

Peer Review Report

Review Report on Geosciences and the Energy Transition

Review, Earth Sci. Syst. Soc.

Reviewer: David Manning

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EVALUATION

Q 1 Please summarize the main theme of the review.

This manuscript presents an overview of the requirements for the production of minerals and other geological resources (especially heat and coolth) to enable society to successfully navigate the energy transition. It is produced by a team of authors from across the geosciences and associated policy areas, providing an authoritative account that could be used by readers from a range of disciplinary and professional backgrounds. It addresses a perceived shortage of skills in the geosciences.

Q 2 Please highlight the limitations and strengths.

This manuscript appears to represent an academic geoscientist's perspective, which is both a limitation and a strength. The key limitations are that it lacks grounding in the practicalities of mining from a commercial and operational perspective, and it overlooks the really important matter of construction materials – equally these are mined products, and their production will rocket in response to the challenges of net zero.

The strengths focus on the quality of the discussion for the materials and resources that are considered. It could be used by a wide audience as a benchmark paper.

Q 3 Does the review include a balanced, comprehensive and critical view of the research area?

A balanced view is given, overall, bearing in mind the comments made above and below.

I'd like to see how the authors respond to some of the challenges that my comments present, as those challenges will also come from influential readership communities, especially those who define policy.

Q 4 Check List

Is the English language of sufficient quality?

Yes.

Is the quality of the figures and/or tables satisfactory?

No.

Does this manuscript refer predominantly to published research? (unpublished or original research is non-standard for a review article, and should be properly contextualised by the author)

Yes.

Does the manuscript cover the topic in an objective and analytical manner

Yes.

Does the reference list cover the relevant literature adequately and in an unbiased manner?

Yes.

Does the manuscript include recent developments?

Yes.

Does the review add new insights to the scholarly literature with respect to previously published reviews?

Yes.

Q 5 Please provide your detailed review report to the editor and authors (including any comments on the Q4 Check List):

It would be fantastic to include in this debate someone with expertise in minerals law, and someone with expertise in minerals planning, because these can provide the show-stoppers that affect the rapid in-country roll-out of minerals projects.

It would also help if sections were numbered, as I'm going to struggle to refer to these unambiguously from now on. Please bear with me.

When reviewing a manuscript of this type, it is always easy to find topics that should be added, and no doubt I have done that in what follows. But please take these suggestions into account, as there is a danger that the reader sees what's in the spotlight rather than a wider landscape for the Geosciences.

Low enthalpy and high enthalpy geothermal

I'm not really happy about the definition of low enthalpy as <500m, and high enthalpy >500m. I appreciate that the terms are poorly defined, but I would prefer low enthalpy to be restricted to heating and cooling, and high enthalpy to be restricted to projects with the potential to generate electricity (usually recovering heat in the process). The distinction rests in the ability to power a turbine. Lines 249–250 illustrate the inconsistency of a definition based on depth.

Line 512 on: Raw Materials for the Energy Transition

This section has subsections on Metals and Critical Metals, then Implications for Mining. There needs to be a subsection of equal weight on Construction Minerals. This is a sector of mining that uses local resources (and so is very high in the minds of the people who live close to a project and its supply chain). As an example, the lithium ion battery factory being built in Northumberland required (according to some sources) approx 300,000 tonnes of aggregate for its subbase – which is typically a year's production from a single quarry. That's even before any concrete has been poured, or steel erected.

As an unexpected example for the impact on construction minerals, in their magazine 'Mineral Products Today' (<https://mineralproducts.org/Publications/Mineral-Products-Today.aspx>), the Mineral Products Association estimates that 6 million tonnes of aggregates and 1 million tonnes of cement will be needed for the floating pontoons planned for North Sea generation of just 5GW of offshore wind power generation. This is a new market, on top of existing energy requirements.

Public engagement and 'understanding'

I think this has to be discussed at greater length and with great care. Minerals are only mined because society gives permission for mining (and exploration) to take place. OK, that is my perspective from the comfort of a well-regulated country, but one way or another that is the situation everywhere.

So, how do geoscientists respond to the fact that they need licence to practice, and to act as so cogently spelled out in this manuscript? Most of the authors are from universities, so it is natural to complain about falling enrolment onto geoscience programmes. But we need to remember that the majority of geoscience graduates leave the subject (I think the Geological Society once said, at the peak of oil, that only 30% of UK

graduates found jobs in geology). I think that is to be celebrated, as it means that 70% of geoscience graduates found jobs in society in positions where they could bring the perspective that only a geologist has (and many do very nicely thank you in non-geological occupations). We have to revise our curricula to encourage a wider range of students from different backgrounds to study geosciences, and that might give us some challenges that are uncomfortable – many students might not want to study the ‘hard science’ that excites others. Table 3 should be revised with care concerning this point; it doesn’t do our discipline any favours to give the impression we are failing (although we may have problems, this is a really exciting time for the universities to revamp geoscience provision). And reference to Anon should be avoided.

Closer to the current discussion, there are two aspects of the matter that should be covered. One, in the context of lithium and geothermal energy, is the issue of ownership of ‘mineral’ rights. In the UK, exploration includes brines (Cornwall, NE England etc), and in some minds there is ambiguity over who owns the mineral rights of an element in solution, or of heat. A recent paper by McClean and Pedersen may be relevant here: <https://doi.org/10.1016/j.enpol.2022.113378>

It could also be useful to consider minerals planning, although this differs (slightly) in the different UK nations. Aggregates, for example, are managed by local authorities and the Scottish Government as a strategic resource – so local government planners are required to know what the future landbank is that should be allocated to mining, with a horizon typically of 20–30 years. This strategic approach could well be adapted to the metals and critical metals discussed here, should the UK wish to develop domestic production, as is essential for construction materials.

Returning to public ‘understanding’, this really should be considered from a society-led point of view, recognising the shape and character of the ‘market’ for geosciences knowledge and the need for geoscientists to be led by the ‘public’ and what non-experts demand. Again, that might be uncomfortable, but it would strengthen this manuscript enormously if the text was changed so it becomes more humble, especially around lines 692–695. I wouldn’t use the words ‘public understanding’ in any case. The Postscript sets the tone much better, and perhaps could be integrated into the main text, given that one of the authors has a Geological Society address.

Carbon life cycle analysis

In many places, reference is made to carbon LCA (e.g. line 128 onwards; line 298). I am a bit concerned that the references cited range over 15–20 years, and in that time the rules that underpin LCA have changed, becoming much more rigorous. So the figures cited in Table 1 are not really comparable, even though they come from a single authoritative source – which has simply drawn from a range of references. Could you carry out a quality check on the LCA data to make sure that comparisons are internally consistent (especially in terms of the definition of the system boundaries), and focus on those carried out according to appropriate ISO standards?

The section Geoscience and geotechnics for energy infrastructure is very thin, given the importance of engineering geology and geotechnical engineering for Net Zero. The demand for materials for foundations and earthworks is enormous, and if floating concrete platforms ‘take off’ for wind generation the implications are significant for all stages of the supply chain. It is really important to address this, as the readership will (hopefully) include engineers who would welcome a reminder that the materials they sometimes take for granted are part of an evolving landscape within geoscience.

Challenges and Opportunities

Having covered the paragraphs 2 and 3 of this section above, I want to comment on the final paragraph. Use of hydrocarbons and coal in manufacturing, as raw materials, is not going to stop quickly, because of the scale of what is required. Methane is essential for the manufacture of nitrogen fertilizers via the Haber-Bosch process, and coal is essential for the reduction of iron oxide ores in the first step of steel making. Demand for both

products will grow as population grows, and as net-zero infrastructure grows, yet the alternative to coal or hydrocarbons as a chemical reagent (not a fuel), hydrogen, is going to take decades to rise from current humble beginnings, which exist, to the scale of the challenge posed by the chemistry of two manufacturing processes. I think something should be said about this.

More minor comments

Around Line 36: I would add 'and to update existing infrastructure' or similar words.

Line 88: 'plant and animal species', rather than just 'species'.

Line 94: remove 'or' as it is not necessary and could be ambiguous (suggesting an alternative) in readers' minds.

Line 118: it would be useful to have an estimate of the total cumulative CO₂ emissions from fossil fuels. Also, Figure 1 should state clearly in the caption or y-axis that these are annual emissions.

Line 174: 'Thus far' is a colloquialism - please replace with alternative words.

Line 209 and elsewhere: semicolons are often used where a comma would suffice (especially lines 522-525 and 659-662). Please check throughout the manuscript.

Line 265: please describe in terms of electrical power generating capacity, as some confuse thermal power with that.

Line 280-282 should be in the previous section, on geothermal for heating and cooling.

Line 306: However, not although.

Line 330-331: some text may be missing; something has gone wrong here.

Line 371 has a floating left parenthesis that seems to be there by mistake.

Line 429-430: is this like the schemes to lift weights up and down old mine shafts, or something different?

Line 448 on: enhanced weathering sees the inorganic carbon exported to the oceans rather than forming solid carbonates. Please check a Beerling/Renforth paper or similar.

Line 476: add 'industrial' to the list of waste sources.

Line 500-502: there are other sites, especially in Sweden, Switzerland and France (all well ahead of the UK), so please revise the writing so the reader knows why this Finnish site is mentioned exclusively.

Line 601: some grades of industrial minerals - please be more specific, as this is a new idea in the manuscript that readers may want to follow up.

Line 632: work, not worked.

Line 661-662: is it worth mentioning brines as a source of Li?

Line 673: the sentence needs to be finished - it runs out of steam.


Table 2: I found the colouring made it hard to read - please reconsider how this table is presented.

Figure 2: correct the spelling of 'infrastructure'.

Figure 3: correct the 2 in CO₂ so it is subscript.

Figure 5: correct the spelling of 'environmental' within the figure.

QUALITY ASSESSMENT

Q 6	Quality of generalization and summary	
Q 7	Significance to the field	
Q 8	Interest to a general audience	
Q 9	Quality of the writing	