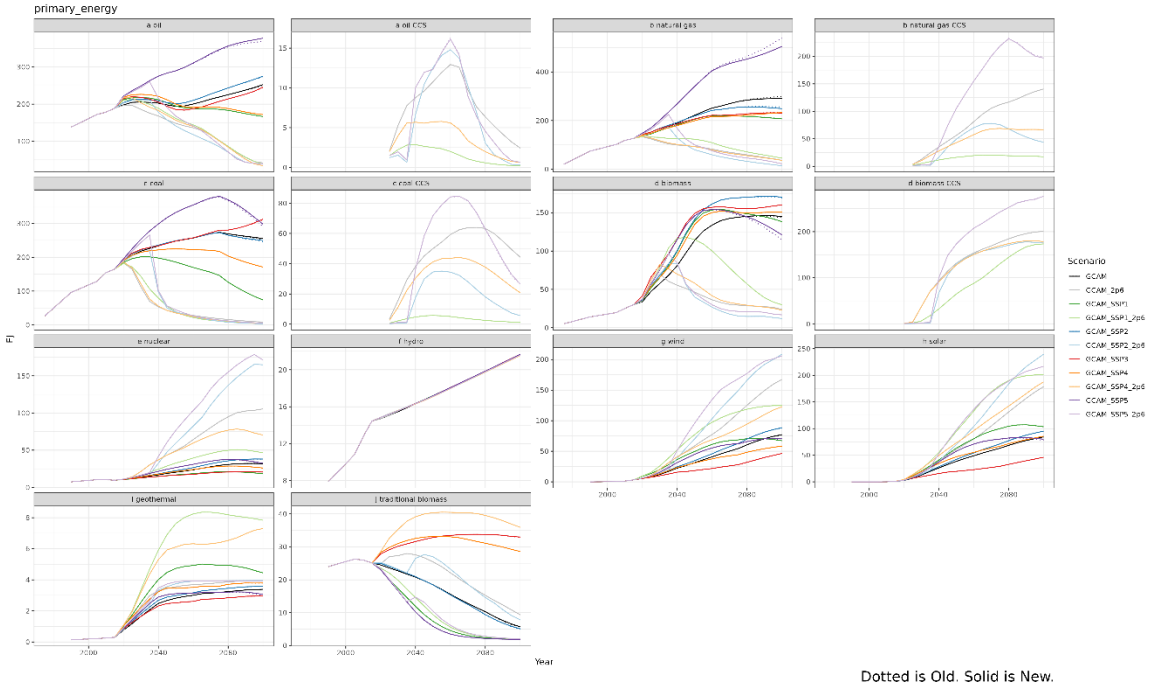
We can see the extremely large slope the solver attempts to navigate when solving in the final grade of the natural gas supply curve:



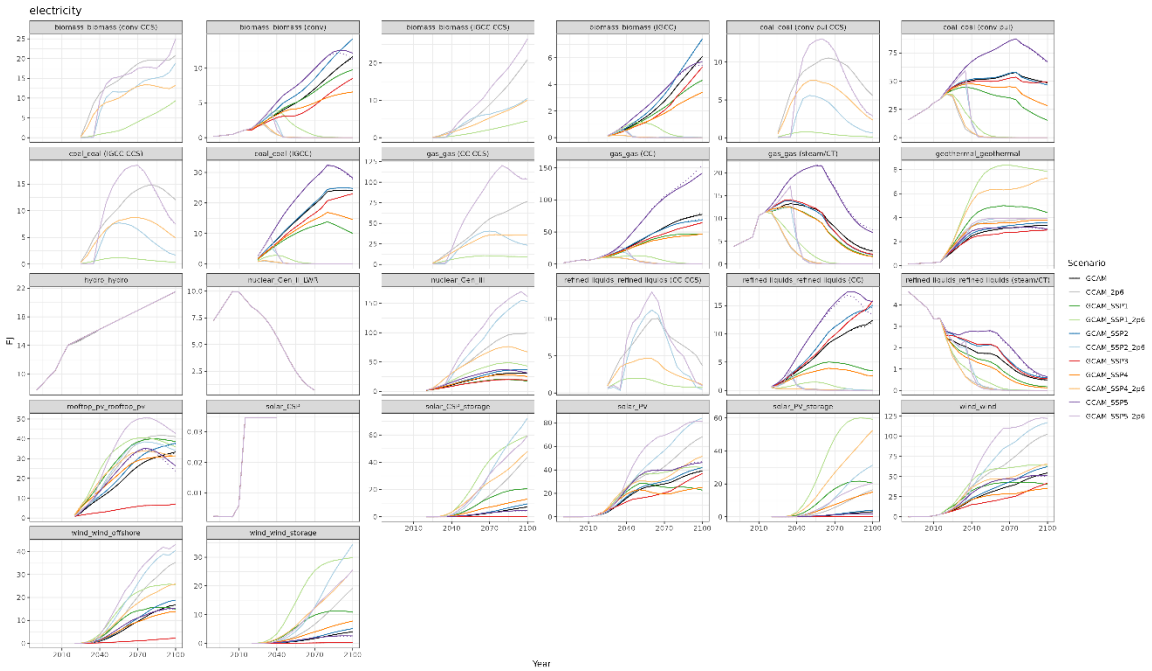
The updated final extraction cost helps to give some slope:



Of course, changing the terminal price point will have some effect in scenarios which consume that much natural gas. However, the effect is not large:



Dotted is Old. Solid is New.



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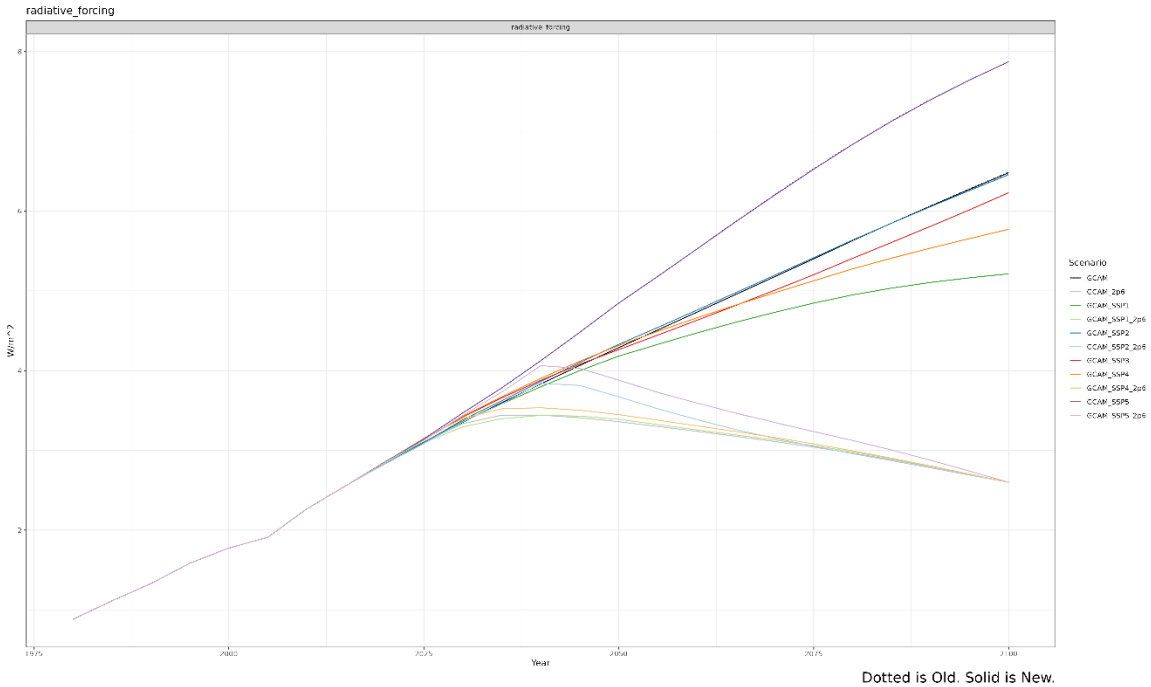

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