Comparative Life Cycle Assessment of Direct Air Capture Technologies

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Objectives

- To provide a systematic comparative evaluation of environmental impacts of current prototypes of the two Direcr Air Capture (DAC) technologies- **Temperature Swing Adsorption (TSA)** and **High Temperature Aqueous Solution (HT-Aq)** DAC- with carbon storage (DACCS), under various technology cases encompassing different technical parameters.
- To investigate the changes in the impacts when these technologies are deployed at a large scale i.e. 1Mt CO_2 captured per year.

Motivation

Importance of direct air capture (DAC) of atmospheric carbon dioxide (CO_2) through DAC technologies to fight climate change is highlighted by The Intergovernmental Panel on Climate Change (IPCC) but this is an energy and material intensive process.

Research Gap: Lack of knowledge on:

1) comparative environmental impact of the current prototypes of the DAC technologies

(2) the environmental implication of their large scale deployment.

Methodology

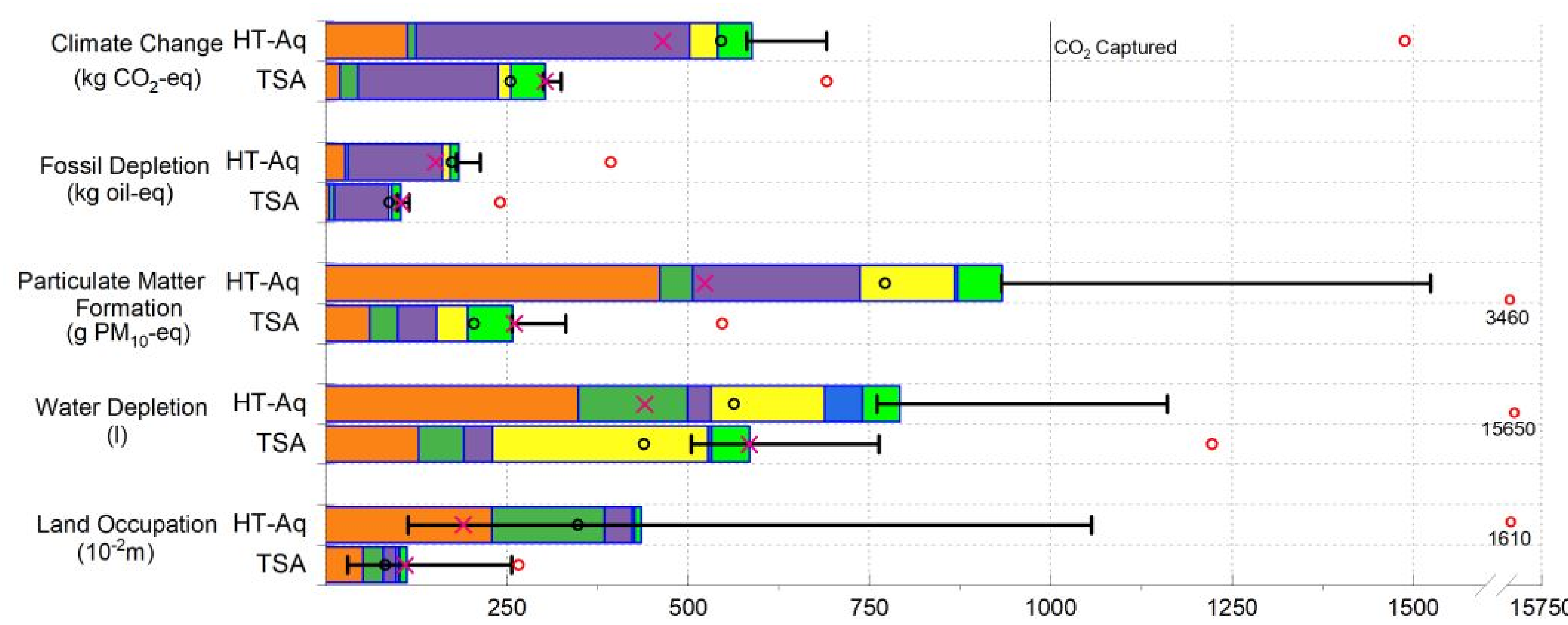
Attributional Life Cycle Assessment (LCA) is used to compare different technology development cases and scale-up scenarios (See table 1) for the **TSA** and **HT-Aq** DAC technologies.

Impact Categories: Climate change, Fossil depletion, Particulate matter formation, Water depletion and Land occupation.

Assumption: Compressed CO_2 is transferred by pipelines for 300 km and injected (7kWh/t CO_2) into geological wells.[1,2]

Monte-Carlo analysis: To estimate the inherent uncertainty of the data used for DAC infrastructure (Eg: Steel, concrete, aluminium etc.).

LCA Results



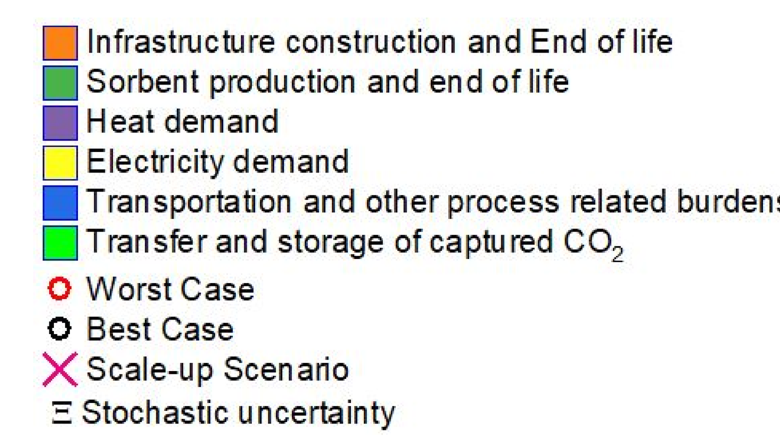


Figure 1:LCA results for the reference case, best case, worst case and the scale-up case for functional unit: 1t CO_2 captured.*

Note: 1) CO_2 capture capacity per year for reference, best and worst case of TSA DAC is 50t and and HT-Aq DAC is 345t.
2) TSA DAC units are modular[4]. Hence, identical material and energy inputs for reference case and scale-up case DAC units are considered.

Important Result

- HT-Aq and TSA DAC emit 0.58t and 0.30t CO_2-eq per ton CO_2 captured respectively.
- TSA DAC emissions, due to lower heat requirement, in most impact categories is higher than HT-Aq DAC by 2-3 folds.
- Worst technology case for HT-Aq is not carbon negative (0.4 t CO_2 emitted per t CO_2 captured), mainly due to a low sorbent recovery rate.
- Heat and electricity of DACs have the maximum impact in 4 out of 5 categories studied.

Technological variation and Scale-up case

Table 1a: Important parameters used for the different technological variations and scale-up cases for HT-aq DAC.

HT-AQ DAC	Lifetime of DAC	Heat	Electricity	Sorbent(1M KOH)	Sorbent Recovery Rate
Reference Case	20 yrs	4.47 GJ	345 kWh	0.05 kg	99.90 %
Best Case	22 yrs	4.05 GJ	337 kWh	0.005 kg	99.99 %
Worst Case	15 yrs	4.47 GJ	449 kWh	3.5 kg	95 %
Scale-up Case	20 yrs	4.05 GJ	473 kWh	0.05 kg	99.90 %

Table 1b: Important parameters used for the different technological variations and scale-up cases for TSA DAC.

TSA DAC	Lifetime of DAC	Heat	Electricity	Sorbent (PEI-Silica)	Sorbent Lifetime
Reference Case	20 yrs	2.6 GJ	177 kWh	7 kg	1 yrs
Best Case	22 yrs	2.3 GJ	130 kWh	1.5 kg	3 yrs
Worst Case	15 yrs	6.2 GJ	354 kWh	34 kg	0.5 yrs
Scale-up Case	20 yrs	2.6 GJ	177 kWh	7 kg	1 yrs

Note: Heat, electricity and sorbent required are shown for 1 ton CO_2 captured.[3]

1Mt CO_2 Captured per year

- Reduction in environmental footprint, due to efficiency of scale, is observed in the HT-Aq DAC Scale-up case w.r.t the reference case of HT-Aq DAC.
- Land footprint of TSA DAC (0.25 km^2)[4]and HT- Aq DAC (0.005 km^2)[5] are a major concern for their large scale deployment. Stack-able modular nature of TSA DAC can reduce its land footprint by 1/6.

Conclusion

- Both the DAC technologie have potential to be carbon negative.
- Low-carbon energy source and long lifetime (or high sorbent recovery rate) of the DAC sorbents are the key for reducing the environmental footprint of the technologies.

References

1. Pehnt and Henkel (2009) International Journal of Greenhouse Gas Control
2. Goudarzi et al. (2019) International Journal of Greenhouse Gas Control
3. Fasihi et al. (2019) Journal of Cleaner Production
4. Webpage: https://www.climeworks.com/our products
5. Kieth et al. (2019) Joule

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** This work is currently under review.*