CO2U Life Cycle Analysis

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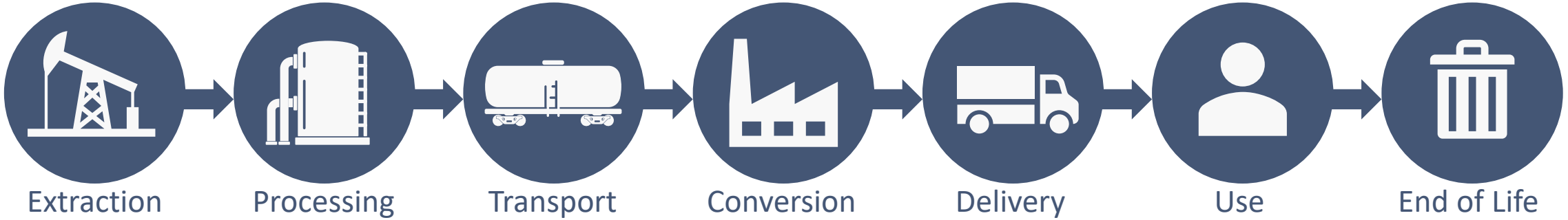
Carbon Utilization Project Review Meeting

October 21, 2020

NATIONAL ENERGY TECHNOLOGY LABORATORY

Energy Life Cycle Analysis (LCA)

Cradle-to-Grave Environmental Footprint of Energy Systems



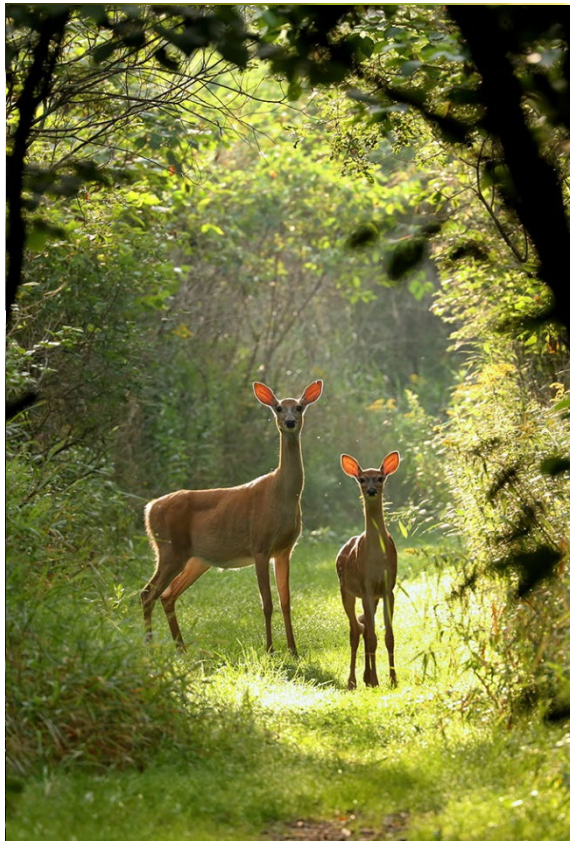
What is Life Cycle Assessment/Analysis (LCA)?

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?

Why what we do is important

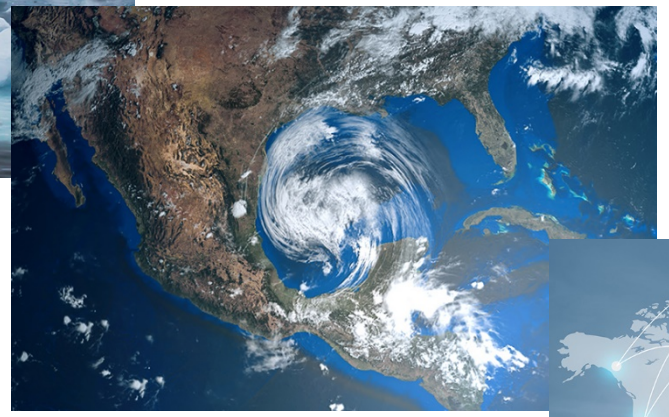


Air — Water — Ecosystems — Built Environment

Why LCA?

Driving towards global stewardship



Air — Water — Ecosystems — Built Environment

Why LCA?

Inform Business Decisions: R&D to commercialization

- **Guide research and development investment**
  we want to invest in emerging technology that is better than we have today

- **Evaluate existing systems to identify opportunities for improvement**
  where should we invest to get the greatest return on investment

- **Identify data gaps and validation needs to improve decision making**
  inform and guide environmental field monitoring activities (data collection)

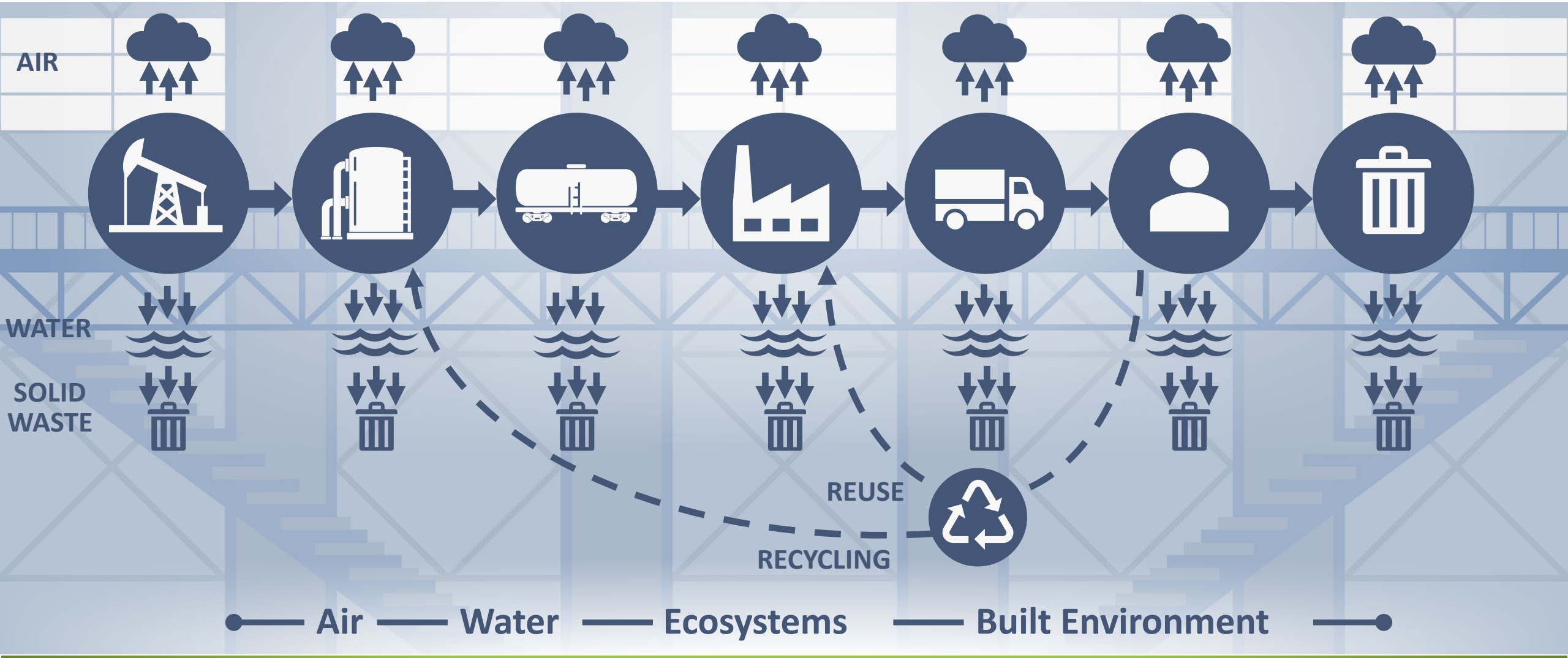
- **Assess benefit potential from NETL technology commercialization**
  quantify the environmental value at varying levels of commercial adoption (at what scale will our technology make a measurable difference)

How?

LCA Method

How?

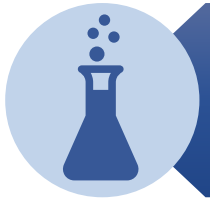
LCA Method



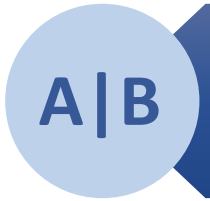
How we use LCA?

Depends on the question of interest…

Establish National Baselines



Assess Emerging and Existing Technologies



Compare Technology and Scenario Tradeoffs

Plan for the Future and Look Ahead

Assess Emerging and Existing Technologies

CO2U LCA Guidance Toolkit

Scope Overview

- CO2 utilization LCA guidance and tool package for Carbon Utilization Program primary research projects
- LCA guidance, opensource LCA software (openLCA), NETL data, and results reporting tools

Highlights

- An openLCA database has been populated with data and an example to help principle investigators (PIs) conduct LCA within the openLCA software
- An Excel tool has been created to take openLCA results and translate them into stacked bar charts for results communication
- Nearly 100 pages of guidance has been written to help PIs conduct LCA on their CO2 utilization project

Outcomes

- Toolkit available at netl.doe.gov/LCA/CO2U

NETL CO2U LCA Toolkit Goals

1. Provide LCA guidance, data, and tools to U.S. DOE Carbon Utilization Program project PIs to complete their project LCA and documentation requirements

2. Foster better decision-making for the U.S. DOE Carbon Utilization Program by providing an analysis and reporting structure for the project LCAs that allows for consistency and transparency

3. Provide LCA guidance, data, and tools to others seeking guidance on conducting LCA in the area of CO2U

4. Contribute to the global discussion on CO2U LCA and LCA methods

NETL CO2U Guidance Key Points

Comparative LCA

LCA goal is to compare the CO2U system to the long-run marginal competitor in the market (comparison system)

Multiproduct functional unit with system expansion

Improve comparability and results interpretation

Default scenarios for CO_2 sources

Coal-fired power generation: flue gas, captured CO_2 greenfield and retrofit

***expanding to all CO_2 sources in 2020/2021*

Guidance for comparison processes and system

Data quality and representativeness: expectations based on TRL

Three modeling options

1. openLCA with provided data
2. Excel-based documentation sheet
3. Other commercial LCA modeling software

Interpretation requirements

Specific data/figures to provide consistency to study comparisons

The NETL CO2U LCA Guidance Toolkit

netl.doe.gov/LCA/CO2U

- **Supports funding recipients with their LCA requirements**
- **Simplifies the process of LCA**
- **Improves consistency in communicating results**
- **Toolkit site: netl.doe.gov/LCA/CO2U**

The NETL CO2U LCA Guidance Toolkit

netl.doe.gov/LCA/CO2U

GUIDANCE DOCUMENT

Analysis requirements and instructions for using the supporting data and tools

Starting point for understanding LCA requirements

OPENLCA MODEL TRAINING

Provided to funding recipients to aid in modeling an LCA in openLCA

Training videos and live webinars will be available as developed at www.netl.doe.gov/LCA/CO2U

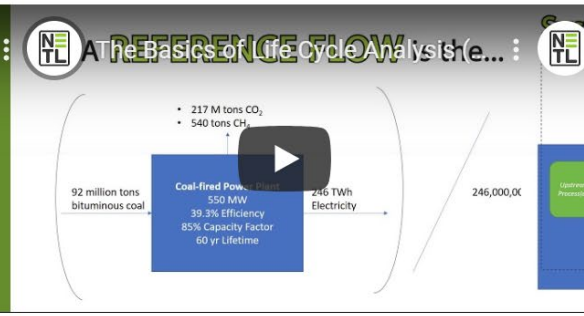
SUBJECT MATTER EXPERT SUPPORT

Available to funding recipients for all phases of the LCA from conception to documentation

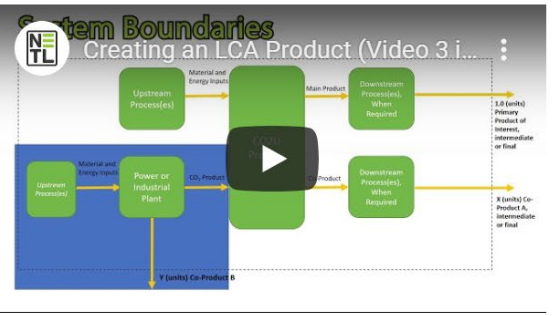
Contact us with questions at LCA@netl.doe.gov

(for NETL Project Recipients)

1. Overview



2. The Basics of Life Cycle Analysis



3. Creating an LCA Product

The NETL CO2U LCA Guidance Toolkit

netl.doe.gov/LCA/CO2U

OPENLCA LCI DATABASE

openLCA database that includes NETL unit process data and an example CO2U LCA

OPENLCA CONTRIBUTION TOOL

Excel template that translates openLCA results into required charts

LCA REPORT TEMPLATE

Word report template for summarizing data and results

PI CHOSEN LCA SOFTWARE OR SPREADSHEET SOFTWARE

DOCUMENTATION SPREADSHEET

Excel file that can be used to document data when not using openLCA

LCA REPORT TEMPLATE

Word report template for summarizing data and results

CO2U LCA Toolkit Knowledge Session Webinars

- **Webinar 1** Gives an overview of Life Cycle Analysis (LCA) basics and the NETL CO2U LCA toolkit. Tues, Oct 20, 2020 and Wed, Oct 28, 2020 1 – 2 pm EST.

- **Webinar 2** Goes over the basics of using openLCA to complete a CO2 utilization LCA. Tues, Nov 24, 2020 and Wed, Dec 2, 2020, 1 - 2:30 pm EST.

- **Webinar 3** Gives more detail on LCA results analysis using tools from the CO2U LCA Toolkit. Tues, Jan 19, 2021 and Wed, Jan 27, 2021, 1 – 2 pm EST.

If you are a PI and did not receive a Webinar invite, email LCA@netl.doe.gov

Current Carbon Utilization Support Activities

RIC Carbon Utilization FWP, Task 5 Support

1. State-of-the-Science Monthly Technical Reviews
2. CO2U Guidance Toolkit Maintenance Strategy
3. CO2U LCA Knowledge Session
4. Algae to Biofuels LCA CO2U Toolkit Report Example
5. Algae to Biofuels LCA Journal Manuscript
6. Electrochemical CO_2 Catalyst (ECC) LCA CO2U Toolkit Report Example
7. Electrochemical CO_2 Catalyst (ECC) LCA Screening Tool
8. Mineralization LCA
9. Steam Methane Reforming and Microwave-Assisted Catalysis LCA
10. National Academy of Sciences (NAS) CO_2 Utilization Recommendations

State-of-the-Science Monthly Technical Reviews

Rationale

- The value of this effort is increased knowledge and awareness of the state-of-the-science within the field of life cycle analysis for carbon utilization technologies/products and other areas of programmatic interest.

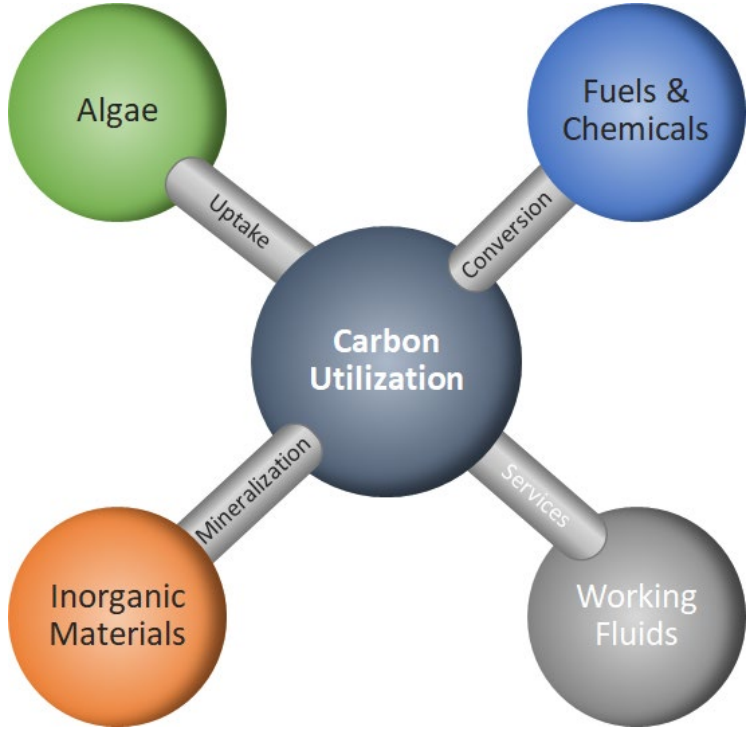
Approach

- This support provides two technical reviews of life cycle analysis related external publications of relevance to the Program on a monthly basis.
- External publications may include, but not limited to, peer-reviewed journal articles, non-profit or for-profit reports, and non-NETL internal reports.

Outcome

- On-going through EY22

Carbon Utilization
(https://netl.doe.gov/coal/carbon-utilization)



CO2U Guidance Toolkit Maintenance Strategy

Rationale

- The NETL CO2U LCA Guidance Toolkit was released to the Funding Opportunity Announcement funding recipients in 2019 (netl.doe.gov/LCA/CO2U)
- The NETL LCA Team needed a way to keep track of necessary updates and new work to maintain the Toolkit

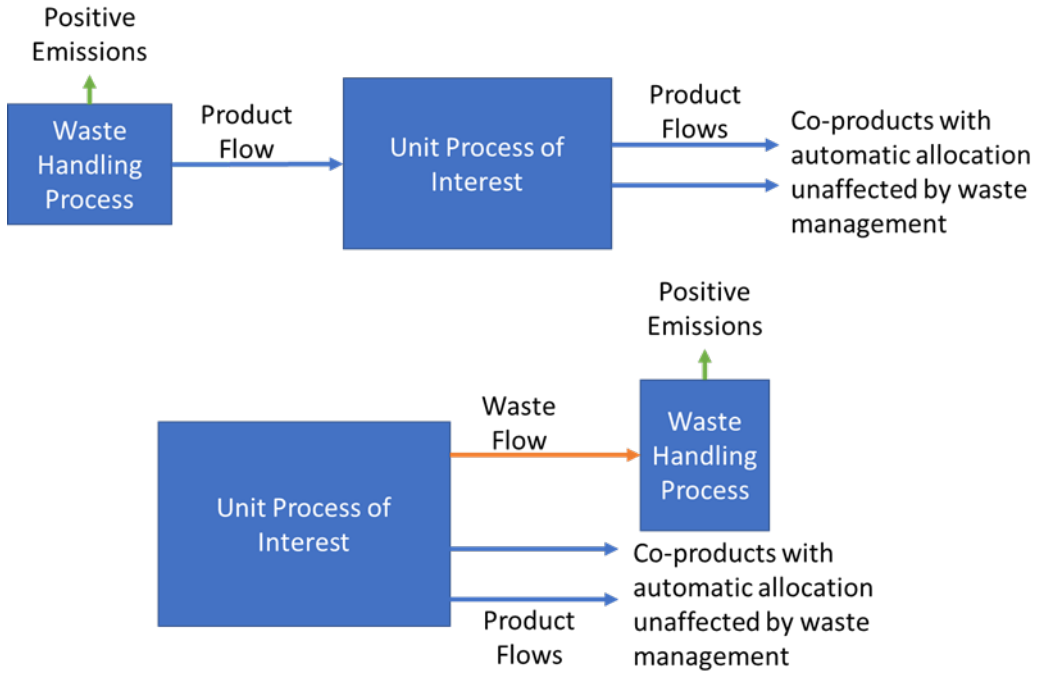
Approach

- The CO2U Guidance Toolkit Maintenance Strategy is a living document that will account for all of the updates that will be needed to keep the toolkit up-to-date
- The CO2U Guidance Toolkit Maintenance Strategy is separated into three sections
  - Existing toolkit updates
  - New deliverables
  - Communication with funding recipients
- Example updates are as follows:
  - Changing how waste flows are handled in openLCA software
  - Updating the Toolkit to include the NETL Electricity Baseline work
  - Adding an expanded list of potential industrial upstream CO_2 sources
  - Creating a user guide for reviewing funding recipient LCAs

Outcome

- Current draft is under internal review

openLCA Waste Flow Modeling Update



CO2U LCA Knowledge Session

Rationale

- The NETL CO2U LCA Guidance Toolkit was released to the Funding Opportunity Announcement funding recipients in 2019 (netl.doe.gov/LCA/CO2U)
- The NETL LCA Team needed a way to provide toolkit training to the funding recipients

Approach

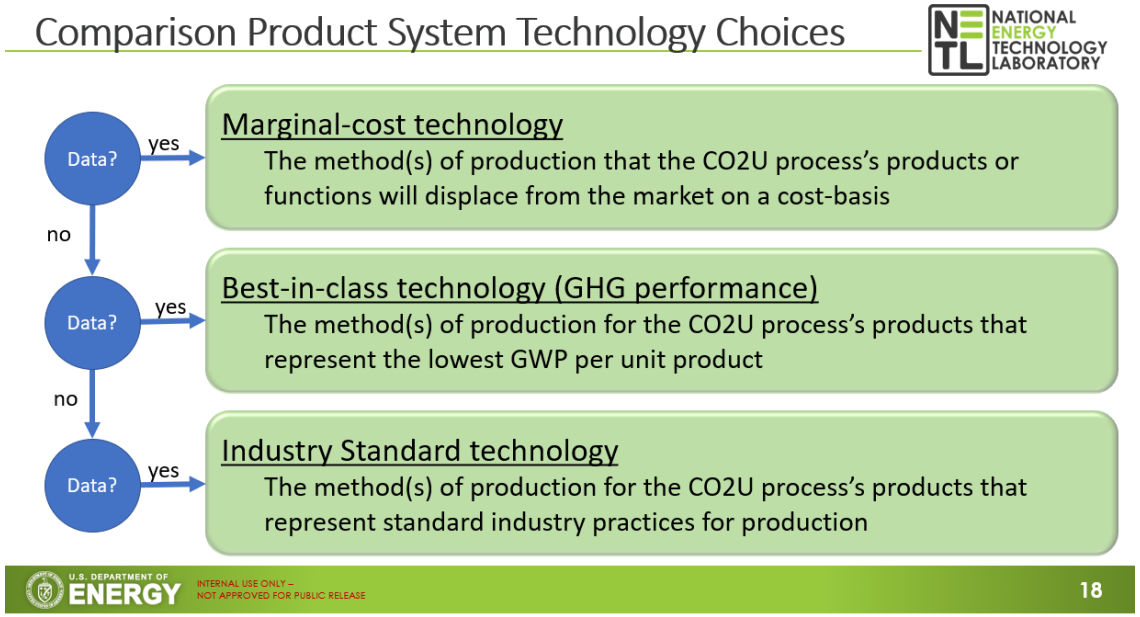
- The NETL LCA Team is conducting live webinars for funding recipients covering different aspects of the NETL CO2U LCA Guidance Toolkit
- So far, the webinars have been attended by 10-20 participants per module with approximately three audience questions received per webinar

Outcome

- Knowledge Session 1 module completed in January 2020
- Knowledge Session 2 module completed in March 2020
- Knowledge Session 3 module to be completed in May and June 2020

- Next Knowledge Sessions starting October 20, 2020.

Knowledge Session Screenshot



Algae to Biofuels LCA CO2U Toolkit Report Example

Rationale

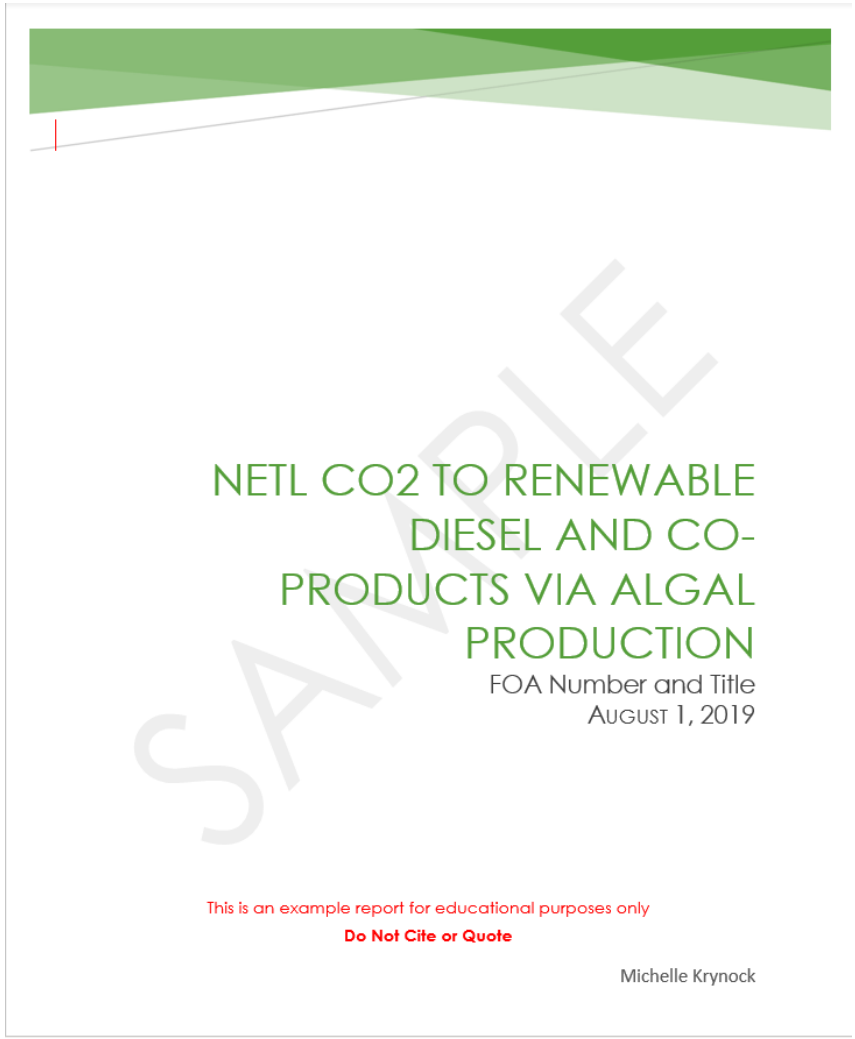
- The DOE FOA program asks third parties to develop LCAs for CO2 utilization projects. These third parties may or may not have any previous LCA experience. The CO2U toolkit can seem complex for beginners, so a completed example LCA will help comprehension and learning by external program funding recipients.

Approach

- Reformat the work from the Algae-to-Biofuels Journal Article into an example report for the CO2U toolkit
- Report will be documented in the CO2 Utilization Toolkit LCA report format as a “gold standard” example using a sub-set (2 to 4) of the algae scenarios modeled.

Outcome

- CO2 Utilization LCA Example Report, Algae to Biofuels: November 2020



Algae to Biofuels LCA Journal Manuscript

Rationale

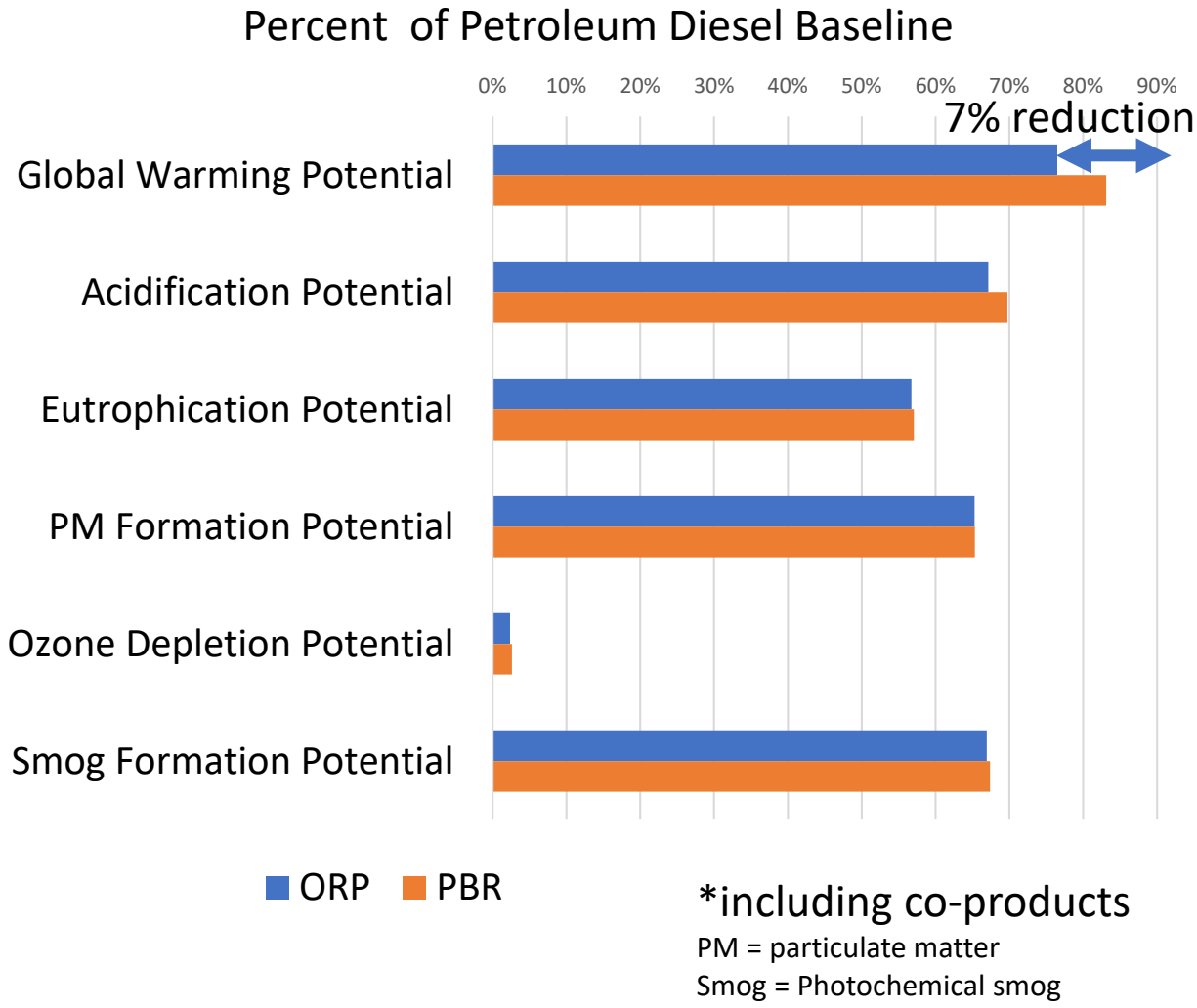
- LCA provides an in-depth framework to compare algae-to-biofuels technology pathways on the basis of more than just global warming potential (GWP)

Approach

- Use NREL farm study and photobioreactor (PBR) studies to create parameterizable algae-to-biofuels model
- Complete full LCA of 72 scenarios to compare:
  - PBR vs ORP
  - CAP vs HTL
  - Flue gas vs captured CO_2 feedstock
  - SCPC vs SubPC vs NGCC vs SOFC vs OxyPC CO_2 source

Outcome

- LCA of Algae-to-Biofuels Journal Article under review



*including co-products

PM = particulate matter

Smog = Photochemical smog

Electrochemical CO_2 Catalyst LCA CO2U Toolkit Report Example

Rationale

- Electrochemical conversion of CO_2 into chemical products provides an alternative value-added pathway to utilize captured CO_2
- Additional CO_2 utilization guidance example of electrochemical catalysis will further help funding recipients in how to report their own project findings

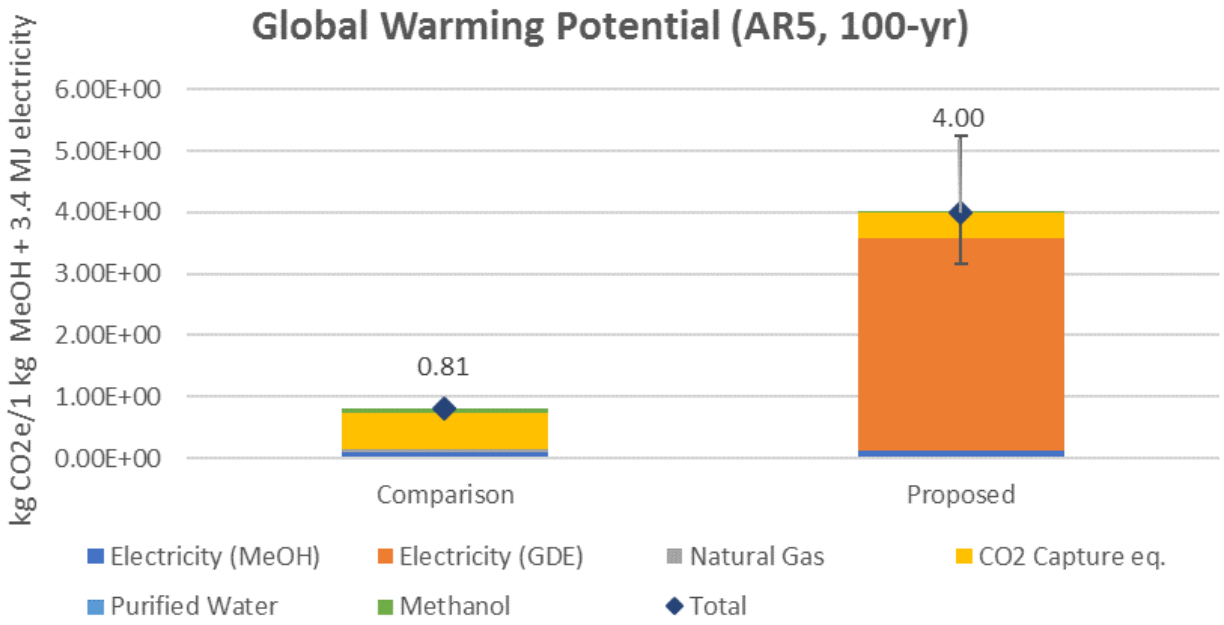
Approach

- Literature review of electrochemical conversion of CO_2 performed and a preliminary LCA performed in partnership with the NETL TEA team for methanol
- The outcome of this effort is an NETL document entitled "NETL CO_2 to Chemical Products via Electrochemical Catalyst Conversion" that includes work from peer-reviewed literature and preliminary NETL LCA & TEA

Outcome

- CO2 Utilization LCA Example Report, CO_2 to Methanol: November 2020

EY20 ECC LCA GWP - Comparison vs. Proposed System



Electrochemical CO_2 Catalyst (ECC) LCA Screening Tool

Rationale

- Electrochemical conversion of CO_2 into chemical products provides an alternative value-added pathway to utilize captured CO_2
- A screening tool will allow RIC researchers to evaluate the environmental impacts of electrochemical CO_2 catalyst systems from cradle-to-gate

Approach

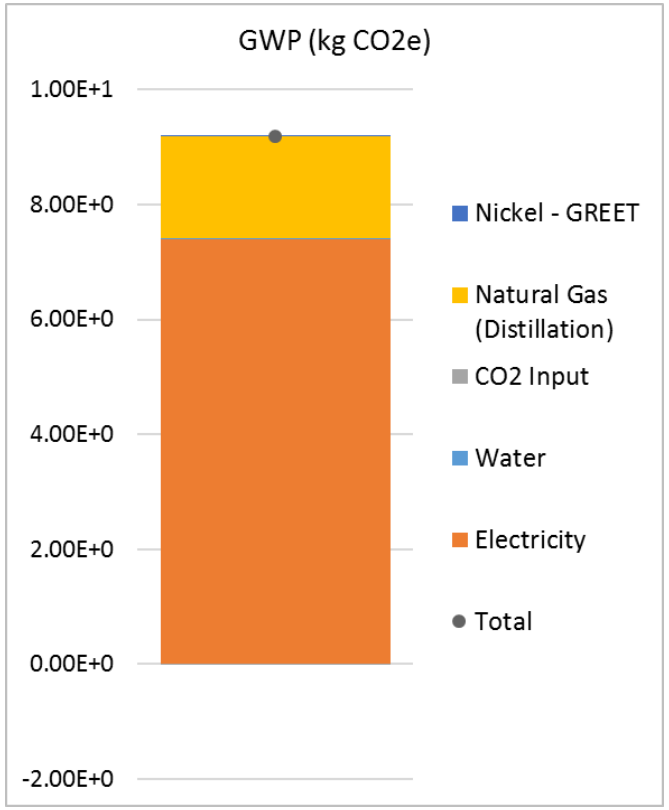
- The tool is designed to inform RIC researchers on how environmental impacts of an electrochemical system changes in response to shifts in various system parameters
- Features of the tool include parameter sensitivity analysis and breakeven analysis to find what percentage of renewable energy is needed for the electrochemical system to match a conventional system in a given impact category for a chosen chemical

Outcome

- ECC LCA Screening Tool, June 2020 - COMPLETED

EY20 ECC GHG Screening Tool Results - Ethanol

Input	Value	Unit
Electricity	70.51	MJ/kg product
Water	1.30	kg/kg product
CO2 input	1.91	kg/kg product
Natural Gas (Distillation)	26.20	MJ/kg product
Nickel – GREET	3.46E-04	kg/kg product



Mineralization LCA

Rationale

- The Program has funded several mineralization projects as part of the external project portfolio.
- This effort will build a knowledgebase of best practices to assess the environmental performance of utilizing CO2 to enhance concrete production for use as building materials and composite railroad ties

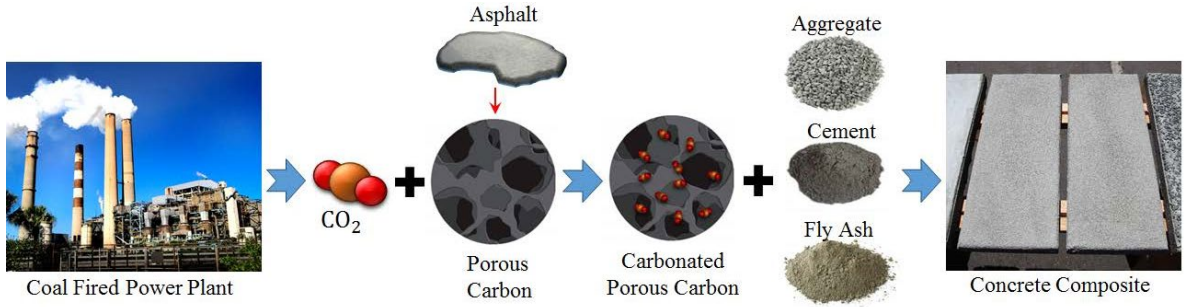
Approach

- This effort will build a knowledgebase of best practices to assess the environmental performance of utilizing CO2 to enhance concrete production for use as building materials and composite railroad ties.
- This work will leverage LCA research under the Capture Program to model Portland cement production with and without carbon capture.

Outcome

- Environmental LCA journal article, submission ready, of enhanced concrete production for use as building materials and composite railroad ties: June 2021

Mineralization Pathway (netl.doe.gov/node/7160)



SMR and Microwave-Assisted Catalysis LCA

SMR – Steam Methane Reforming

Rationale

- Provide research guidance on environmental hot spots and environmental comparison to traditional steam methane reforming to guide internal NETL R&D and FE Progam.
- RIC in-house microwave assisted catalysis operation will be modeled as the alternative catalytic conversion process
- Steam methane reforming environmental performance will be used as the commercial comparative technology.

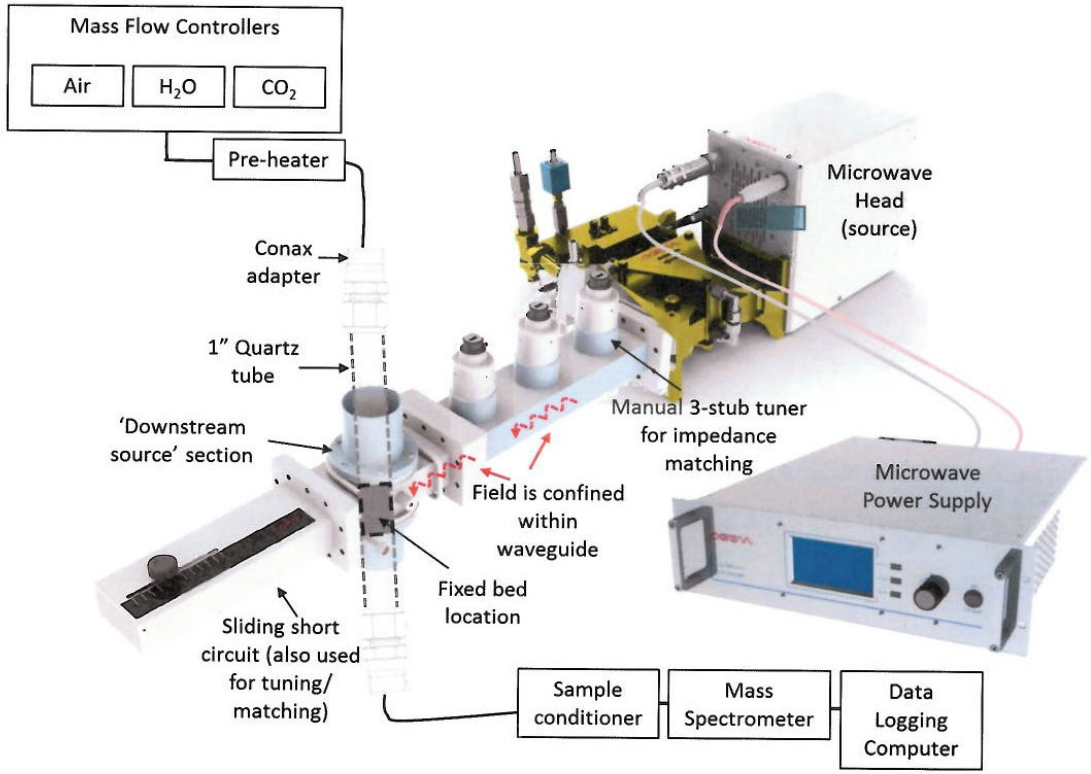
Approach

- LCA will be aligned and coordinated with the TEA comparative assessment of catalytic and non-catalytic conversion of carbon monoxide to syngas.
- Results will be provided for internal use and programmatic support

Outcome

- A completed draft of a peer-reviewed manuscript highlighting results of a TEA and LCA of NETL-RIC's microwave-based CO_2 conversion technology: March 2021

Microwave-Assisted Catalysis (netl.doe.gov/node/8542)



NAS CO_2 Utilization Recommendations

NAS – National Academy of Sciences

Rationale

- This effort will continue the consensus building approach to evaluating disruptive emerging carbon utilization technologies.

Approach

- EY19 efforts were focused on assessing and developing a list of "life cycle assessment benchmarking" inventory data sets to support the Program and reduce the development cost of individual external projects.
- Initial focus in EY20 is anticipated to be on carbon dioxide waste generation sources and hydrogen production profiles.
- EY20 and EY21 efforts will focus on the third NAS recommendation "Assessment of disruptive change.

Outcome

- Memo summarizing the EY20 progress to build consensus in the CO2U analysis community on modeling the environmental life cycle performance of CO2U technologies: March 2021

"Overall, the committee identified priority research needs to address the issues raised in this chapter. Priority areas include the following:

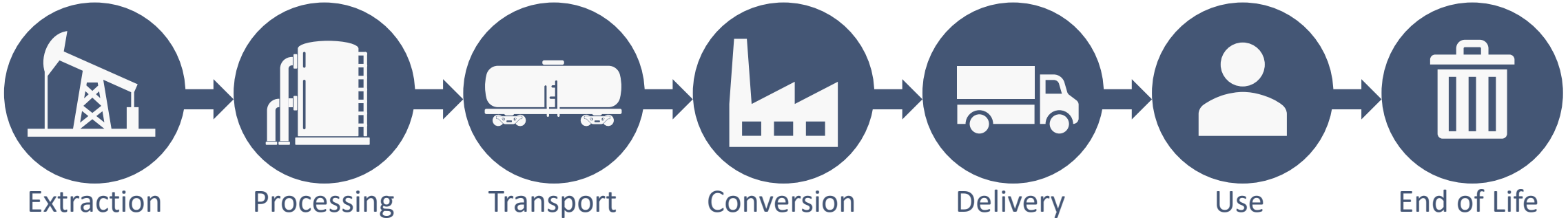
Life-cycle assessment benchmarking
Research is needed to develop benchmark life-cycle assessments of waste gas generation, waste gas cleanup, waste gas transport, electricity inputs, hydrogen inputs, and other enabling technologies to facilitate consistent and transparent assessments of the net greenhouse gas emissions of carbon utilization technologies. These benchmark assessments should include multiple environmental attributes of carbon utilization life cycles, such as greenhouse gas emissions, water use, air emissions, and materials use. This could lead to more consistent assessments of technologies.

Life-cycle assessment of emerging waste carbon utilization technologies
Research is needed to learn from transparent life-cycle assessments of emerging technologies, taking into account a system boundary that includes waste gas capture and cleanup, the conversion process, the use phase, and end-of-life considerations. Although LCA results for emerging technologies will undoubtedly evolve, LCA at this early stage will help guide research toward activities that will heighten energy and environmental benefits.

Assessment of disruptive change
Research is needed to develop life-cycle assessment tools that move beyond assessing marginal changes in existing, static systems and address disruptive changes resulting from large-scale carbon utilization. This will provide tools for assessing disruptive changes necessary for performing consequential LCAs of CCU systems."

Energy Life Cycle Analysis

Cradle-to-grave environmental footprint of energy systems



Mission

Evaluate existing and emerging energy systems to guide R&D and protect the environment for future generations

Vision

A world-class research and analysis team that integrates results which inform and recommend sustainable energy strategy and technology development

LCA Life Cycle Analysis • energy sustainability •

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