Life Cycle Analysis of Emerging CO2 Utilization Technologies: Challenges and Current Best Practices

NATIONAL ENERGY TECHNOLOGY LABORATORY

Solutions for Today | Options for Tomorrow

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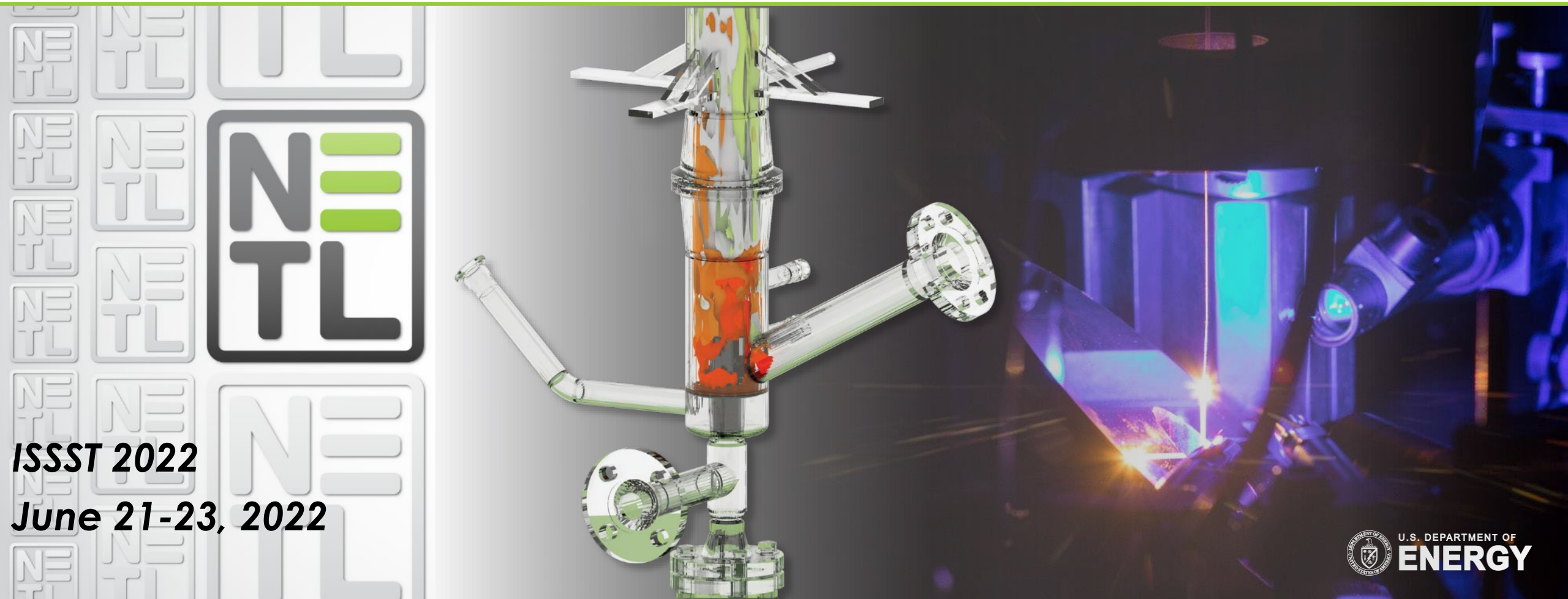

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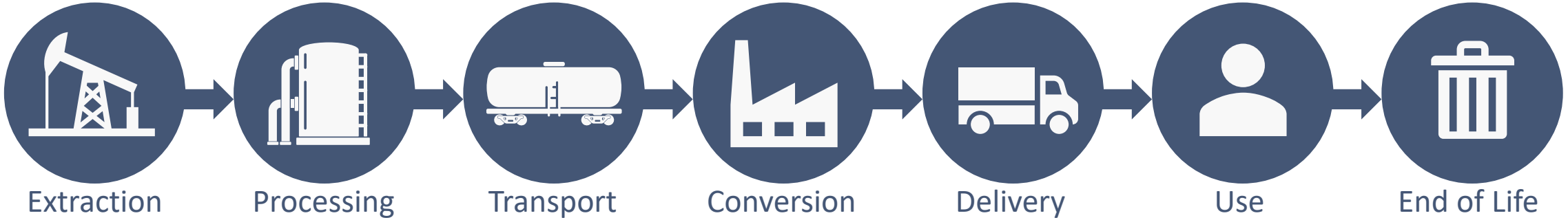
Energy Life Cycle Analysis (LCA)

Cradle-to-Grave Environmental Footprint of Energy Systems



What is Life Cycle Assessment/Analysis (LCA)?

LCA is a technique that helps people make better decisions to improve and protect the environment by accounting for the potential impacts from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal (i.e., cradle-to-grave).

Why LCA?

Inform Business Decisions: R&D to Commercialization

- **Guide research and development investment.**
  We want to invest in emerging technologies that are better than existing technologies.
- **Evaluate existing systems to identify opportunities for improvement.**
  Where should we invest to obtain the greatest return on investment?
- **Identify data gaps and validation needs to improve decision-making.**
  Inform and guide environmental field monitoring activities (data collection).
- **Assess potential benefits from commercializing technologies.**
  Quantify the environmental value at various levels of commercial adoption (at what scale will our technology make a measurable difference?).

How Do We Use LCA?

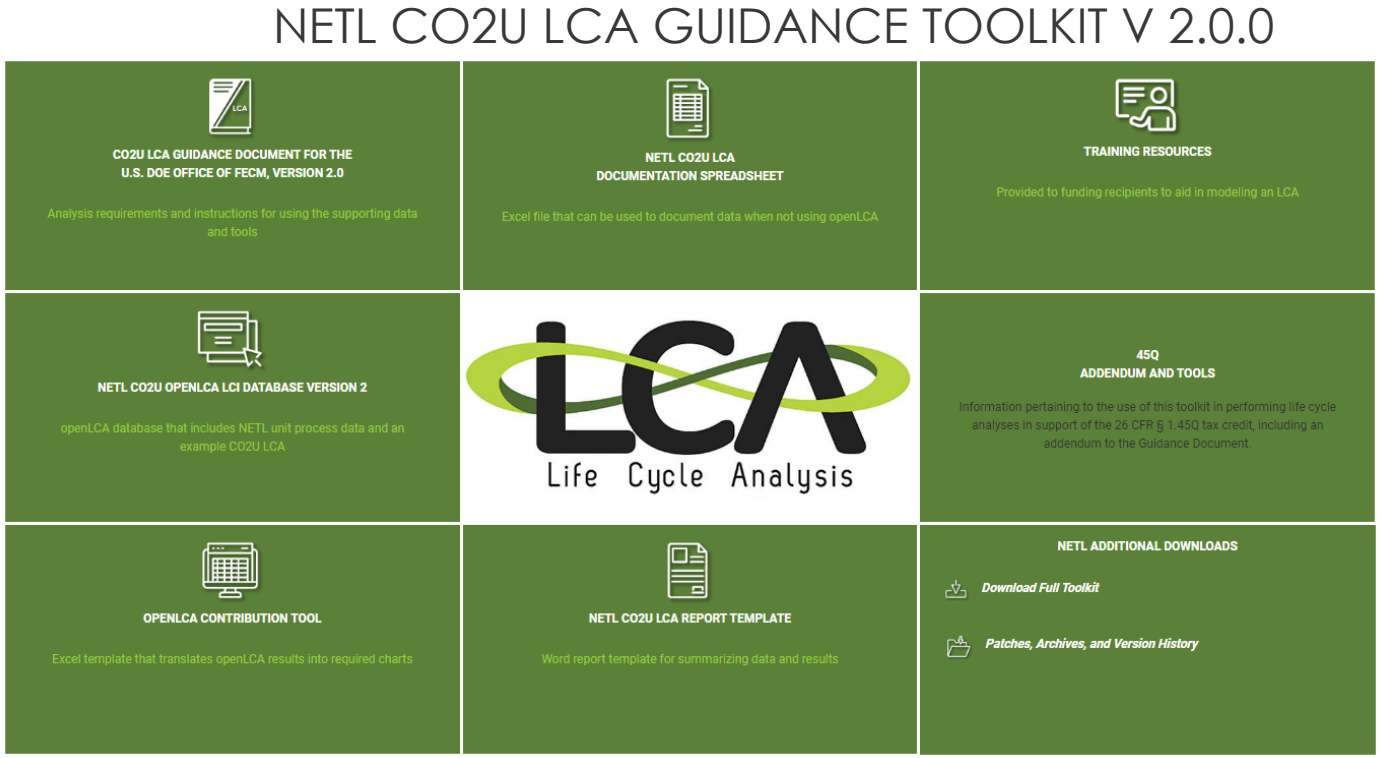
Depends on the Question of Interest….

- Establish National Baselines
- Assess Emerging and Existing Technologies
- A|B Compare Technology and Scenario Tradeoffs
- Plan for the Future and Look Ahead

The NETL CO2U LCA Guidance Toolkit

Overview

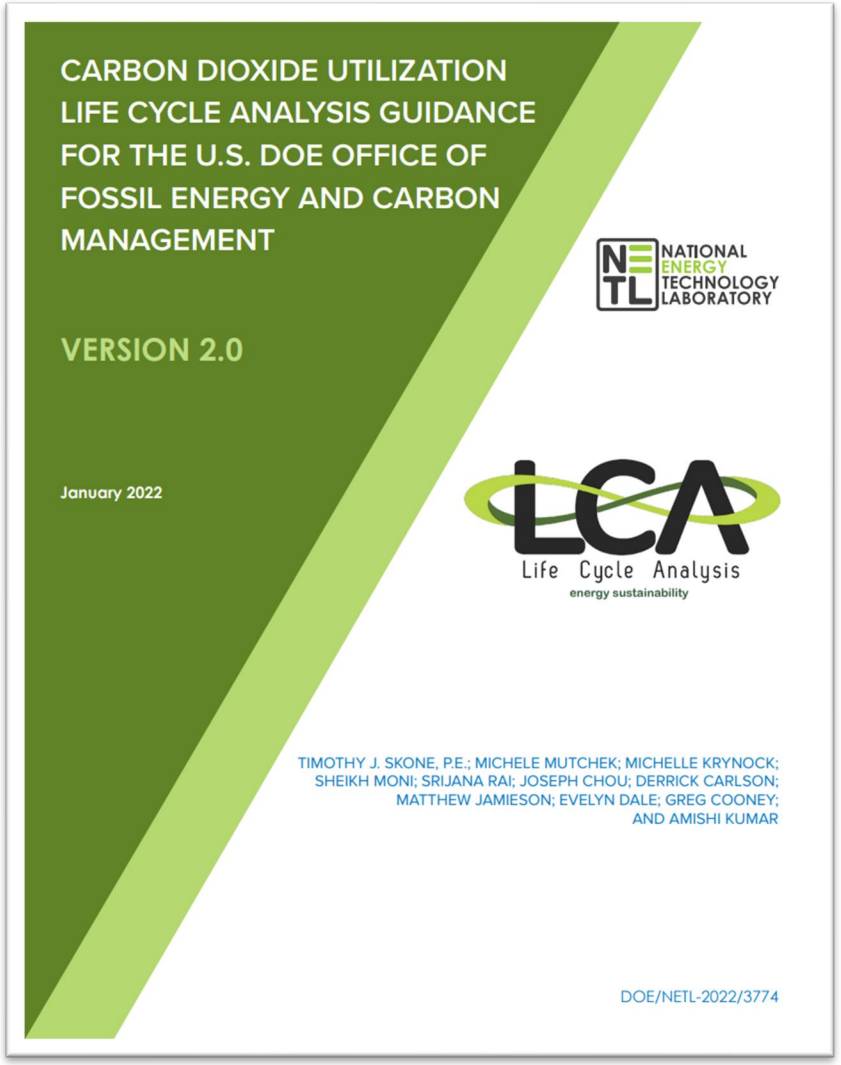
- Supports funding recipients with their LCA requirements
- Foster better decision-making for the U.S. DOE Carbon Utilization Program by providing consistent and transparent analysis and reporting structure
- Provide LCA guidance, data, and tools to LCA practitioners in the area of CO2U
- Contribute to the global discussion on CO2U LCA and LCA methods
- Toolkit site: netl.doe.gov/LCA/CO2U



The NETL CO2U LCA Guidance Toolkit

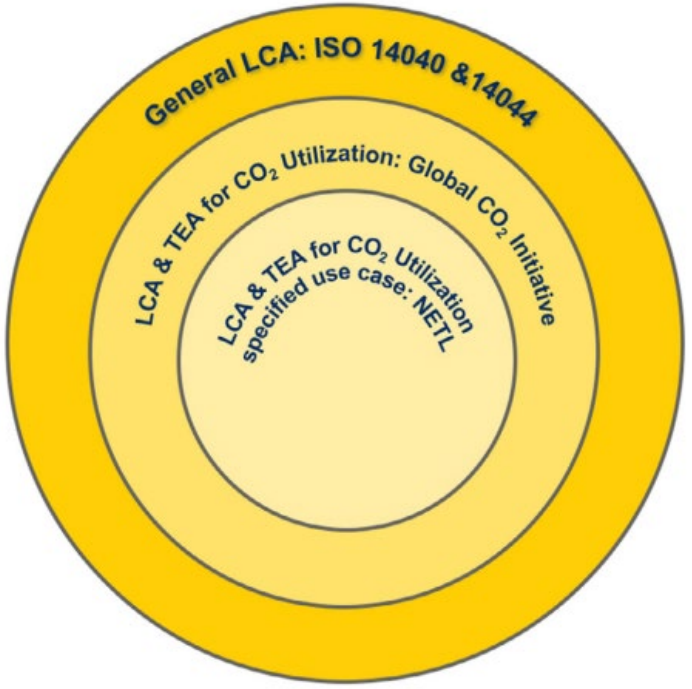
Overview

- Specific guidance for projects funded by DOE CO2U program. For general guidance on applying, commissioning & interpreting LCA – the underlying assumptions of the guidance should be examined and adjusted for use in other programs
- Technology neutral (both in guidance and provided worked examples) – no recommendations or preference is given for specific technologies or pathways. All project associated materials are purely educational or instructional
- Scheme specific guidance – we built this document for a DOE FOA program and the goal is to receive consistent, comparable LCAs back from project PIs



Need for Harmonized LCA approach

- ISO 14040 and 14044 is generic and a variety of approaches has been developed and in use
- Emerging from this variety is a need for harmonization of procedures for LCA of CCU for consistent interpretation and reporting of the results



The Need for and Path to Harmonized Life Cycle Assessment and Techno-Economic Assessment for Carbon Dioxide Capture and Utilization

Volker Sick, Katy Armstrong, Gregory Cooney, Lorenzo Cremonese, Alexandra Eggleston, Grant Faber, Gregory Hackett, Arne Kätelhön, Greg Keoleian, John Marano, Joseph Marriott, Stephen McCord, Shelie A. Miller, Michele Mutchek, Barbara Olfe-Kräutlein, Dwarakanath Ravikumar, Louise Kjellerup Roper, Joshua Schaidle, Timothy Skone, Lorraine Smith, Till Strunge, Peter Styring, Ling Tao, Simon Völker, and Arno Zimmermann*

Contribute to Global Discussion

International Carbon Capture and Utilization (CCU) Assessment Harmonization Group

- The NETL LCA team co-led discussions to develop a globally consistent approach to perform LCA and techno-economic analysis (TEA) of CO2U technologies.
- The collaboration formed International CCU Assessment Harmonization Group which will enable the development of consistent guidelines for LCA and TEA of CO_2 utilization technologies.
- The NETL LCA team contributed to this harmonization effort by leading and participating in multiple task force teams.
- Findings from this collaborative effort were presented in a series of mini webinars in May 2021.
- A number of peer-reviewed journal articles has been published in Frontiers in Climate.

International CCU Assessment Harmonization Group Participants

Special Issue in Frontiers in Climate

Research Topic

Harmonizing Life Cycle Analysis (LCA) and Techno-Economic Analysis (TEA) guidelines: A Common Framework for consistent conduct and transparent reporting of carbon dioxide removal and CCU Technology Appraisal

Harmonization of TEA and LCA for CCU

Focus Areas

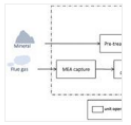
- AssessCCUS Resource Website
- Common Terminology
- LCA and TEA at different TRL
- Adaptation of Technology Learning Curve
- Selecting Proper Benchmark
- Future Scenarios

AssessCCUS: An Integrated Approach for Aggregating Resources to Enable Techno-Economic and Life Cycle Assessment of Carbon Management Technologies

Grant Faber , Christophe Mangin, Barbara Olfe-Kräutlein and Joshua A. Schaidle

Data Report

Published on 17 February 2022
Front. Clim. doi: 10.3389/fclim.2022.817211



Adapting Technology Learning Curves for Prospective Techno-Economic and Life Cycle Assessments of Emerging Carbon Capture and Utilization Pathways

Grant Faber , Andrew Ruttinger , Till Strunge , Tim Langhorst, Arno Zimmermann , Mitchell van der Hulst, Farid Bensebaa, Sheikh Moni and Ling Tao

Original Research Comparisons of emerging carbon capture and utilization (CCU) technologies with equivalent incumbent technologies are necessary to support technology developers and to help policy-makers design appropriate long-term incentives to mitigate climate ...

Published on 14 April 2022
Front. Clim. doi: 10.3389/fclim.2022.820261

Life-Cycle and Techno-Economic Assessment of Early-Stage Carbon Capture and Utilization Technologies—A Discussion of Current Challenges and Best Practices

Arno W. Zimmermann , Tim Langhorst , Sheikh Moni , Joshua A. Schaidle , Farid Bensebaa and André Bardow

Policy and Practice Reviews The mitigation of climate change requires research, development, and deployment of new technologies that are not only economically viable but also environmentally benign. Systematic and continuous technology assessment from early technology maturity ...

Published on 28 March 2022
Front. Clim. doi: 10.3389/fclim.2022.841907

Why Terminology Matters for Successful Rollout of Carbon Dioxide Utilization Technologies

Barbara Olfe-Kraeutlein , Katy Armstrong, Michele Mutchek , Lorenzo Cremonese and Volker Sick

Perspective To realize their full sustainability potential, carbon dioxide utilization technologies (carbon capture and utilization/CCU) presently require policy support. Consequently, they require acceptance among a variety of stakeholders in industry, policy ...

Accepted on 06 May 2022
Front. Clim. doi: 10.3389/fclim.2022.830660

LCA of Early TRL Technologies

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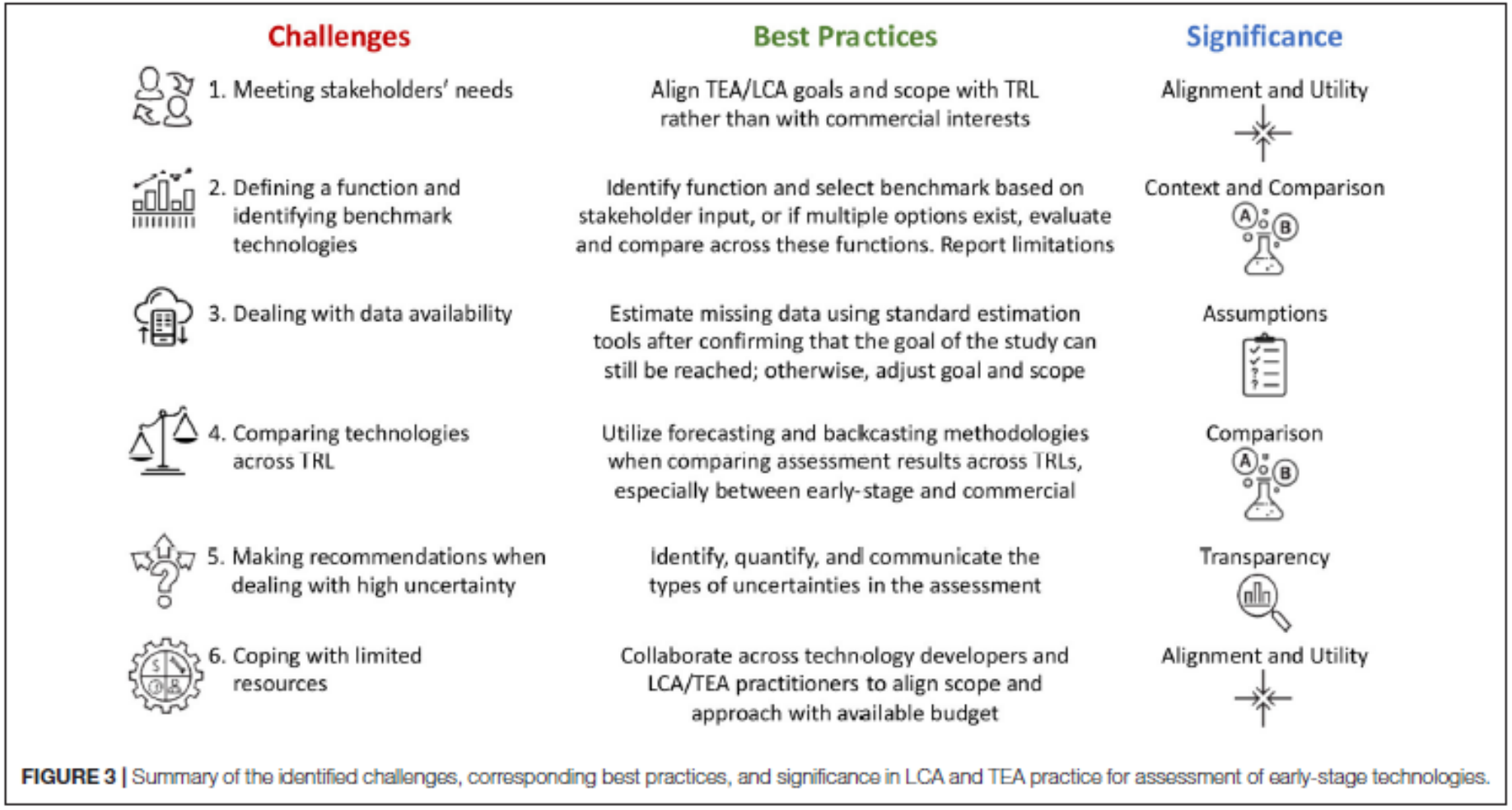

Challenges	Best Practices	Significance
1. Meeting stakeholders' needs	Align TEA/LCA goals and scope with TRL rather than with commercial interests	Alignment and Utility
2. Defining a function and identifying benchmark technologies	Identify function and select benchmark based on stakeholder input, or if multiple options exist, evaluate and compare across these functions. Report limitations	Context and Comparison
3. Dealing with data availability	Estimate missing data using standard estimation tools after confirming that the goal of the study can still be reached; otherwise, adjust goal and scope	Assumptions
4. Comparing technologies across TRL	Utilize forecasting and backcasting methodologies when comparing assessment results across TRLs, especially between early-stage and commercial	Comparison
5. Making recommendations when dealing with high uncertainty	Identify, quantify, and communicate the types of uncertainties in the assessment	Transparency
6. Coping with limited resources	Collaborate across technology developers and LCA/TEA practitioners to align scope and approach with available budget	Alignment and Utility

FIGURE 3 | Summary of the identified challenges, corresponding best practices, and significance in LCA and TEA practice for assessment of early-stage technologies.

Zimmermann et al. (2022) Front. Clim. doi: 10.3389/fclim.2022.841907

Adaptation of TLC in LCA and TEA

- While learning curve approaches have been developed for various technologies, a harmonized methodology for using TLCs in TEA and LCA for CCU in particular is essential.
- This paper proposed a methodology that incorporates TLCs into TEA and LCA to forecast the environmental and economic performance of emerging CCU technologies.
- The proposed methodology is based on both an evaluation of the state of the art of learning curve assessment and a literature review of TLC approaches developed in various manufacturing and energy generation sectors.
- The method has been demonstrated using a case study on a CO_2 mineralization pathway.

Faber et al. (2022)
Front. Clim. doi: 10.3389/fclim.2022.820261

TLC Methodology (Hybrid approach)

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$$TPC_N = TPC_1 N^{-b}$$

TPC: Total plant cost (direct and indirect costs)

"1" correspond to the FOAK (First-of-a-kind)

"N" correspond to NOAK (nth-of-a-kind)

"b" is learning rate exponent: $b = -\frac{\log(1-lr)}{\log(2)}$

"lr" is the learning rate

FOAK plant is estimated using a comprehensive bottom -up approach, followed by a top-down learning curve approach to determine NOAK plant costs

Faber et al. (2022)
Front. Clim. doi: 10.3389/fclim.2022.820261

TLC Methodology - GHG calculation

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- **Most learning rates are derived through economic data**
- **Technology learning is applied for capital expenditure (and OPEX)**
- **Few data are available for GHG emissions**
- **Options considered to expand environmental impact assessments:**
  - ❑ Energy and materials consumptions could be used as proxy for CO2 emissions
  - ❑ $\mathrm{GHG_{NOAK}} = \mathrm{GHG_{FOAK}} \cdot \mathrm{N}^{-b}$

Faber et al. (2022)
Front. Clim. doi: 10.3389/fclim.2022.820261

Defining Benchmark for CCU Technologies

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Technology Maturity of the Proposed Technology	Comparison Case Minimum Expectation for Reporting	Recommended Guidance
TRL 1 – 4 (Concept/Lab)	Highest Market Share	BIC GHG
TRL 5 – 6 (Prototype/Scale-up)	Industry Average GHG	BIC GHG
TRL 7 – 8 (Demonstration/1st plant)	BIC GHG	Marginal Cost
TRL 9 (Commercial)	Marginal Cost	Marginal Cost

Contribute to Global Discussion

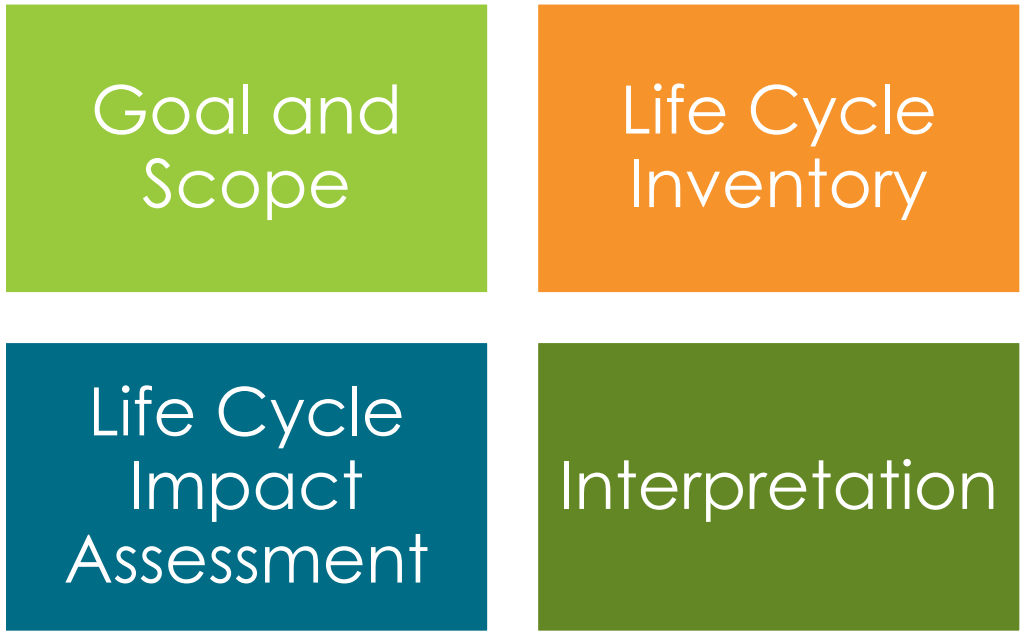
SETAC-ACLCA Working Group: LCA Recommendations for Emerging Technologies

- The NETL LCA Team is collaborating with a diverse group of LCA experts to develop recommendations for LCA of emerging technologies as part of the SETAC-ACLCA LCA Working Group (https://www.setac.org/group/SNAIGLCA).
- This collaborative effort will enable LCA practitioners to:
  - Understand the state-of-the-art in LCA for emerging technologies.
  - Identify limitations and gaps in current LCA techniques.
  - Develop a roadmap to enable LCA of emerging technologies to better serve decision-making.
- Recently, NETL participated in the "Emerging Technologies" special session at the ACLCA 2021 conference, and co-presented findings from the SETAC-ACLCA LCA Working Group's LCA effort.

SETAC-ACLCA Working Group

Activity Highlights

- Four sub-groups to focus on each stage of LCA
- NETL participated in the "Emerging Technologies" special session at the ACLCA 2021 conference, and co-presented findings from the SETAC-ACLCA LCA Working Group's LCA effort
- The SETAC-ACLCA LCA Working Group presented in "CCU TEA and LCA Guidance – A Harmonized Approach" Workshop co-organized by GCI and DOE NETL in May 2022
- Special Session in ISSST 2022



Contribute to Global Discussion

- **Outcomes from global collaboration efforts included:**
  - The launch of the AssessCCUS website.
  - Glossary of accepted TEA and LCA terms for CCUS.
  - Recommendations to conduct LCA and TEA for CCU technologies/emerging technologies at low technology readiness level.
  - Strategy to define comparison product system representatives.
  - Guidelines to evaluate the technology learning curve and its implications on future performance.

- **These international efforts continue to support the development of consistent guidelines to advance the commercialization of products produced from captured carbon dioxide to reduce the environmental impact on local and global communities to ensure a sustainable future.**

NETL RESOURCES

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