GLOBAL CO_2 INITIATIVE

CCU TEA and LCA Guidance 2023
– A Harmonized Approach –

Workshop report

Goal of the workshop

The Global CO_2 Initiative hosted the 2023 TEA/LCA Workshop on Harmonizing CCU Assessments on May 16-18. This fifth workshop in the series was planned and conducted by the International CCU Assessment Harmonization Group with members from the USA (GCI at U-M, NETL, NREL, ANL), Canada (NRC), Germany (RIFS, formerly known as IASS), Switzerland (ETH Zürich), and Japan (NIAIST). This team works to advance transparent and uniform assessments of CCU technologies and products.

These workshops have traditionally engaged a broad audience in breakout sessions to debate, resolve, and define key issues with assessments in CCU. Note that occasionally, it makes sense to include border aspects and include assessments of CO_2 sequestration into the discussions. Hence, in some sections, the mention of CCUS is included.

The focus topics for 2023 had been selected to address social aspects and standardization. 51 on-site and up to 265 remote attendees spent one-and a-half days in lively discussions. This report presents a summary of the breakout session discussions, key status descriptions, and open issues.

We will take this as a starting point for a year of continued collaboration to advance LCA & TEA for CCU and for planning our next annual gathering on May 22 & 23, 2024 in Ann Arbor. We welcome suggestions and questions that can be submitted to info@globalco2initiative.org

Support

We acknowledge and appreciate the support of the College of Engineering at the University of Michigan, the Global CO_2 Initiative, and the Grantham Foundation for the Protection of the Environment.

Report Access

It is noted that the summary provided in this report reflects the discussions to which many more have contributed than is reflected in the list of authors. The authors have taken extensive notes (Thank you notetakers!) from the breakout sessions and condensed them into this report document.

This report can be downloaded from the University of Michigan's Deep Blue repository via DOI: https://dx.doi.org/10.7302/8081 or through the Global CO_2 Initiative's website.

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Table of Contents

Key Observations and Needs

- Best practices in methodology meet legal (e.g around tax credits) or business (sale of CO_2 storage credits) requirements
    - How to deal with moving from 'theory' to 'practice' on a large scale - are PCRs and EPDs good enough? How could they be improved?
- The relevance of open source data availability.
    - How to generate, vet, and share data?
- Leveraging new technologies.
    - How to use artificial intelligence, machine learning, etc.?
- Additional shared case studies and guidance for emerging carbon management solutions
    - Examples: Carbon Dioxide Removal
- The multidisciplinary challenges related to social life cycle assessment need to be addressed
    - A respective working group should be formed and could be the target effort for the Harmonization Group
- As an emerging area of focus within life cycle analysis, there are a number of questions and issues that should be considered priorities for the research and policy communities. These include:
    1. CDR-specific guidelines on how to evaluate sustainability and impacts related to cultivation of biogenic feedstocks as a vector for CO_2 capture, and how to allocate upstream emissions.
    2. Guidance on the use of earth-systems models as a means of quantifying CO_2 removal.
    3. Development of life cycle inventories that describe the end-of-life scenarios of durable products used as CO_2 sinks (for example, where CO_2 is utilized in durable plastics, understanding the extent of leakage that can be expected due to various waste management practices).
    4. Use of probabilistic methods to estimate rates of leakage/reversal and establish buffer requirements to address risk and uncertainty.
    5. Standards that mandate separate reporting of avoided CO_2 and removed CO_2.
    6. Guidance on temporal issues (i.e., how to consider and report the rate of removal over time).

Social Impact Assessment / S-LCA for CCU

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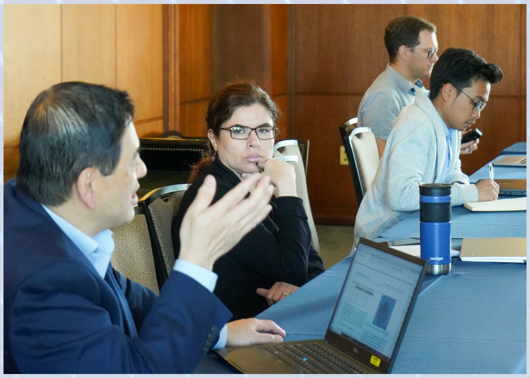
Throughout the discussion, a number of key themes emerged as being of particular importance and interest to the working group. With a focus primarily on social life cycle analysis (S-LCA), discussions centered on data, characterization, and how the outputs of studies could be effectively utilized. These key themes should not be seen as independent but as part of a related broader challenge in developing the mechanics of S-LCA (data, and characterization or scoring) for CCU and the identification of applicable use cases.



Beyond this, another challenge became clear in the need to differentiate social impact from social acceptance when discussing the social dimension. While the two are related, the impact of an activity and the perception or acceptance of the activity are distinct, and the methods required to measure the two should be considered as somewhat independent disciplines.

It was acknowledged that while the United Nations Environment Programme Society of Environmental Toxicology and Chemistry Social Life Cycle Assessment (UNEP SETAC S-LCA) guidance provides something of a framework, there is a significant need to further develop this into a more detailed methodological approach for CCU. As shown by the direction of the discussion, data and characterization/scoring were seen as areas in which work needs to be completed.

The discussion on social data covered several key aspects, including reliability, accessibility, availability, and granularity. A brief discussion on the types of data required was followed by considering where this data may be sourced. It was acknowledged that there are numerous reliable metric and data sources freely available on the web, e.g., United Nations Commodity Trade Statistics Database (UN COMTRADE) data for assessing material flows from country to country, the Organisation for Economic Co-operation and Development (OECD) data, and World bank data. However, these data sources lack aggregation in a centralized location or database made freely available. While ‘paid for’ databases exist, this does create a barrier to entry for many practitioners. Furthermore, both free and premium resources contain a concerning inconsistency in the amount of data available on a country-by-country basis. Given that less economically developed countries tend to suffer from poorer data availability and quality, this does cause potential issues in creating blind spots while assessing.

With regards to data granularity, a general issue discussed was that most of this data is available at a country-wide level. This brings obvious challenges when trying to assess life cycle impacts with any level of specificity beyond this. The viability of primary data collection for specific projects was considered (e.g., through site visits and community engagement), with the caveat that this is expensive and likely not suitable for early-stage assessments.

The discussion on characterization and scoring focused primarily on how best to use the data available to adequately describe the social impact a project, process, or service delivers. Scoring methods were discussed, with a conclusion reached that reducing all inputs to a single number score is potentially reductionist and open to bias or a high level of variance from practitioner to practitioner. An identified issue with single scores is that they may lead to the missing of particular hotspots within an aggregated score - or the inverse, if the aggregation method utilized looks for a maximum in place of an average for example. Consistency within scoring systems across categories also remains challenging, regardless of whether scores will be aggregated or not. Implementing multi-criteria analysis methods to weight scores can help with this, albeit with adding further (decision maker) bias. Recent examples of scoring systems for impact assessment within can be found [1], but these still hold clear limitations.

The final major thread of the discussion considered how to best apply or use S-LCA in a manner that adds value. While S-LCA could be used to monitor progress, the discussion focused predominantly on the use of social impact within a decision-making process. There was discussion as to when S-LCA could best be applied to help in this instance, with implementation earlier in the development cycle identified as beneficial before stakeholders become too ‘locked in’ on decisions that may be hard to change later. Methodologically this poses significant challenges due to the large amounts of uncertainty associated with low-maturity technologies. It is here where hotspot analysis may be more beneficial.

A discussion was also had on what to do with results where negative impacts were found. Resolving to not use materials that carry social impact risks can have significant unintended impacts on local economies, for example . Should the action be not using the material or trying to influence positive societal change to resolve the issue instead? An example of this type of issue can be found in Cobalt, where significant social and environmental issues have been linked to mining of the material in the DRC [2]. The USGS shows that the DRC is the world’s largest producer of cobalt [3], and this contributes a significant amount (13% in 2019 down from 20% in 2018) to the countries GDP, where the 'extractive sector' in broad accounts for 46% of government revenue and 99% of all exports [4]. Efforts such as 'Cobalt for Development' [5] aim to improve conditions of artisanal miners in the country, rather than move wholesale away from the use of the material.

Questions such as the above were a common theme, highlighting the most important conclusion that can be drawn from the entire discussion: The challenges faced here are multi-disciplinary, and a broader working group needs to be established to tackle these effectively.

Social Impact Factors

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In the first breakout session on S-LCA and social impact a focus was given to assessment, discussing the need and challenges faced primarily in the development and implementation of a detailed impact assessment methodology.
Here, in the social impact and acceptance factors breakout session, the discussion steps away from S-LCA and considers metrics in a broader fashion. This discussion covered several related themes including: what social impact/acceptance metrics are currently accepted and used? How are they reported and calculated? Who is the target audience of these metrics? How can we utilize existing lessons and practices within the world of CCU?

The intention for this session was to initially focus solely on social impact, however throughout the discussion the related and somewhat intertwined concept of social acceptance was brought up frequently. This has been captured in this report, and the session title has been amended to best reflect this. An advantage to working acceptance into this discussion is that it allows for some indication as to what metrics different stakeholder groups believe to be of most value – and thus arguably warrant additional focus for capturing as measured impact factors.

Starting with a discussion on which metrics are generally of most interest to the local community when projects are first proposed or discussed prior to construction/deployment, specific topics were then discussed. A focus was put on immediate ‘practical’ issues, such as the impact on local infrastructure and living conditions: the short-term and longer-term impact on traffic in the area, will there be noise or light pollution during construction or operation, will there be impacts to local air quality and will there be disruptions to water and power availability. Another common theme was on both short- and long-term job prospects related to the project, and whether programs and scholarships would be made available to help local people ‘upskill’ if required to fill these job opportunities.

Following this, the discussion shifted to consider what indicators and metrics are currently used to assess social impact. The discussion covered aspects such as the ‘EJ screen tool’ produced by the US EPA, and how these tools, much like many available data sets, may lack the granular detail needed to assess at the individual project scale.
ESG reporting was also discussed as part of this topic, with it noted that within this context social is only a singular aspect of a multi-dimensional report output. A particular issue noted for ESG is the diversity in ‘standards and frameworks’ currently available, which makes comparisons of metrics both intra- and inter- industry particularly challenging.
The plans of the US SEC to ‘enhance and standardize climate-related disclosures for investors’ highlights this issue to an extent, although the challenges around aspects such as scope 3 emissions disclosures remain the subject of much debate [6]. Turning back to social impact, the discussion continued with considerations for what ‘scope 3’ would look like in S-LCA and whether this type of metric could be useful for helping to determine ‘who is responsible and where’ for both positive and negative impacts.

The session moved onto a discussion on social impacts beyond job creation. Much of this discussion mirrors the highlights presented above. It was discussed once again that understanding how to measure local impacts: taxes, road construction, impact on utility costs & reliability, impacts to local area GRDP (gross regional domestic product). Each of these factors have socio-economic importance that extends beyond job creation, yet job creation tends to remain as the headline when reported. Other impacts like land use change were noted to be under-represented (or not included at all) in social analysis. Such impacts are considered elsewhere in impact analysis (such as environmental LCA), where established models and datasets are used to determine the environmental impact of such changes with varying levels of certainty (much of this data is ‘average’ and not necessarily representative of a particular location).

Similarly, health impacts were also discussed, where it was decided that a particular challenge for social impact is the need to combine long-term stable operational impact assessment against the risk (and potential impact) of ‘disaster’ events such as one-time pollutant releases. Such approaches blur the line between impact assessment and risk assessment, but this may not be an issue for determining high level metrics in some instances.

Utility of Geospatial Analysis

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Conversations began around the notion that in recent years the use of geospatial analysis for ex-ante technology assessment has been growing. These can take different forms and often rely on geoinformation systems (GIS) to assist in modeling or results analysis. Prominent examples are the use of GIS to model the transport of CO_2 or feedstocks for CCU processes at different locations or incorporate different location specific assumptions (e.g., efficiency factors for solar energy production in different regions). A main benefit might lie in using results of these geospatial analyses for developing governmental programs (e.g., tax or funding programs). Additionally, geospatial analyses might be particularly useful for deployment decisions, especially for start-ups or others in the deployment stage of novel technologies, a phase many CCU technologies are currently in, as many CCU technologies have now left lab and demonstration phases and are moving towards deployment.

For many CCU technologies such as CO_2 fuel production a geospatial view will be required for detailed environmental analysis to include a better understanding of emissions interactions with the environment, for example for hydrogen production or transport, electricity emissions as well transport emissions for feedstocks. A geospatial analysis could be necessary to understand the potential capacity for a technology like mineralization which may be required to be distributed locally for logistical reasons. Beyond the scope of LCA and TEA, geospatial analysis can be in particular helpful, some might argue even necessary, for social analysis on any granular level to understand which communities are being affected by a deployment of a CCU technology. While there are many benefits for using geospatial analyses for ex-ante modeling of CCU technologies, often the resolution of input data varies significantly (e.g., electricity data is very granular, while social indicators often have low granularity, often at the country level) which provides a challenge for modelers. These differences in granularity of input data can often lead to big gaps which need to be replaced by an estimate, increasing uncertainty of these assessments and sometimes arguably their utility. Furthermore, geospatial analyses can become computationally expensive and often require more time to be developed than geospatially simplified analyses. During this breakout session we discussed the utility and challenges of geospatial analysis techniques for CCU technologies in particular with a focus on social implications.

Utility of geospatial analysis for social acceptance

In the discussions it became clear that geospatial analysis can be an important tool to bring ex-ante analyses towards holistic analysis, but often it might be necessary to combine it with other methods (e.g., stakeholder analysis) because social factors alone cannot reliably make predictions. Nevertheless, geospatial modeling might be helpful for creating and comparing different deployment scenarios which could be used for public engagement (e.g., Showing how the system changes, when a technology is deployed in region/location A vs B). Research has shown that acceptance for deployment of new technologies such as renewable energy production coincides with the local residents' experience and trust in a siting process (i.e., process to choose a location for deployment) [7]. Hence, geospatial analysis could be used not only to assess different deployment scenarios but also might be useful to show "alternatives" to the proposed location with the aim to increase transparency on siting decisions. Following this discussion an idea from a social scientist in the group was shared, proposing the utilization of geospatial analysis as an iterative process with communities selected for potential deployment of a technology (e.g., proposed scenarios get feedback from stakeholders), where outcomes of geospatial analysis are discussed with local stakeholders which feed into the next iteration of the model to iteratively find a "quasi-optimal" solution. Here, geospatial analysis would become a resource to support other analyses and methods (e.g., stakeholder workshops). Following the discussion, the majority of participants agreed that funding programs should use geospatial analyses as requirements for funding applications. To this regard the community benefits requirements for recent Department of Energy (DOE) funding opportunity announcements (FOAs) already show the DOE is looking at the issue and working toward the goals of the Justice40 initiative, but many participants familiar with the system agreed a more formalized system inclusive of rigorous data is necessary to make a difference. This is where geospatial models or toolkits could take an important role.

Interpretation and understanding of results

It was highlighted that a double edged sword of geospatial analysis can be understanding and interpretation of presented results. On the one hand, some results can be presented in a much more engaging manner (e.g., distribution of solar power efficiency over a country), since overall, it is very attractive to look at a map rather than a graph. On the other hand, coloring and aggregation of results can be very misleading (e.g., using signal colors red or green can bring a bias into the results) and can even be used for bringing bias into a result as shown in the book "How to lie with maps" [8]. This becomes particularly challenging for more complex analyses with multiple indicators. For example, maps usually do not show error bars and often geospatial analysis do not use uncertainty analyses due to computational limitations, leading to the presentation of data as being of high certainty, without regard to the actual underlying uncertainty.

Key issues in performing geospatial analyses

Key issues in performing geospatial analyses in the field of CCU lie in the transparency of the analysis as well as data scarcity. As geospatial analyses commonly require the use of complex models, they can not only be misleading for lay people but are also significantly more difficult to review, which can diminish the aim to increase transparency of such an analysis. Additionally, a solid geospatial analysis requires a large set of different data (e.g., a geospatial LCA requires the same amount of data as a conventional LCA but much of the data now needs to have a geospatial resolution). In the discussion some participants argued that researchers tend to trust datasets too much (e.g., data on income, social justice, efficiency factors for solar energy production) and in order to actually validate existing datasets often an interdisciplinary team (e.g., social scientists, engineers, geologists) might be necessary, which often are not present in one team. Additionally, while quite a lot of data is openly available for the US and Europe, data is often not available or accessible for the global south and available data (even for the US) is often scattered around multiple sources, making it difficult to work with and should be made available in one database. But, steps in the right direction have been made by the Open Geospatial Consortium (OGC), which among other things created a standard for data sharing [9]. These key issues might diminish the utility of geospatial analysis for some CCU processes or some locations around the world and should be tackled by the scientific community.

While geospatial analyses might be a helpful tool for designing deployment strategies and policies in an iterative process as suggested above, their utility might be limited for tackling “not in my backyard problems”(NIMBY). But, they might be used to create interactive ways of showing study results which could potentially be used to increase community engagement and thus tackle NIMBY problems.

Integration of Carbon Conversion LCA Methods and Carbon Removal

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Carbon Dioxide Removal (CDR) has emerged as an increasingly important field of greenhouse gas management: The most recent IPCC report has suggested that, in addition to economy-wide decarbonization, massive (i.e., gigatonne-scale) deployment of CDR will be required to limit global warming to 1.5 °C [10].

Carbon Dioxide Removal (sometimes referred to as Negative Emissions Solutions) requires, by definition, CO_2 to be sourced directly from the atmosphere or the surface layer of the ocean or indirectly via biogenic pathways - and sequestered durably. If more CO_2 is removed and sequestered than is emitted by the process, negative emissions can be achieved. Validation of CDR is, therefore, dependent on comprehensive cradle-to-grave life cycle analysis [11].

The varied scope of CDR solutions across technological and nature-based pathways and cradle-to-grave requirements of the life cycle analysis present a number of challenges for life cycle analysts and project proponents alike and a dedicated session on the topic examined respective aspects.

CO_2 capture considerations

"Engineered" CDR pathways like Direct Air Capture and Direct Ocean Capture offer relatively straightforward upstream scenarios, although emissions induced by these pathways' energy and other resource requirements are a concern [12]. Biogenic pathways can be more complicated: Life cycle assessment must account for the emissions and sustainability of biomass feedstocks, with consideration to emissions induced by land use changes and risks associated with issues like food security, biodiversity loss, and nutrient leaching [13].

Pathways that capture CO_2 indirectly, such as by Ocean Alkalinity Enhancement, cannot easily be measured directly, so quantification of the rate of CO_2 capture can be dependent on earth systems models or statistical models. The speed of CO_2 capture can also be a consideration for these pathways: Some interventions cause CO_2 to be drawn out of the atmosphere over time. In some cases, removals may take a number of years after the intervention to occur [14]. The global warming potential of CO_2 removed today is more significant than CO_2 removed in future years, so the rate of capture of an intervention must be considered alongside the total tonnes removed by that intervention [15].

CO_2 sequestration considerations

The durability of sequestered CO_2 is a critical issue in CDR: While there is no clear consensus on clear cutoff criteria for durability, there is a clear distinction between "low" durability pathways (i.e., CO_2 conversion to fuels or other pathways where combustion/oxidation can be expected within a short time) and "high" durability pathways which result in a long sequestration period, on the order of hundreds of years. Only durably sequestered CO_2 should be considered removed [16] which can also be effectively accomplished with so-called Track 1 materials [17].

Even within 'durable' sequestration pathways, the risk of re-emission must be taken into consideration. These considerations are extremely pathway dependent, and end-of-life scenarios can be dependent on uncontrollable factors such as weather (and natural disasters) or consumer behavior [18]. There is currently a lack of inventory data related to most sequestration pathways, and this would be a recommendation for further study. Assessing the risk of reversibility should be handled probabilistically.

Impact assessment

Proponents shall not focus solely on the carbon benefits of a CDR project: Especially at large scale, the non-carbon lifecycle impacts of CDR projects can be significant, regardless of solution pathway [19]. Projects must make efforts to safeguard biodiversity and minimize adverse effects on terrestrial and aquatic ecosystems and on water tables. Furthermore, some of these approaches may potentially yield co-benefits to human health and ecosystems that should be more broadly evaluated and potentially included as part of the assessment. This potentially presents additional complexity in comparing CDR approaches from an LCA perspective since the functions of the systems are expanded beyond just carbon removal.

Since the objective of CDR is to accumulate large masses of CO_2 out of the atmosphere, the gate-to-grave impacts of CO_2 sequestration can be significant at scale and over time. Ecotoxicity can be a concern where mined minerals or mine tailings are used as a reactive medium since even trace quantities of toxins can accumulate in soils over time [20]. Moreover, where CO_2 is sequestered in durable products, landfill waste creates social and environmental impacts that depend strongly on local factors.

Interpretation & reporting

Because the focus of CDR is on the capture and custody of CO_2 molecules, CDR can be less dependent on counterfactual scenarios than other emissions reduction pathways like CCUS: Removals should always be reported separately from avoided emissions. Systems that co-produce products or other co-benefits must handle emissions allocations with care; allocation of negative emissions in multi-product systems is an area where further consensus and guidelines would be helpful. Impact metrics should be reported in terms of the functional unit “per metric tonne of net CO_2 removed” to ensure consistency across analyses. Other functional units may also be reported depending on the CDR pathway under consideration.

CO_2 capture and implications on industry perception

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In the session "CO_2 capture and industry implications," participants discussed the challenges emerging from CO_2 capture retrofitted in industrial processes, and explored sub-topics related to the extended use of fossil carbon, hydrogen energy usage versus renewable energy, carbon removal versus carbon reduction, bioenergy with carbon capture and storage (BECCS) as zero emission technology, challenges due to blue hydrogen implementation, the potential co-benefits of CO_2 capture (i.e., removal of other emissions), and communication metrics with public stakeholders, as highlighted in the following paragraphs.

The variety of CO_2 emission sources presents multiple opportunities to deploy and scale CCUS technologies into industrial processes, such as cement, steel, power generation, biofuels, and oil & gas, to achieve carbon reduction targets within those segments. However, despite the potential to achieve carbon reduction/neutrality/removal goals, the deployment of CCUS in these industries also raises concerns related to the extended use of fossil carbon. Retrofitting of carbon capture technologies into segments responsible for fossil CO_2 emissions can be used as an argument to incentivize,increase and prorogate those industrial segments.

Policies that foresee carbon credits and reward industrial manufacturers for retrofitting CCS in their facilities should be considered carefully and pursue internal mechanisms to avoid increased incentives to the fossil fuel industry. For example, the amendments in the 45Q tax credits due to the Inflation Reduction Act can benefit and promote a variety of CCUS projects, ranging from hard-to-abate sectors to gas/coal power plants. However, there are no formal limits for credits issued to industrial clusters which use large portions of fossil energy inside their facilities.

Hydrogen production was also discussed in the section. Hydrogen can be extracted through 2 main processes, called gray hydrogen, which is generated using natural gas as raw material, and green hydrogen, which is generated through electrolysis of renewable energy processes. If CCS is retrofitted in gray hydrogen production, it is called blue hydrogen. Despite the relevance and emerging potential to retrofit CCS at large scale, blue hydrogen facilities could collaborate to increase the usage of natural gas depending on the current regulatory mechanisms and the fuel prices in the global market.

Complementarily, the risks of implementing BECCS using non-native species were remarked upon. BECCS is a crucial net zero emission system that captures the CO_2 emitted from biomass conversion in industrial processes. However, BECCS may encourage agricultural systems with crop plantation of non-native species to produce bio-energy and, consequently, aggravate and trigger effects related to land-use change.

The metrics to quantify the carbon savings of CO_2 capture were also discussed. Life-cycle Assessment (LCA) is one of the most important tools to quantify the overall carbon footprint of CCUS in industrial processes and can also identify aggregated co-benefits, such as the removal of other emissions, through systematic analysis of the impact categories. However, there is still a major need to improve the communication of LCA effectively to the community, including public stakeholders, by consolidating strong data and providing iterative information to the inventories. Another important aspect discussed around LCA was Social LCA, which can provide important benefits to specific regions where the social impacts would be largely affected.

Certification vs Standardization: pros and cons

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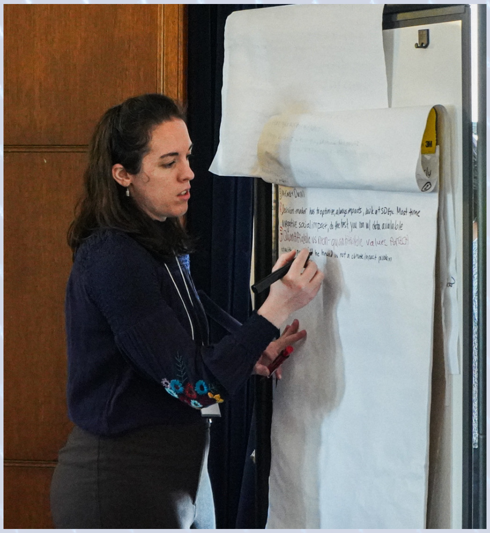
A core topic of the workshop, in fact the entire workshop series relates to whether dedicated standards for LCA in the CCUS context are needed, useful, or limiting? An introduction to respective procedures was helpful to set the stage for in-depth discussions.

Definitions



Certification and standardization are related but distinct concepts. Standardization involves the development and establishment of specific guidelines, specifications, or requirements that define the characteristics, processes, or practices for products, services, or systems. On the other hand, certification is a process through which an independent third-party organization assesses and verifies that a product, service, or system meets specific standards or requirements. Certification confirms that the entity being certified complies with the established standards and has undergone the necessary evaluations or audits to demonstrate conformity. Standardization sets the rules, and certification verifies compliance with those rules. Standardization is thus a step that needs to be taken before certification.

Pros

The pros of standardization include interoperability and intercomparison of different processes, as it creates a common ground to assess different technologies under the same framework. Bad actors are cropped out as it is more difficult for them to fulfill the rules of the standards. Standards help improve transparency.

Cons

However, the cons of standardization include possible stifling of innovation and limiting access to smaller operators who might have fewer resources or data availability. Another con of standards is that usually, there is more than one standard. Some examples include ISO, ANSI, CSA, etc. They are not necessarily consistent. Not only does this fragment markets, but it makes it even harder for medium and small operators who now must dedicate even more resources to investigate and understand more than one standard.

Another con is the slow pace at which standards evolve. As new situations arise, it has been evidenced that some rules set in the standard have led to nefarious consequences. For example, ISO recommends sticking to either displacement or allocation (no hybrid system allowed), with displacement preferred and allocation only as a last resort. This has led to some fuels claiming negative carbon intensities after various displacements have happened - this is often a misleading result, since the combustion of fuels almost always results in net increase of GHGs in the atmosphere [21]. Emerging situations reveal shortcomings in standards, but revisions will take time.

The ambiguity with CO_2

Currently, there is no standard for assessing CCU, though a number of guidance documents exist, e.g. [22–24]. In 2019, as an output of the first of this series of LCA/TEA workshops, a paper was published that clearly spelled out the need for harmonization across guidance efforts to help reduce confusion and conflicting results [25]. The process of creating harmonized guidance, let alone a standard, is complicated by many factors. In CCU cases, the CO_2, a gas that is traditionally considered a waste, becomes a useful co-product and two main questions arise: 1) What is the best way to allocate between co-products, 2) What system, the one capturing or the one using the CO_2, benefits from the CO_2 reduction? If CO_2 is recycled but eventually emitted, the risk of double-counting the CO_2 reduction exists. The case for Direct Air Capture (DAC) is somewhat simpler, but various considerations also exist [11].

Best practices will lead to protocols, which then can lead to standards as the consensus on best practices increases. There is a push toward standards, but the reality might be that different circumstances might call for different methods. Several methods have been defined, including the incremental approach endorsed by Argonne National Lab (ANL) and the system expansion currently defined under 45Q incentives or UP Grants. What system is preferred will probably depend on the goal of the analysis. The 45Q and UP Grant methods avoid allocation by estimating a delta of CO_2 emissions between the expanded system and the combination of two traditional systems with multi-product functionality. The assessment estimates the total mass of CO_2 avoided instead of producing a carbon intensity number normalized to the functional unit, as the ANL method does. The 45Q method, by virtue of being an expansion-based method, requires data and knowledge of larger systems. The ANL method has other shortcomings, as it decouples carbon separation as if it did not exist in the original (non-carbon capture) design. Another roadblock is the lack of data. While some good open-source databases exist, most summarize country-level data and are not granular enough to facilitate precise life cycle assessments. Other good datasets live behind paywalls, which not only limit their impact but restrict the transparency of assessments that use them. NETL has a good electricity baseline. EPA and EIA could be a starting point, GREET is also a life cycle inventory (LCI). In the absence of primary data, a decent alternative might be the LCA commons database. Could a standard for data be created? Standards could create ceilings or floors, and there could be tiers of data based on geographic aggregation (global, national, state, region, etc)

Certifications

Certification schemes can be established based on existing standards. Certification bodies can be accredited through a regulatory body (e.g. California Air Resources Board for LCFS or European Commission for RED II) or self-established by an independent agent to meet market needs. Certification bodies ensure the analysis is completed according to certain specifications and a product is certified to meet certain criteria. Advantages of certification are that a third body can corroborate the meeting of certain criteria. Cons of certification are that small and medium size companies will have difficulties. Certification could be a requirement for regulations, but could also be part of a voluntary certification scheme where a company wants to be able to show that their product meets certain specifications to potential customers or stakeholders. Certification schemes could enhance transparency if implemented well. A good certification should allow for checks and balances with independent verification by a third party, be accepted by the main stakeholders, based on public data, and should be limited in time. When data is limited, we should rely on conservative data.

There is a need for mechanisms like engineering professional licensure that will allow for accountability in LCA practice. In cases where the impact of an LCA has clear financial consequences (such as a 45Q review that is tied to tax credits), a license can tie the practice of LCA (and its review) to a body of knowledge and create an expected standard of practice. On the one hand, this will ensure quality and accompanying standards of practice. In addition, it will provide a legal structure to indemnify either the practitioner and/or the LCA commissioner from legal consequences in the event of suspected malpractice. For such a system to exist, a clear body of knowledge and qualifications for licensure must be developed. ACLCA is in the process of developing a skills framework that is a first step in the direction.

Certification should be based on clear standards backed by an institution or body, especially if tied to loans or incentives, as in the case of IRA-based tax incentives or UPGrants. However, truly certifying an LCA could imply certification of all the information contained within it as well as the methodology, which would require significant time and effort, especially given the potential liability of “certifying” an LCA used for monetary purposes. A more efficient review process is often needed in which the reviewer bases the pass/fail conditions on the ultimate goal program. Thus the reviewer may need to determine if they are simply checking for complete metadata, as in the USLCI program, only reviewing the operational data in the foreground, or some other boundary. For example, NETL will review LCAs submitted under the UPGrants program, but will not “certify” the GWP found in the study, only provide assurance to the program that there is confidence that the results represent at least a 10 percent difference from the comparison product system.

- Certifications based on LCA can be expensive: Some project developers push back on LCA requirements in certification processes, arguing that they impose costs and unnecessary R&D pressure, especially for low TRL projects or products. For large projects these costs usually represent only a small fraction of the budget and are less of a concern. Another concern is the large quantity of potentially-proprietary data required to conduct LCA by certification authorities: Companies are naturally wary to share details. NDAs could be helpful in these cases, but reticence might persist, especially if a benefit is not clearly appreciated. Obtaining the necessary data can be difficult despite their legal right to access it and the presence of non-disclosure agreements (NDAs). Involvement from the Federal Trade Commission (FTC) could potentially solve this issue; however, their personnel may not be adequately trained.

Some failures are being seen in the carbon market. As non-experts are trying to build tools for the voluntary carbon market, including historically avoided embodied emissions, which are highly uncertain. Embodied emissions also are uncertain, as they require prediction (project lifetime), and it is difficult if not impossible to validate, and we don't have 40 years.

Some tools that could be helpful, such as the methane tracking platform, which provides facility-level data, are unknown to industry, due to a lack of vertical integration.

Methodologies to Tools or ML/AI for Data in LCA

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This section summarizes the main discussion points during the breakout session on the past, present, and future of ML/AI in the field of CO_2 life cycle assessment (LCA). Traditional LCA methods require significant manual efforts, such as developing life cycle inventory for a wide range of systems and products, making them time-consuming and resource intensive. However, the emergence of ML and AI technologies has opened up new opportunities to streamline and enhance the accuracy of CO_2 LCA. The session aimed to explore the various tools available, examine how ML and artificial intelligence (AI) can contribute to LCA, including LCA for carbon capture and utilization (referred to as CO_2 LCA in this document), and identify potential risks associated with their implementation.

Participants recognized that ML algorithms can effectively analyze large datasets, identify complex patterns, and generate accurate predictions. By leveraging these capabilities, ML can help improve the accuracy of CO2 emission estimates, identify emission hotspots, and optimize mitigation strategies. Furthermore, ML techniques enable the integration of real-time data from various sources, facilitating dynamic and up-to-date assessments of carbon footprints.

During the discussions, special attention was given to the context, applicability, progress, and next-generation opportunities of ML/AI in CO_2 LCA. The first point of discussion in the breakout session centered around the identification of potential areas of application of ML/AI in the context of CO_2 LCA. The following are the major areas identified during the discussion.

Goal and scope definition and decision making

While LCA starts with setting up of goals and the boundaries of the inventory analysis (i.e., scope definition), it ends with decision making. These require significant human effort to pre-process a significant amount of text-based and tabular datasets. The group envisioned that the methods such as Bayesian optimization and reinforcement learning can be used for this purpose based on the information gathered via natural language processing (NLP) and generative AI (e.g., Open AI ChatGPT, Google Bard, Microsoft Bing Chat). R&D efforts toward developing an integrated and automated approach would be useful for the LCA community for quickly assessing the implications of any new technologies.

Inventory data compilation, curation, and new variable identification

Each step of the LCA requires specific data inputs. The data needed for LCA includes information related to the product or system being assessed, such as raw material inputs, energy consumption, emissions, waste generation, and other relevant parameters. The data can be obtained from various sources, including literature, databases, industry reports, and company records. NLP has been used previously to compile data, however, within a limited scope. The breakout group identified the importance of NLP-based automated data compilation and curation process. During the discussions, a workshop participant acknowledged the use of a similar approach for their corporate data compilation and curation, though not for LCA alone. The breakout group also recognized the importance of new variable/feature design for LCA, for which NLP can play a major role.

Predictive model development and data generation for unknown scenarios

At present, ML/AI are mostly used in LCA for developing regression-based ML models for inventory analysis and impact assessment, as recognized by the breakout group. The breakout group emphasized the need for interpretable ML models and reiterated the importance of explainable ML model development in contrast to the currently used black-box models. Robust LCA requires considering all scenarios, which is limited by the availability of data. The group identified that ML/AI can be used for generating hypothetical datasets for yet unknown systems/scenarios.

Interpretation, understanding, and causal inference

The final decision making of practitioners or policymakers depends on how they interpret and understand LCA and their ability to establish causal inference from input and output data. The breakout group recognized that ML/AI tools can be used to get an informed understanding of LCA. Integrating explainable ML with causal inference will guide next-generation practitioners to systematically separate important information from clutters during LCA.

The second point of discussion in the breakout session centered around the tools available for implementing ML in CO_2 LCA. Participants highlighted a range of software frameworks, libraries, and programming languages commonly used in ML applications. Figure 1 shows a list of 24 commonly used ML/AI packages. These tools provide a foundation for developing predictive models, conducting data analysis, and automating various stages of the LCA process. Also, there are several database management tools available for life cycle assessment (LCA) that can help in organizing, managing, and accessing LCA data for ML/AI. These include Ecoinvent, GaBi, Gabi Databases, SimaPro, OpenLCA, and the European Reference Life Cycle Database (ELCD). While the specific machine learning (ML) interfaces for the mentioned LCA tools and databases may vary, it is important to note that ML techniques can be applied in conjunction with these tools to enhance data analysis, modeling, and decision-making.

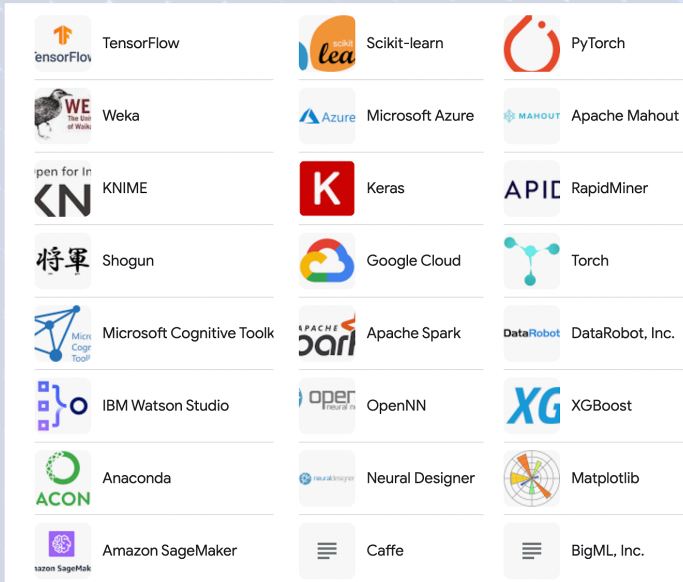

Figure created by A. Ahmed. Logos retrieved from various sources on Google Images. All logos are credited to the developers of their respective software. (Date of Access: Jun 6, 2023)

However, the breakout session also emphasized the importance of considering potential risks associated with the adoption of ML in CO_2 LCA. These risks include data privacy concerns, algorithmic bias, and the interpretability of ML models. The breakout group identified the following sources associated with the risks:

Incomplete, biased, or corrupted data

The effectiveness of AI/ML tools heavily relies on the availability and quality of data. Limited, biased, or inadequate data can lead to biased or unreliable LCA reports.

Lack of model benchmark against first principles

There is a risk that relying too heavily on AI/ML models may lead to a detachment from the fundamental principles of LCA and the underlying physical, chemical, and engineering concepts.

Blindly relying on black box AI/ML approaches

AI/ML models can sometimes be perceived as black boxes, where the inner workings and assumptions are not fully understood. It is important to avoid blindly relying on AI/ML outputs without critically evaluating and interpreting the results. The transparency and interpretability of ML models should be emphasized.

Participants acknowledged the need for robust data collection and management practices, ethical considerations in algorithm design, and transparent reporting of results. It is important to strike a balance between leveraging AI/ML techniques and maintaining a sound understanding of the LCA methodology. Additionally, the session highlighted the importance of expert oversight to ensure the reliability and integrity of ML-based LCA results.

In conclusion, this report will delve deeper into the tools available for ML implementation in CO_2 LCA, discuss how ML and AI can enhance CO_2 LCA practices, and address the associated risks. By exploring these aspects, the report aims to provide valuable insights for stakeholders interested in leveraging ML to improve the accuracy and efficiency of CO_2 LCA methodologies.

References

[1] McCord S, Armstrong K, Styring P. Developing a triple helix approach for CO2 utilisation assessment. Faraday Discuss 2021;230:247–70. https://doi.org/10.1039/d1fd00002k.

[2] Valentina Ruiz Leotaud. Researchers link cobalt mining in the DRC to violence, substance abuse, food-water insecurity. MININGCOM 2021. https://www.mining.com/researchers-link-cobalt-mining-in-the-drc-to-violence-substance-abuse-food-water-insecurity/ (accessed August 18, 2023).

[3] US Geological Survey. Mineral Commodity Summaries: Cobalt 2022.

[4] EITI. Democratic Republic of the Congo. EITI n.d. https://eiti.org/countries/democratic-republic-congo (accessed August 18, 2023).

[5] Cobalt for Development. Cobalt for Development (C4D) - Towards responsible artisanal cobalt mining in the DR Congo. Cobalt for Development (C4D) n.d. https://cobalt4development.com (accessed August 15, 2023).

[6] Warren Z, Warren Z. Upcoming SEC climate disclosure rules bring urgency to ESG data strategy planning. Reuters 2023.

[7] Petrova MA. NIMBYism revisited: public acceptance of wind energy in the United States. WIREs Climate Change 2013;4:575–601. https://doi.org/10.1002/wcc.250.

[8] Monmonier M. How to Lie with Maps, Third Edition. Chicago, IL: University of Chicago Press; 2018.

[9] Open Geospatial Consortium. Standards. Open Geospatial Consortium 2023. https://www.ogc.org/standards/ (accessed August 14, 2023).

[10] Calvin K, Dasgupta D, Krinner G, Mukherji A, Thorne PW, Trisos C, et al. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. First. Intergovernmental Panel on Climate Change (IPCC); 2023. https://doi.org/10.59327/IPCC/AR6-9789291691647.

[11] US Department of Energy Office of Fossil Energy and Carbon Management. Best Practices for Life Cycle Assessment of Direct Air Capture with Storage (DACS). EnergyGov n.d. https://www.energy.gov/fecm/best-practices-life-cycle-assessment-direct-air-capture-storage-dacs (accessed August 14, 2023).

[12] Qiu Y, Lamers P, Daioglou V, McQueen N, de Boer H-S, Harmsen M, et al. Environmental trade-offs of direct air capture technologies in climate change mitigation toward 2100. Nat Commun 2022;13:3635. https://doi.org/10.1038/s41467-022-31146-1.

[13] Griscom BW, Adams J, Ellis PW, Houghton RA, Lomax G, Miteva DA, et al. Natural climate solutions. Proceedings of the National Academy of Sciences 2017;114:11645–50. https://doi.org/10.1073/pnas.1710465114.

[14] Bach LT, Ho DT, Boyd PW, Tyka MD. Toward a consensus framework to evaluate air–sea CO2 equilibration for marine CO2 removal. Limnology and Oceanography Letters n.d.;n/a. https://doi.org/10.1002/lol2.10330.

[15] Supekar SD, Lim T-H, Skerlos SJ. Costs to achieve target net emissions reductions in the US electric sector using direct air capture. Environmental Research Letters 2019;14. https://doi.org/10.1088/1748-9326/ab30aa.

[16] Arcusa S, Lackner K, Page R, Sriramprasad V, Hagood E. Carbon Removal Accounting Methodologies: How to rethink the system for negative carbon emissions 2022.

[17] Sick V, Stokes G, Mason FC. CO2 Utilization and Market Size Projection for CO2-treated Construction Materials. Frontiers in Climate 2022;4. https://doi.org/10.3389/fclim.2022.878756.

[18] Carbon Gap. A Guide to Certifying Carbon Removal. Carbon Gap 2022.

https://carbongap.org/our-white-paper-launch/ (accessed August 14, 2023).
[19] Förster J, Beck S, Borchers M, Gawel E, Korte K, Markus T, et al. Framework for Assessing the Feasibility of Carbon Dioxide Removal Options Within the National Context of Germany. Frontiers in Climate 2022;4.
[20] Dupla X, Möller B, Baveye PC, Grand S. Potential accumulation of toxic trace elements in soils during enhanced rock weathering. European Journal of Soil Science 2023;74:e13343. https://doi.org/10.1111/ejss.13343.
[21] Tanzer SE, Ramírez A. When are negative emissions negative emissions? Energy & Environmental Science 2019;12:1210–8. https://doi.org/10.1039/c8ee03338b.
[22] National Energy Technology Laboratory. Carbon Dioxide Utilization Life Cycle Analysis Guidance Toolkit 2020.
[23] Zimmermann A, Wunderlich J, Buchner G, Müller L, Armstrong K, Michailos S, et al. Techno-Economic Assessment & Life-Cycle Assessment Guidelines for CO2 Utilization. Ann Arbor, MI, USA: University of Michigan,; 2018. https://doi.org/10.3998/2027.42/145436.
[24] Langhorst T, McCord S, Zimmermann A, Müller L, Cremonese L, Till Strunge, et al. Techno-Economic Assessment & Life-Cycle Assessment Guidelines for CO2 Utilization (Version 2). Global CO2 Initiative, University of Michigan; 2022. https://dx.doi.org/10.7302/4190.
[25] Sick V, Armstrong K, Cooney G, Cremonese L, Eggleston A, Faber G, et al. The need for and path to harmonized life cycle assessment and techno-economic assessment for carbon dioxide capture and utilization. Energy Technology 2019:1901034. https://doi.org/10.1002/ente.201901034.

Appendix: Workshop agenda

Hosted by the Global CO_2 Initiative
Organized and conducted by the International CCU Assessment Harmonization Group
Venue: University of Michigan, Rackham Graduate School, Ann Arbor, MI, USA & Zoom

May 16, 2023
6:00 - 8:00 PM **Informal welcome reception** (hors d'oeuvres, drinks) ***(Assembly Hall)***

May 17, 2023
8:00 - 8:30 AM **Continental breakfast** ***(Assembly Hall)***

8:30 - 9:00 AM **Welcome and workshop overview** ***(Amphitheater)***
- Volker Sick (GCI) & Greg Cooney (DOE)

9:00 - 9:15 AM **How far did we get last year?** ***(Amphitheater)***
- Stephen McCord (GCI)

9:15 - 9:30 AM **US Federal view of CCUS** ***(Amphitheater)***
- Noah Deich (DOE)

9:30 - 10:30 AM **CCUS and Societal Considerations** ***(Amphitheater)***
- Holly Buck (U. Buffalo)
- Jennifer Dunn (Northwestern)
- Andreas Ciroth (GreenDelta)

10:30 - 10:35 AM **Setting the stage for breakouts** ***(Amphitheater)***
- 2 x 2 on-site breakouts
- Zoom breakout rooms for virtual participants with 7 members per room. Self-guided discussion

10:35 - 10:50 AM **Break**

10:50 - 12:00 PM **Breakout sessions (2 breakout rooms per topic plus virtual-only breakouts)**

- **A: Social impact assessment / S-LCA in early TRLs** ***(East Conference Room, West Conference Room, Assembly Hall & Amphitheater)***
  - *Moderators: Stephen McCord (GCI), Jennifer Dunn (Northwestern)*
    - How to deal with uncertainty in low TRLs and lack of data?
    - Should we do S-LCA in low TRLs? Why or why not?

- What questions could be answered with S-LCA in low TRLs?
- What are the limitations of S-LCA? What are societal concerns that require different analytical frameworks?
- What has peoples' experience been with engagement with local communities and is CO_2 utilization on their radar? What are their metrics for addressing environmental justice issues and how could we work to adapt or integrate work done or being done with CO_2 utilization as part of their agenda?

- **B: CO_2 capture and implications on industry perception**
  - *Moderators: Emily Connor (US DOE), Mark Rigby (DTE Energy, ret.)* *Rosana & Till*
    - Concerns about unduly extending fossil carbon use?
    - Assessment of potential co-benefits of carbon capture (i.e., removal of other emissions)
    - How can LCA be used to effectively inform public stakeholders?

12:00 - 12:30 PM **Report outs *(Amphitheater)***
- *Breakout moderators*

12:30 - 1:30 PM **Lunch *(Assembly Hall)***

1:30 - 2:30 PM **Geospatial analysis & policies to meet the needs of everyone *(Amphitheater)***
- Jessie Stolark (Carbon Capture Coalition)
- Xinyi Wu (ANL)

2:30 - 4:00 PM **Breakouts (2 breakout rooms per topic plus virtual-only breakouts) *(East Conference Room, West Conference Room, Assembly Hall & Amphitheater)***
- **A: Utility of Geospatial analysis**
  - *Moderators: Till Strunge (IASS), Michelle Krynock (NETL)*
    - *Challenges of geospatial analyses: What kind of data is available ? What drawbacks might be present?*
    - *Should geospatial analyses include social factors?*
    - *Social acceptance of new CO2 pipelines is difficult (CO_2 pipelines in Illinois, California, and others are already facing stiff community resistance)*
    - *Exploring other CO_2 transportation options (bottled CO_2, dry ice, pipelines, etc.): How do we incorporate social factors into decision-making? How do we value social impacts? How do we value social factors alongside technical, economic, and environmental factors? How do we actually use social factors in a meaningful way?*
    - *How do we fight misinformation (particularly around siting)? How can we raise awareness? What are effective ways to counteract their narrative?*
    - *How do we equitably consider the NIMBY issue? How do we decide whose backyard will take precedence? How can we change the dynamic that lack of*

resources, power, and influence create for disadvantaged communities? How do we level the playing field? How do we give disadvantaged/underserved communities better resources and a louder voice?

- **B: Social Impact Factors**
  - *Moderators: Stephen McCord (GCI), Volker Sick (GCI)*
    - *Get feedback from industry folks about what are the best practices in industry for social factors - have discussion/conversation around best practices*
    - *What are the best framework and standards available today? Certified B corp, UN SDG, SDG Indicators — SDG Indicators (un.org), Pre SVI Handbook, others.*
    - *Social impacts go well beyond job creation - how are these being factored into decision-making? Consider JEDI in job creation, but also consider impacts on local social fabric, local culture and customs, procedural justice, distributive justice, communication channels, community compensation packages, etc.*

4:00 - 4:15 PM **Break**

4:15 - 4:45 PM **Report outs and summary of Day 1 *(Amphitheater)***

- *Breakout moderators*

5:00 - 6:00 PM **Poster session, hors d'oeuvres, drinks *(Assembly Hall)***

6:00 - 8:00 PM **Dinner @ Rackham Graduate School *(Assembly Hall)***

“CCU TEA and LCA Guidance – A Harmonized Approach”

May 18, 2023

8:00 - 8:45 AM **Continental breakfast *(Assembly Hall)***

8:45 - 8:50 AM **Overview of scope of the day *(Amphitheater)***

8:50 - 10:40 AM **Guidelines and Standardization *(Amphitheater)***

8:50 - 9:00 AM **Overview of guidelines and standards around the world *(Amphitheater)***

- Michelle Krynock (NETL), Volker Sick (GCI)

9:00 - 9:15 AM **DIN spec and path to ISO *(Amphitheater)***

- Stefan Kelnberger (DIN)

9:15 - 9:30 AM **LCA Guidelines in Japan *(Amphitheater)***

- Shin Morimoto (AIST)

9:30 - 9:40 AM **GCI *(Amphitheater)***

- Stephen McCord (GCI)

9:40 - 9:50 AM **NETL *(Amphitheater)***

- Sheikh Moni (NETL)

9:50 - 10:00 AM **BREAK**

10:00 - 10:10 AM **NREL *(Amphitheater)***

- Eric Tan

10:10 - 10:20 AM **ANL *(Amphitheater)***

- Michael Wang

10:20 - 10:30 AM **NRC *(Amphitheater)***

- Ryan Baker

10:30 - 10:40 AM **ACLCA *(Amphitheater)***

- Amlan Mukherjee

10:40 - 11:00 AM **Break**

11:00 - 12:00 PM **Breakout sessions (plus virtual-only breakouts) *(East Conference Room, West Conference Room, & Amphitheater)***

- **A: Methodologies to tools or ML/AI for data in LCA**
  - *Moderators: Alauddin Ahmed (U-M)*
    - What tools are available?
    - How will ML and AI help?
    - What risks might have to be considered?

- **B: Integration of Carbon Conversion LCA/TEA Methods and Carbon Removal**
  - *Moderators: Greg Cooney (DOE) Mark & Alauddin*
    - Biogenic carbon accounting
    - CO_2 as waste input?
    - CO_2 as a co-product

- **C: Certification vs Standardization pros and cons**
  - *Moderators: Amlan Mukherjee (MTU) Rosa & Alauddin*
    - What are the pros and cons of standardization?
    - What are the pros and cons of a certification scheme?
    - What would the ideal certification look like?
    - Needs for standard data sets
    - EPDs

12:00 - 12:15 PM **Report outs & discussion *(Amphitheater)***

12:15 - 12:30 PM **Concluding remarks: *(Amphitheater)***
- Volker Sick (GCI)

12:30 PM **Lunch *(Assembly Hall)***

1:30 PM **Adjourn**

1:30 - 4:00 PM **Writing team to work on a workshop report *(East Conference Room)***