Task 2. Carbon Conversion for the Energy Transition

2022

Task sponsored by El Paso Electric Company and Las Cruces Utilities, City of Las Cruces
Task proposed by El Paso Electric Company and Las Cruces Utilities

Background

The earth's average surface temperature is now about 2.12 °F (1.1°C) warmer than it was at the beginning of the industrial revolution in the late 19th century, with most of the warming occurring in the last 40 years[1]. If current trends in carbon dioxide emissions continue, climate model simulations predict that the global temperature will increase by 1.1 to 5.4 °C by the year 2100[2]. Scientists believe there is a 95% chance that global climate change is due to human activity, primarily from the increase in the release of CO_2 and other gases into the atmosphere due to burning fossil fuels.

To avoid the worst climate impacts, predictions indicate that carbon dioxide (CO_2) emissions need to be reduced by half by 2030 and reach net zero (not adding new emissions to the atmosphere) around 2050. Additional greenhouse gases, such as methane, nitrous oxide and fluorinated gases are given a slightly longer target of around 2068 for net-zero emissions, since they are more difficult to phase out.

Industries across the planet have made the commitment to move toward net zero emissions, and companies that are providing power to their communities, such as El Paso Electric Co., are seeking ways to reduce their carbon footprint. The first-phase goal is to reduce CO_2 emissions by introducing renewable energy sources. However, the burning of fossil fuels, such as coal and natural gas is still required because renewable energy sources cannot reliably fulfill current energy demands.

To gain perspective on the amount of CO_2 released in the atmosphere from power plants, the EPA Power Plants Sector reported that from 2011-2017, natural gas units had an average emission rate of 898 pounds CO_2 per megawatt-hour (MWh), while coal units had an emissions rate of 2,180 pounds CO_2 per MWh[3].

There are three options for capturing CO_2 at a power plant and each is dependent on how the plant processes natural gas[4]. Post-combustion techniques capture CO_2 after combustion and absorb it using a liquid solvent or other separation methods; the solvent is later heated to release CO_2 in a high-purity stream. Oxyfuel combustion is a second option that uses oxygen, rather than air, for fuel combustion. The exhaust gas is mostly CO_2 and water vapor and the CO_2 can be easily separated into a high-purity stream. The third carbon capture option involves pre-combustion processes. These are the most complex and are difficult to implement in most existing power plants. Fuel must be converted to a gaseous mixture of hydrogen and CO_2. The hydrogen is separated from the CO_2 and is burned while the CO_2 is compressed, transported, and stored.

<u>Carbon Capture</u>

Most commonly, reductions in CO_2 emissions are attempted through capturing and sequestering carbon so that it does not become part of the atmosphere. Although successful in removing CO_2 from the atmosphere, this approach has several drawbacks: simply capturing and storing CO_2 does not contribute a value-added product, it requires extensive storage facilities to contain the CO_2, and, by removing the CO_2 from easy accessibility, it may have the unintended consequence of too severely reducing the availability of CO_2 needed for healthy plant growth.

<u>CO_2 Conversion</u>

A more sustainable approach is to convert CO_2 to a useful substance. Although this may be more expensive and potentially energy intensive, it will have the dual advantage of both reducing free CO_2 in the atmosphere and creating a useful product. Efforts toward sustainability will be most effective if the energy required for the CO_2 conversion is derived from a renewable source.

The key to converting CO_2 to a useful substance lies in reducing the carbon's oxidation state. Electrochemically, carbon exists in anywhere from a +4 to a -4 oxidation state. Carbon in CO_2 is in the +4 state, which is very stable in the environment. Carbon in an oxidation state anything less than +4 is reactive and therefore useful as a building block for other compounds. As an example, carbon black, which has an oxidation state of zero, is a precursor for many other products and thus would be a possible conversion target for CO_2. The ultimate goal for this task, therefore, is to convert the +4 carbon in CO_2 to a reduced oxidation state. After accomplishing that, it can be used to produce a variety of useful products. See Alves, et al.[5] and Darensbourg[6] for to begin gaining insights into CO_2 conversion.

Problem statement

Your team will research, evaluate, and design a way of reducing CO_2 emissions from a natural gas power plant that emits 900 pounds CO_2 per megawatt-hour (MWh) by converting CO_2 to a useful product.

Your bench-scale solution will assume that the CO_2 has already been captured as a 99.9% pure CO_2 gas from the power plant. Your scale-up solution will address how your team's product will be produced at a rate comparable to the power plant emissions rate.

Design requirements

Your proposed design should provide specific details and outcomes as follows:

- Design a means of converting as much of the CO_2 emissions as possible from a natural gas power plant that emits 900 pounds CO_2 per megawatt-hour (MWh).
- Your technical report should include a complete process flow diagram showing all inputs and output and the stoichiometry of the balanced reaction.
- Discuss the cost versus benefit of your technology.
- Reflect on alternative designs and situations in which those designs might be more viable than your chosen design, recalling that an optimal solution depends on outside factors–the "best" design may be dependent on region and may change over time.
- Present a Techno-economic Analysis (a.k.a. Techno-economic Assessment, or TEA) to construct a full-scale CO_2 emission-reduction process to treat 900 pounds CO_2 per megawatt-hour (MWh) using your selected technology.

  The TEA will include your estimate of capital costs (CAPEX) and operational costs (OPEX) for a full-scale solution and appropriate graphical representation of your cost data.
  - Capital expenses typically include, but are not limited to, equipment, pipes, pumps, etc. Do not include costs of buildings and appurtenances to the treatment process.
  - Operating expenses (OPEX) should be calculated as cost per ton of CO_2 removed, including, but not limited to, materials needed, including consumables (chemicals, sacrificial components, etc.) In addition to other operating costs that your team identifies, include these operating costs: staff labor rate of $70/hour; solids disposal costs ($50/ton); energy requirements using an electricity rate of $0.09/kWh.
  - Visualization tools: Sensitivity analyses, etc. (Recommended: NMSU TEA Short Course).
- Address any intangible benefits of the selected treatment process.
- Address safety aspects of handling the CO_2, waste streams, and any final products.
  Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

WERC Task 2. Carbon Conversion for the Energy Transition

Bench Scale Demonstration

Bench-scale demonstrations will serve to illustrate the design considerations listed above.

The bench-scale treatment should demonstrate a means of converting CO_2 to a useful product, with capacity to scale up to production rates at a natural gas power plant that emits 900 pounds CO_2 per megawatt-hour (MWh).

Each team will be provided with gas cylinder(s) of CO_2 with 99.9% purity to work with during the bench-scale demonstration. Contact WERC by 2/07/2022 to request the number of pounds of CO_2 your process will need. If your solution requires higher purity than provided, contact WERC.

Teams will be expected to bring their own regulators and piping needed to attach to the cylinders and to run their bench-scale demonstration.

After CO_2 conversion, your team will submit the finished product for analysis.

Analytical Testing Techniques

By February 7, 2022, as a part of the preliminary report, teams will submit a plan for how the product will be analyzed in the team's lab and by WERC to prove the amount of CO_2 conversion that has occurred.

In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation, but shall not be substitutes for the bench-scale demonstration.

Preliminary Report Requirements

The preliminary report describes your proposed approach. It is due February 7, 2022. The report is intended to help your team get early feedback about your plans. This will help you prepare a robust technical report and bench-scale demonstration. Your team will receive guidance from the task designers within one week of submission.

Include:

1. A complete process flow diagram showing all inputs, outputs, and the stoichiometry of the balanced reaction;
2. The quantity of CO_2 needed for your bench-scale demonstration;
3. The analytical methods needed to prove CO_2 conversion has occurred.

Technical Report Requirements

The technical report should demonstrate your team's insight into the full scope of the issue and include all aspects of the problem, including evaluation of alternative technologies and your proposed solution. The report will be evaluated for quality of writing, logic, organization, clarity, reason, and coherence. Standards for publications in technical journals apply.

In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, Evaluation Criteria, and 2022 Team Manual.

WERC Task 2. Carbon Conversion for the Energy Transition

Evaluation Criteria

Each team is advised to read the 2022 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in this manual, your response to this Task consists of four parts: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation, and a poster that conveys the essence of your work in a concise fashion using a mix of text and graphics. General criteria used by the judges in evaluation of these four components are described in the Team Manual.

Judges' evaluation of your entry will include consideration of the following points specific to this task.

- Potential for real-life implementation, including
  - energy required,
  - cost per pound of CO_2 converted,
  - rate of conversion, and
  - expected reliability and maintainability.
  - cost/benefit of your solution as compared with those of other teams.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- The quality of the product produced, based on bench-scale analysis.
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs).

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/.

FAQs/Dates/Deadlines

- Mid-December, 2021 EH&S Short Course (watch website for dates and registration info).
- Mid-January, 2022: EH&S Short Course; TEA Short Course
- 1 February, 2022: Experimental Safety Plan (ESP) due
- 7 February, 2022: Preliminary Report due
- 7 March, 2022: Send a draft of the technical report to your auditors (approx. date–see Team Manual)
- 28 March, 2022: Technical Report due
- Weekly: Teams are expected to check the FAQs online weekly for any updates in the task requirements. (wercdesigncontest.nmsu.edu)

Short Courses

WERC is offering two short courses. The optional courses are designed to prepare teams to more effectively complete their technical report and earn digital badges to add to their professional development portfolio. The courses are also available to the general public to gain professional development. Fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration.
Courses offered:

- Health and Environmental Safety (EH & S) (Mid-December and Mid-January)
- Techno-economic Assessment and Analysis (TEA) (Mid-January)

References

[1] NASA Global Climate Change: How Do We Know? https://climate.nasa.gov/evidence/ (Accessed 7/20/21)

[2] Herring, David. Climate Change: Global Temperature Projections. NOAA Climate.gov, March 6, 2012. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature-projections (Accessed 7/20/21)

[3] Greenhouse Gas Reporting Program Industrial Profile: Power Plants Sector. September, 2019. EPA Power Plants Sector. https://www.epa.gov/sites/production/files/2020-12/documents/power_plants_2017_industrial_profile_updated_2020.pdf

[4] Global CCS (Carbon Capture and Storage). Fact Sheet: Capturing CO_2 (https://www.globalccsinstitute.com/wp-content/uploads/2018/12/Global-CCS-Institute-Fact-Sheet_Capturing-CO2.pdf) (Accessed 7/20/21)

[5] Alves, M., et al. 2017. Organocatalyzed coupling of carbon dioxide with epoxides for the synthesis of cyclic carbonates: catalyst design and mechanistic studies. Catal. Sci. Technol., 2017, Volume 7, 2651-2684 (https://pubs.rsc.org/en/content/articlelanding/2017/cy/c7cy00438a#!divAbstract)

[6] Darensbourg, Donald J. 2007. Making Plastics from Carbon Dioxide: Salen Metal Complexes as Catalysts for the Production of Polycarbonates from Epoxides and CO_2. (https://pubs.acs.org/doi/10.1021/cr068363q)

Awards

Each year, the WERC Environmental Design Contest and its sponsors award more than $25,000 in cash prizes. Successful completion of every stage of the design project qualifies each team for the following awards.

1. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Freeport-McMoRan Innovation in Sustainability Award ($2500)
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award ($500)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. (Minimum: $500, according to funding).

Award amounts listed are minimum amounts and may increase with available funding.
Detailed criteria for each award:
https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/