LCA Tools Available at NETL

Solutions for Today | Options for Tomorrow

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2022 Annual Carbon Management Review Meeting
Aug. 15–19, 2022
Agenda

- Power Plant Flexible Model (PPFM).
- Electricity LCI / Grid Mix Explorer.
- Upstream dashboard.
- Upcoming updated saline storage LCA Model.
- DOE Direct Air Capture (DAC) guidance.
- DAC guidance/toolkit for development this year.
- Biomass profiles added to the CO2U guidance database.
- Bioenergy with Carbon Capture and Storage (BECCS) screening tool.
- Upcoming work.
About Power Plant Flexible Model

- Spreadsheet model for
  - Pulverized coal.
  - Circulating fluidized bed power plants.
  - Cooling types.
  - Emissions control.

- Reduced-order model allowing change of coal characteristics and configuration of pollution control equipment.

- Emissions limited to those available in NETL techno-economic assessments.
  - \( \text{CO}_2 \), \( \text{SO}_2 \), Hg, \( \text{NO}_x \), particulate matter (PM).

https://netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=785
PPFM Uses
Co-fire biomass vs. CO₂ emissions and net plant power

• PPFM intended as a tool to quickly assess changes in equipment or feedstock.

• Example: Can relatively quickly assess impacts of co-firing varying amounts of biomass while maintaining sulfur emissions.
  • 97.6% to 98% removal rate for SO₂ (Wet Flue Gas Desulfurization) at 0.327 kg SO₂/MWh net.
Moving Beyond GHGs, CAPs, and Water Use

- **Past focus:** LCAs have been performed on greenhouse gases (GHGs), criteria air pollutants (CAPs), and water use.

- **Broadening analysis:** Expanding inventory across all NETL models to support broader analyses; Impact analysis - EPA TRACI 2.1.

- **Motivation:** As an input to other models (i.e., CO$_2$-enhanced oil recovery, CO$_2$-EOR); PPFM emissions inventory needed to be expanded.
The Electricity Baseline
A complete inventory of U.S. power consumption in 2016

• What is the electricity baseline?
  • Open-source life-cycle inventory data.
  • Formatted for the Federal LCA Commons.
  • Based on publicly accessible data sources.
  • Designed for automated data processing.

• How is the baseline used?
  • Historical, current, and anticipated environmental footprint of U.S. electricity.
The Electricity Baseline
A complete inventory of U.S. power consumption in 2016

Where can the baseline be found?

LCA Practitioners
✓ JSON-LD and ILCD exports
✓ Choose selected region and export full product system to openLCA for connection with rest of system
lcacommons.gov/lca-collaboration

Energy and Env Analysts
✓ Create customized technology mix and inventory
✓ Explore inventory and TRACI impacts for selected region
✓ Add advanced technologies
netl.doe.gov/LCA

Researchers & Developers
✓ Complete transparency into inventory dev
✓ Flexibility to adjust model parameters
✓ Integration into other frameworks
github.com/USEPA/ElectricityLCI
Model Framework Summary

Goals
• High-quality data for technology evaluation.
• Assessment of regional impacts/benefits.
• Consistent national baseline.

Objectives
• Complete inventory for U.S. power consumption in 2016.
• Open-source data.
• Transparent modeling approach.
• Coordination with EPA and DOE.
**Purpose:** To provide cradle-to-gate inventories for common power plant feedstocks with Monte Carlo functionality.

**Raw material acquisition and transport customizability:** Limited parameterization is provided to customize the feedstocks (e.g., coal mine methane, biomass yield rate, and transport distances) and energy conversion facility.
Upstream Dashboard

Results

- Emissions inventory table and GHG equivalents.
- Graph of GHG equivalents.
- Monte Carlo simulation.
- Criteria Air Pollutants and water use.
Upcoming Saline Storage LCA Model

• Gate-to-grave boundary, 100-yr period.
  • Site preparation.
  • Well construction.
  • CO₂ storage operations.
  • Site monitoring.
  • Brine management.
  • Well closure.
  • Land use.

• Covers all 228 identified U.S. saline aquifer formations.
  • Vary power supply types and water management strategies.

• With and without land reversion options added.

• Updated Excel and openLCA models.

• TRACI 2.1, IPCC AR5 impact method.
Upcoming Saline Storage LCA Model

Global Warming Potential (GWP), 20-yr impacts

Parameters:

• Fuel use rates.
• Combustion emissions factors.
• Non-combustion use factors.
• Energy use.
• Saline aquifer operations.
Upcoming Saline Storage LCA Model

Findings

• The injectability of a formation has a large influence on the magnitude of impacts.

• Scenarios.
  • Grid electricity has higher overall impacts on freshwater consumption and PM.
  • Diesel has higher overall impacts on acidification, 100-year GWP, ozone depletion, and smog.
  • Natural gas and diesel show high relative impacts on eutrophication and 20-year GWP.

• Natural gas for site operations and brine management scenarios shows the best environmental results.

• CO₂ and brine leakage are significant drivers of impact uncertainty.
Direct Air Capture (DAC)

Objective: Expand number of DAC system configurations – current industry configurations

- Manuscript in internal review.
- Updates/additional profiles (Infinitree, Skytree, Climeworks).

Life Cycle GHG Intensity (AR5, GWP 100-yr) (kg CO2e/kg CO2 Captured at DAC Facility)

Solvent: -0.39
Sorbent: -0.48

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Sorbent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary *</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Compressor (CO₂ Product)</td>
<td>0.09</td>
</tr>
<tr>
<td>Air Separation Unit</td>
<td>0.05</td>
</tr>
<tr>
<td>Slaker</td>
<td>0.02</td>
</tr>
<tr>
<td>Calciner (Natural Gas)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pellet Reactor</td>
<td>0.02</td>
</tr>
<tr>
<td>Air Contactor</td>
<td>0.05</td>
</tr>
<tr>
<td>Natural Gas (Upstream)</td>
<td>0.02</td>
</tr>
<tr>
<td>Calcium Carbonate (Upstream)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Potassium Hydroxide (Upstream)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Water</td>
<td>-0.65</td>
</tr>
<tr>
<td>Mass of Atmospheric CO₂ **</td>
<td>-0.71</td>
</tr>
<tr>
<td>Total</td>
<td>-0.39</td>
</tr>
</tbody>
</table>

* Auxiliary loads consist of circulating water pumps, cooling tower fans, CO₂ capture and removal auxiliaries (for natural gas boiler), CO₂ compression (for natural gas boiler), feedwater pumps, ground water pumps, selective catalytic reduction (attached to the natural gas boiler for flue gas treatment), and miscellaneous plant balance.

** The Mass of Atmospheric CO₂ is less than 1 kg because a portion of the kg of CO₂ product is captured from natural gas combustion onsite and not removed from the atmosphere.
Provides negative emissions under all modeled grid intensities.

- DAC-to-Aquifer Storage

Graph showing Net System GHG Intensity (ARS, GWP 100) vs. Grid GHG Intensity (kg CO₂e/MWh) for various energy sources and technologies:

- 100% Renewables
- NGCC w/ CCS
- SCPC w/ CCS
- NGCC w/o CCS
- US Grid Mix
- US Fleet Average Coal

Sorbents and Solvents:

- DAC EOR
- Algae Biofuels
- Saline Aquifer
- DAC (Cradle-to-gate)
DAC-to-EOR provides a scenario for carbon reducing technologies but not negative emissions technologies.
• Foster consistency of LCA of Direct Air Capture with Storage (DACS) systems to enable more complete understanding of potential impacts of carbon dioxide removal.

• Assess sensitivity and uncertainty in results to provide confidence in the study outcomes and potential risk envelopes for technology performance.

• Understand potential tradeoffs and co-benefits of DACS systems.

• Leverage best practices from the LCA research and practitioner community.

https://www.energy.gov/fecm/best-practices-LCA-DACS
BECCS Profiles for CO2U Database

- New grid mix and biomass roll-ups are added to CO2U database.
  - 2020 U.S. grid mix.
  - 2050 U.S. grid mix.
  - Fossil power w/ CCS.
  - Renewables.
  - Saline Aquifer Transport and Storage.
  - Forest residue.
  - Southern yellow pine.
  - Hybrid poplar.
  - Switchgrass.
  - Corn stover.

- Metadata is included.
  - Inventory sources, date of representativeness, disclaimer.

- CO2U Toolkit change log has been updated.
  - Worked with web development team and posted changes.
BECCS Profiles for CO2U Database

GWP, 100-yr impacts – Grid

- Current U.S. Grid Mix: 0.14 kg CO2e/MJ electricity
- 2050 U.S. Grid Mix: 0.12 kg CO2e/MJ electricity
- Fossil Power with CCS: 0.06 kg CO2e/MJ electricity
- Renewables: 0.01 kg CO2e/MJ electricity
BECCS Profiles for CO2U Database

GWP, 100-yr impacts – Biomass

<table>
<thead>
<tr>
<th>Biomass Type</th>
<th>kg CO2e/kg biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest residue, raw</td>
<td>-0.99</td>
</tr>
<tr>
<td>Forest residue, chipped</td>
<td>-0.93</td>
</tr>
<tr>
<td>Forest residue, torrefied</td>
<td>-1.18</td>
</tr>
<tr>
<td>Hybrid poplar, raw</td>
<td>-0.79</td>
</tr>
<tr>
<td>Hybrid poplar, chipped</td>
<td>-0.74</td>
</tr>
<tr>
<td>Hybrid poplar, torrefied</td>
<td>-0.83</td>
</tr>
<tr>
<td>Southern pine, raw</td>
<td>-0.83</td>
</tr>
<tr>
<td>Southern pine, chipped</td>
<td>-0.78</td>
</tr>
<tr>
<td>Southern pine, torrefied</td>
<td>-0.90</td>
</tr>
<tr>
<td>Corn stover, raw</td>
<td>-1.04</td>
</tr>
<tr>
<td>Switchgrass, raw</td>
<td>-0.79</td>
</tr>
</tbody>
</table>
# BECCS Screening Tool

## Global Warming Potential (100 yr) - TRACI 2.1 (NETL) (kg CO2e per MWh)

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>BECCS Scenario 1</th>
<th>BECCS Scenario 2</th>
<th>Result 1</th>
<th>Result 2</th>
<th>kg CO2e per MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential (100 yr) - TRACI 2.1 (NETL)</td>
<td></td>
<td></td>
<td>7.9E+02</td>
<td>-1.2E+03</td>
<td></td>
</tr>
</tbody>
</table>

### Inputs

<table>
<thead>
<tr>
<th>Biomass Type</th>
<th>BECCS Scenario 1</th>
<th>BECCS Scenario 2</th>
<th>Units</th>
<th>Scaling Factor</th>
<th>Acceptable Range</th>
<th>Default Values</th>
<th>Difference 1</th>
<th>Difference 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid Poplar</td>
<td>Hybrid Poplar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbituminous</td>
<td>Subbituminous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulpitization and Drying</td>
<td>Torrefaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture Content</td>
<td>19%</td>
<td>5%</td>
<td>km</td>
<td>0.000039743</td>
<td>0.0000767461</td>
<td>9963.501484</td>
<td>0.0020-0.02</td>
<td>0.0002906</td>
</tr>
</tbody>
</table>

| Biomass Mass % | 20 | yes | Saline Aquifer | 0.73x1.44 | 1 | 35 | -15 | 65 |
| Carbon Capture | no | yes | EOR | | | | | |
| Disposition | | | | | | | | |
Upcoming Work – BECCS Retrofit

Existing Sub-Critical Pulverized Coal Power Plants

• **Background:** A 2012 NETL study showed that retrofit of an existing plant to co-fire biomass (10%) increased the cost of electricity by 31%.⁴

• **Updating the model:** To provide an option for conversion of up to 100% biomass plus the addition of CCS.

  • Systems smaller than the 650 MW greenfield plant will be explored as existing plants may be smaller, biomass has a lower heating value than coal, and parasitic loads from the capture system will lower net output.

  • Drax Power Station in the United Kingdom has converted four of its six coal units to operate on biomass.⁵

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Upcoming Work – Circulating Fluidized Bed

Ongoing Analysis of 100 MW CFB with Hybrid Poplar and Forest Residue

- Circulating fluidized bed (CFB) technologies are favored for combustion and gasification processes.
  - Globally, CFBs make up 18% of biomass co-firing.¹
  - CFBs fueled by 100% biomass exist but are not prevalent.
- Key characteristics of CFBs include:
  - Load flexibility and high heat transfer rates.
  - Fuel flexibility, ideal for handling high moisture and ash content of low-rank coals and biomass.²
  - Uniform temperature throughout gasifier (850–950°C).³
  - Low NOx emissions due to low temperatures.

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2. (NETL website), [https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/fluidizedbed](https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/fluidizedbed)
3. (Vakkilainen, 2017), [http://dx.doi.org/10.1016/B978-0-12-804389-9.00010-1](http://dx.doi.org/10.1016/B978-0-12-804389-9.00010-1)
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