Overview of Energy Life Cycle Analysis at NETL

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MISSION
Advancing energy options to fuel our economy, strengthen our security, and improve our environment
Overview of Energy Life Cycle Analysis at NETL
(The Agenda)

1. LCA Definitions & Methods

2. NETL LCA Tools
   - Power Life Cycle Analysis Tool (LCAT)
   - Calculating Uncertainty in Biomass Emissions (CUBE)
   - Upstream Life Cycle Emissions Dashboard

3. Life Cycle Analysis Studies
   - Natural Gas Extraction, Delivery and Electricity Production
   - Alternative Aviation Fuels
   - Nuclear Power
   - Wind Power with Gas Backup
   - Cofiring Coal and Biomass for Power

4. Forthcoming Studies
   1. Geothermal, Solar Thermal, Conventional Hydro
   2. Dynamic Coal-Biomass Power with Emissions Control Options
Purpose of Energy Systems LCA Program

1. **Produce Energy System LCAs**
   - Inform and defend the Technology Programs
   - Baseline different energy system technologies
   - Understand technology strengths and weaknesses when viewed from a life cycle perspective
   - Identify opportunities for R&D innovation (through depth and transparency of analysis)

2. **Improve LCA methods**
   - Expand inventory
   - Characterize uncertainty and variability
   - Build flexible and dynamic models
   - Keep data collection and modeling current with state-of-the-art LCA

3. **Enhance interpretation and comparability of inventory results without losing depth and transparency**
   - Stochastic simulation of life cycle inventory
   - Tools to explore uncertainty and variability

NETL has a library of over 300 custom Unit Processes, and dozens of models to characterize energy systems and address questions from stakeholders.
LCA: Definitions, Boundaries, Metrics

• Compilation and evaluation of inputs, outputs, and potential environmental impacts of a product or service throughout its life cycle, from raw material acquisition to final use and disposal

• The ability to compare different technologies depends on functional unit (denominator); e.g., for energy studies:
  – 1 MWh of electricity delivered to end user
  – 1 MJ of fuel combusted

Converted to Carbon Dioxide equivalents using 2007 IPCC Global Warming Potential (GWP)

<table>
<thead>
<tr>
<th>GHG</th>
<th>20-year</th>
<th>100-year (Default)</th>
<th>500-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CH₄</td>
<td>72</td>
<td>25</td>
<td>7.6</td>
</tr>
<tr>
<td>N₂O</td>
<td>289</td>
<td>298</td>
<td>153</td>
</tr>
<tr>
<td>SF₆</td>
<td>16,300</td>
<td>22,800</td>
<td>32,600</td>
</tr>
</tbody>
</table>

• Greenhouse Gases
  – CO₂, CH₄, N₂O, SF₆

• Criteria Air Pollutants
  – NOₓ, SOₓ, CO, PM10, Pb

• Air Emissions Species of Interest
  – Hg, NH₃, radionuclides

• Solid Waste
• Raw Materials
  – Energy Return on Investment (EROI)

• Water Use
  – Withdrawn water, consumption, water returned to source
  – Water Quality

• Land Use
  – Direct & indirect, Acres transformed, greenhouse gases

• Life Cycle Cost
  – Cost of Electricity (COE), Total Overnight Cost (TOC)
The unit process describes how to scale collected environmental data to the reference flow.
Life Cycle Process Flow

Unit processes are connected via their inputs and outputs and scaled to the functional unit.
Power Life Cycle Analysis Tool (LCAT)

- Interactive comparison tool (PowerSim) which gives users access to key financial and environmental results and parameters from detailed power LCAs
- Ongoing partnership between NETL and Sandia National Laboratory

**Included Technologies:**
- IGCC
- IGCC/ccs
- EXPC
- EXPC/ccs
- EXPC/ccs + RP
- SCPC
- SCPC/ccs
- NGCC
- NGCC/ccs
- Onshore Wind
- Gen III+ Nuclear

Sliders allow user to control assumptions and see results update in real time
Calculating Uncertainty in Biomass Emissions (CUBE)

GHG Emissions are highly dependent on underlying assumptions such as land type and yield; NETL study values for biomass GHG emissions are generally conservative.

- Allows users to explore the uncertainty and variability of greenhouse gas emissions from various biomass types in an Analytica-based tool
- Collaboration between NETL and RAND
Upstream Dashboard: Input Sheet

The purpose of the Upstream Dashboard is to develop a fast and easy tool to determine the environmental profile of various energy feedstocks. The model provides NETL's preferred variables as the default values, but allows the user to input information for their specific scenarios. The model includes 16 different feedstocks, 11 modes of transportation, and 26 transportation fuel conversion combinations. The dashboard can calculate the inventory of extracted and processed feedstocks, delivered feedstocks, or converted feedstocks.

To use the model, the user can access the instructions on how to enable the Macro and how to use the tool. The dashboard allows users to easily add upstream life cycle environmental information to their process of interest such as a coal plant or refinery. Users have the ability to adjust parameter values, choose which portions of life cycles to include, and the dashboard is implemented in Excel.

**Inputs**

- Please enable Macro to use this tool: How to enable?

**Legend for Dashboard**

- Blue are headings describing the fields
- Orange are user-adjusted input fields

**Populates values for feedstocks & transportation modes based on user selection**

**Converts results based on user selected output units & GWP time horizon factors**
The Upstream Dashboard

Chart shows total life cycle CO₂e based on calculated results

Table results auto-update based on parameter values above
Boundaries for Natural Gas Life Cycle

Cradle-to-grave
- 1 MWh of electricity delivered to the end customer
- Compared 12 different fuel/baseload plant combinations
  (6 natural gas, 6 coal)

Cradle-to-gate
- 1 MMBtu of domestic fuel delivered to large end user
- Compared 13 fuel sources/mixes
  (10 natural gas, 3 coal)
Onshore vs. Shale GHG Emission Profiles

### Onshore Gas
(34.2 lbs CO₂e/MMBtu)

- Cradle-to-Gate
- Pipeline Fugitive Emissions
- Pipeline Compressors
- Pipeline Construction
- Compressors
- Valve Fugitive Emissions
- Other Point Source Emissions
- Other Fugitive Emissions
- Dehydration
- Acid Gas Removal
- Workovers
- Liquid Unloading
- Well Completion
- Workover

### Shale Gas
(32.5 lbs CO₂e/MMBtu)

- Cradle-to-Gate
- Pipeline Fugitive Emissions
- Pipeline Compressors
- Pipeline Construction
- Compressors
- Valve Fugitive Emissions
- Other Point Source Emissions
- Other Fugitive Emissions
- Dehydration
- Acid Gas Removal
- Workovers
- Liquid Unloading
- Well Completion

13% of Natural Gas Extracted from the Earth is Consumed for Fuel Use, Flared, or Emitted to the Atmosphere (point source or fugitive)

Of this, 70% is Used to Power Equipment

Carbon dioxide equivalents calculated using 2007 IPCC 100-year GWP
Onshore vs. Shale GHG Emission Profiles

**Sensitivity of Model Result to Changes in Parameter Values**

Percentages above are relative to a unit change in parameter value; all parameters are changed by the same amount, allowing comparison of the magnitude of change to the result across all parameters.

**Example:** A 10% increase in Onshore Production Rate from 66 Mcf/day to 73 Mcf/day would result in a 4.5% (10% of 45%) decrease in cradle-to-gate emissions, from 34.2 to 32.6 lbs CO$_2$e/MMBtu.

Carbon dioxide equivalents calculated using 2007 IPCC 100-year GWP
Comparison of Power Generation Technology Life Cycle GHG Footprints

- Upstream GHG emissions are greater for natural gas than coal; full life cycle emissions are larger for coal than natural gas.

- Source of natural gas or coal has little effect on full life cycle emissions for GHGs.
High Level Process Flow for Alternative Jet Fuel

**Raw Material Acquisition (RMA)**
- Montana Rosebud Coal Mining
- Southern Pine Biomass Production
- Land Use Change

**Raw Material Transport (RMT)**
- Rail Transport of Coal
- Truck Transport of Biomass
- Torrefaction of Biomass
- Truck Transport of Torrefied Biomass

**Energy Conversion (EC)**
- CBTL Facility (F-T Jet Fuel Production)
  - 6 Scenarios:
    - 0% Biomass
    - 10% Green Biomass
    - 20% Green Biomass
    - 10% Torrefied Biomass
    - 20% Torrefied Biomass
    - 10% Green Biomass, Separate Gasifiers
- Pipeline Transport of CO₂
- Carbon Management: Enhanced Oil Recovery

**Product Transport (PT)**
- Pipeline Transport of F-T Jet Fuel
- Pipeline Transport of Blended Jet Fuel
- Blending 50% F-T Jet Fuel 50% Conv. Jet Fuel (by vol)
- Petroleum Refinery (2005 US Average)
- Crude Oil Transport (2005 US Average)
- Crude Oil Extraction (2005 US Average)

**End Use (EU)**
- Aircraft Operation (Blended Jet Fuel Combustion)

**Existing & Emerging GHG Emissions Regulations**
- Section 526, Energy Independence and Security Act (EISA) of 2007:
  - *Life Cycle GHG emissions for alternative fuels contracted by a Federal agency other than for research and testing must be less than or equal to life cycle emissions from conventional fuel from conventional sources*
- Other existing and emerging federal/state regulations: US EPA Renewable Fuels Standard; CA Low Carbon Fuel Standard, etc.
Underlying Data Based on Detailed Mass and Energy Balance of an F-T Process
Overall CBTL Jet Results, with 90% Capture and CO₂-EOR

Method for allocating impacts of co-products drive GHG results

Greenhouse Gas Emissions (g CO₂e/MJ)

Disp. Energy Comb.
0% Biomass

Disp. Energy Comb.
10% Biomass, Chipped

Disp. Energy Comb.
10% Biomass, Chipped,
Separate Gasifiers

Disp. Energy Comb.
10% Biomass, Torrefied

Disp. Energy Comb.
20% Biomass, Chipped

Disp. Energy Comb.
20% Biomass, Torrefied

Conventional Jet Fuel Baseline, 87.4 g CO₂e/MJ

Crude Oil Equiv. Required Selling Price

$/bbl
0% Biomass

$/bbl
10% Biomass, Chipped

$/bbl
20% Biomass, Chipped

$/bbl
10% Biomass, Torrefied

$/bbl
20% Biomass, Torrefied

$/bbl
10% Biomass, Chipped,
Underlying Detail Allows for Detailed Results with Sensitivity and Uncertainty

- Coal Mining, Surface
- Biomass Direct Land Use Change
- Biomass Transport to Torrefaction Facility
- Transport of Chipped or Torrefied Biomass to CBTL Plant
- CBTL Plant Operations (includes CO₂ Compression)
- CO₂-EOR Operation and CO₂ Storage
- Blending of F-T and Conv. Jet (includes Conv. Jet Fuel Profile)
- Airplane Operation (Fuel Use)
- Total Greenhouse Gas Emissions

Greenhouse Gas Emissions (g CO₂e / MJ)

Coefficient Value

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>CBTL Plant Operations Scenario</td>
<td>0.82</td>
</tr>
<tr>
<td>Rail Distance</td>
<td>0.47</td>
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<tr>
<td>Indirect Land Use</td>
<td>0.21</td>
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<tr>
<td>Coal Mine Methane</td>
<td>0.19</td>
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<tr>
<td>Biomass Yield</td>
<td>-0.17</td>
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<tr>
<td>CO₂ Pipe Distance</td>
<td>0.07</td>
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<tr>
<td>Blended Jet Pipe Length</td>
<td>0.03</td>
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<tr>
<td>Blended Jet Alt Transport Scenario</td>
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</tr>
<tr>
<td>Chip Type</td>
<td>0.01</td>
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<tr>
<td>CO₂ Pipe Loss Rate</td>
<td>0.01</td>
</tr>
<tr>
<td>Biomass Truck Distance (Farm to CBTL or Farm to Torrefaction)</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Life Cycle Boundaries for Nuclear Power

Study focuses on life cycle comparison of existing reactor technology currently installed in US with the Gen III+ reactor designs currently under review at the NRC.
Life Cycle GHG Profile for Existing and Gen III+ Nuclear Power in the United States

Diffusion enrichment is leading contributor to GHG emissions in nuclear fuel cycle because of electricity requirements of process.

Switching from gaseous diffusion to centrifuge enrichment in US can lead to 60-70% reduction in GHG emissions from fuel cycle depending on reactor type.

Carbon dioxide equivalents calculated using 2007 IPCC 100-year GWP.
# Nuclear Power Life Cycle Cost Results

![Bar Chart](chart.png)

Uncertainty bars represent range of LCOE for a given financial scenario based on range of LCC plant operations parameters (capital costs, plant capacity, fuel costs, operating & maintenance costs, and decommissioning costs).

## Financial Parameter Input

<table>
<thead>
<tr>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
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</thead>
<tbody>
<tr>
<td>Min LCOE</td>
<td>LCOE</td>
<td>Max LCOE</td>
</tr>
<tr>
<td>Debt Term (Years)</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Interest Rate on Loan (%)</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Depreciation Period (Years)</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Expected Rate of Return (%)</td>
<td>7%</td>
<td>15%</td>
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</tbody>
</table>

## Plant Operations Input

<table>
<thead>
<tr>
<th>Plant Operations Input</th>
<th>Existing</th>
<th>Gen III+</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Min LCOE</td>
<td>Best Est. LCOE</td>
</tr>
<tr>
<td>Plant Capacity (MWe)</td>
<td>1,500</td>
<td>1,000</td>
</tr>
<tr>
<td>Unit Cost of Fuel ($/MMBtu)</td>
<td>0.29</td>
<td>0.67</td>
</tr>
<tr>
<td>Overnight Costs ($/kWe)</td>
<td>3,500</td>
<td>4,500</td>
</tr>
<tr>
<td>Fixed O&amp;M ($/kWe/yr)</td>
<td>55</td>
<td>64</td>
</tr>
<tr>
<td>Variable O&amp;M ($/kWh)</td>
<td>0.0047</td>
<td>0.0075</td>
</tr>
<tr>
<td>Decommissioning Costs (Million $)</td>
<td>350</td>
<td>600</td>
</tr>
</tbody>
</table>
Life Cycle Process Flow for Retrofit Cofire Power

Raw Material Acquisition
- Equipment Manufacturing
- Land Preparation
- Diesel Production
- Hybrid Poplar Cultivation
- Hybrid Poplar Harvesting
- Diesel Production
- Underground Mine Construction
- Illinois No. 6 Coal Mining

Raw Material Transport
- Equipment Manufacturing
- Truck Transport
- Diesel Production
- Rail Transport

Energy Conversion Facility
- Biomass Grinding
- Natural Gas
- Biomass Drying
- Biomass Torrefaction
- Subcritical Cofire Power Plant
- Switchyard and Trunkline Operation
- Power Plant Retrofit Construction
- Power Plant De-commissioning
- Electricity
- Natural Gas

Product Transport
- Transmission & Distribution

End Use
- End Use (Assume 100% Efficient)
GHG Drilldown: 20% Hybrid Poplar Cofire

<table>
<thead>
<tr>
<th>Category</th>
<th>Greenhouse Gas Emissions (g CO₂e/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission &amp; Distribution</td>
<td>0.06</td>
</tr>
<tr>
<td>Boiler Operations (Combustion)</td>
<td>0.00</td>
</tr>
<tr>
<td>Retrofit Construction</td>
<td>0.00</td>
</tr>
<tr>
<td>Biomass</td>
<td>0.05</td>
</tr>
<tr>
<td>Cultivation</td>
<td>0.00</td>
</tr>
<tr>
<td>Coal Mining</td>
<td>0.00</td>
</tr>
<tr>
<td>Illinois No. 6 Underground Mining</td>
<td>24.09</td>
</tr>
<tr>
<td>Locomotive Manufacturing</td>
<td>0.05</td>
</tr>
<tr>
<td>Coal Transport</td>
<td>0.05</td>
</tr>
<tr>
<td>Truck &amp; Trailer Manufacturing</td>
<td>0.05</td>
</tr>
<tr>
<td>Diesel Production</td>
<td>0.06</td>
</tr>
<tr>
<td>Biomass Transport</td>
<td>0.09</td>
</tr>
<tr>
<td>Biomass Grinding</td>
<td>4.59</td>
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<tr>
<td>Natural Gas Extraction (Drying)</td>
<td>1.89</td>
</tr>
<tr>
<td>Biomass Drying</td>
<td>7.80</td>
</tr>
<tr>
<td>Retrofit Construction</td>
<td>0.00</td>
</tr>
<tr>
<td>Boiler Operations (Combustion)</td>
<td>283.45</td>
</tr>
<tr>
<td>Transmission &amp; Distribution</td>
<td>0.91</td>
</tr>
<tr>
<td>Total</td>
<td>302.23</td>
</tr>
</tbody>
</table>

- After CO₂ emissions from 33% efficient PC boiler, largest contribution to GHGs is CH₄ from Illinois No. 6 underground mining.
- Sequestered CO₂ from cultivation is largely offset by land use change and methane from coal mining.
Life Cycle GHG Emissions of Cofiring Options

- Percent changes for cofiring cases are relative to no capture, coal only case within each technology group.
- Percent changes for CTL/CBTL cases are relative to petroleum baseline (92.3 g CO₂e/MJ).
- Due to data limitations, the ECF results for CTL/CBTL include RMA and RMT.

<table>
<thead>
<tr>
<th>Cofire Existing Plant Options</th>
<th>Retire &amp; Replace w/ New Powerplant Options</th>
<th>Cogasification Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Capture</td>
<td>CCS</td>
<td>CCUS</td>
</tr>
<tr>
<td>Coal only</td>
<td>Forest Residue 10% by Energy</td>
<td>Hybrid Poplar 10% by Energy</td>
</tr>
</tbody>
</table>

PC, 550 MW, No Capture, 33% Eff.
PC, 385 MW, CO₂ Capture, 22% Eff.
SCPC, 550 MW, No Capture, 39% Eff.
SCPC, 550 MW, CO₂ Capture, 27% Eff.
CFB, 550 MW, No Capture, 43% Eff.
CFB, 550 MW, CO₂ Capture, 34% Eff.
CTL, 109 MW Export Power
CTL, 397 MW Export Power
CBTL, FT Diesel 49 MW Export Power
CBTL, FT Diesel 319 MW Export Power
### Cofire Plant Options: COE (Power) and Required Selling Price (Fuel)

<table>
<thead>
<tr>
<th>Cofire Existing Plant Options</th>
<th>Retire &amp; Replace w/ New Powerplant Options</th>
<th>Cogasification Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal only</td>
<td>Coal only</td>
<td>Coal Only</td>
</tr>
<tr>
<td>Forest Residue 10% by Energy</td>
<td>Forest Residue 13% by Energy</td>
<td>Coal Only</td>
</tr>
<tr>
<td>Hybrid Poplar 10% by Energy</td>
<td>Hybrid Poplar 13% by Energy</td>
<td>Coal Only</td>
</tr>
<tr>
<td>No Capture</td>
<td>No Capture</td>
<td>Coal Only</td>
</tr>
<tr>
<td>No Capture</td>
<td>No Capture</td>
<td>Coal Only</td>
</tr>
<tr>
<td>No Capture</td>
<td>No Capture</td>
<td>Coal Only</td>
</tr>
</tbody>
</table>

**100% coal, no-capture CTL RSP (not shown) is $2.53/gallon ($72.7/MWh)**

Cost of Electricity or Required Selling Price ($/MWh)
Cost of Improving the Existing Coal Fleet

Abatement costs and percent changes relative to the U.S. fleet baseload coal plant, at $29/MWh and 312 g CO₂e/MJ
How does cofiring compare to other power technology options?

Greenhouse Gas Emissions (g CO₂e/MJ)
- Fleet Gas
- Fleet Coal
- IGCC
- IGCC/gas
- SCPC
- SCPC/gas
- EXPC
- NGCC
- NGCC/gas
- GTSC
- Geothermal
- Solar thermal
- Nuclear (Gen II+)
- Onshore Wind
- Offshore Wind
- Hydro (Uprate)

Cost of Electricity ($/MWh)
- Capital
- Fuel
- Fixed O&M
- Variable O&M
- Retro. PC, 10% FR
- CFB, 30% FR

NATIONAL ENERGY TECHNOLOGY LABORATORY
Life Cycle GHG Emissions versus Cost of Electricity

- Greenhouse Gas Emissions (g CO₂e/MJ)
- Cost of Electricity ($/MWh)

- Fleet Coal
- Fleet Gas
- IGCC
- CFB
- GTSC
- EXPC
- PC
- NGCC
- Wind (Onshore)
- Wind (Offshore)
- Geothermal
- Nuclear (Gen III+)
- Hydro (Uprate)

- Base case power (no biomass or CCS/CCUS)
- Coal-biomass cofiring cases
- CCS/CCUS cases
Life Cycle GHG Emissions versus Cost of Electricity

- Base case power (no biomass or CCS/CCUS)
- Coal-biomass cofiring cases
- CCS/CCUS cases
Life Cycle GHG Emissions versus Cost of Electricity

Cost of Electricity ($/MWh)

Greenhouse Gas Emissions (g CO₂e/MJ)

- Base case power (no biomass or CCS/CCUS)
- Coal-biomass cofiring cases
- CCS/CCUS cases

Cases:
- PC: 100% Coal CCS
- PC: 100% Coal CCUS
- PC: 10% FR CCS
- PC: 10% FR CCUS
- PC: 10% HP CCS
- PC: 10% HP CCUS
- SCPC: 13% FR CCS
- CFB: 100% Coal CCS
- CFB: 100% Coal CCUS
- CFB: 30% HP CCS
- CFB: 30% HP CCUS
- CFB: 30% FR CCS
- CFB: 30% FR CCUS

Life Cycle GHG Emissions versus Cost of Electricity

Base case power (no biomass or CCS/CCUS)
Coal-biomass cofiring cases
CCS/CCUS cases
Life Cycle GHG Emissions versus Cost of Electricity

- Base case power (no biomass or CCS/CCUS)
- Coal-biomass cofiring cases
- CCS/CCUS cases
Modeling Structure of Wind Farm

- Onshore Conventional Wind Farm Construction
- Offshore Conventional Wind Farm Construction
- Offshore Wind Farm Construction
- Onshore Wind Farm Operation
- Trunkline Construction
- Offshore Wind Farm Operation
- Switchyard

Key:
- Process or Material Flow
- Waste or Recycling flow

Upstream stages for backup power are accounted for in LC Stage #1 and LC Stage #2 of model.

Landfill
Aluminum Recycling
Steel Recycling
Copper Recycling

Domestic Turbine Component Manufacturing
Foreign Turbine Component Manufacturing

33
GHG Emissions for Wind with Backup Power

- If availability of wind power is considered, environmental burdens of wind power must also account for backup power
  - Nominal onshore wind farm capacity factor is 30%

- Two backup power sources were modeled:
  - Average U.S. power mix
  - Load-following GTSC plant

Negative GHG emissions represent displacement caused by recycling of manufacturing scrap and materials recovered from end-of-life management of turbines.
Upcoming Work:
Dynamic Coal-Biomass Power with Emissions Control Options
Building a Dynamic Power Plant with Linear Programming

**LC Stage #1**
Raw Material Acquisition
- Lignite
- Sub-Bit (PRB)
- SRWC (Poplar)
- Switchgrass

**LC Stage #2**
Raw Material Transport
- Train
- Truck

**LC Stage #3**
Energy Conversion Facility
- CaCO$_3$
- NH$_3$
- Cooling Tech.
- SCPC or SC CFB Plant Const.
- Biomass Drying
- Biomass Grinding
- Biomass Torre.
- Ultra-SCPC (Oxy Fired)
- Ultra-SCPC (Air Fired)
- SC CFB (Air Fired)
- SC CFB (Oxy Fired)
- CO$_2$ EOR
- Sequestration

No CO$_2$ Capture
- CO$_2$ Capture

**Building a Dynamic Power Plant with Linear Programming**

**National Energy Technology Laboratory**
Ultra-Supercritical PC and Circulating Fluidized Bed (CFB) Cases

<table>
<thead>
<tr>
<th>Coal type</th>
<th>Lignite</th>
<th>Sub-bit</th>
</tr>
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<tbody>
<tr>
<td>Biomass %</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Biomass Type</td>
<td>Switchgrass</td>
<td>SRWC (Poplar)</td>
</tr>
<tr>
<td>Torrefaction</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Plant Type</td>
<td>Ultra SC</td>
<td>CFB</td>
</tr>
<tr>
<td>Combustion</td>
<td>Oxy</td>
<td>Air</td>
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<tr>
<td>Cooling</td>
<td>Dry</td>
<td>Wet-dry</td>
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<tr>
<td>CO₂ Capture</td>
<td>90</td>
<td>95</td>
</tr>
<tr>
<td>CCUS</td>
<td>EOR</td>
<td>Saline</td>
</tr>
</tbody>
</table>

- Potential for hundreds of possible permutations, not including options for emissions control technology such as advanced scrubbers and filters
Recently Published and Forthcoming Work

www.netl.doe.gov/energy-analysis

- LCA of Natural Gas Extraction, Delivery and Electricity Production (1/12)
- LC GHG Analysis of Advanced Jet Propulsion Fuels: Fischer-Tropsch Based SPK-1 Case Study (12/11)
- Calculating Uncertainty in Biomass Emissions: Model and Documentation (11/11)
- LC GHG Inventory of Natural Gas Extraction, Delivery and Electricity Production (12/11)
- LCA: Ethanol from Biomass (8/11)
- LC GHG Analysis of Natural Gas Extraction & Delivery in the U.S. (5/11)
- Comparative Assessment of CO₂ Sequestration through EOR and Saline Aquifer (1/11)
- LCA: Power Studies Compilation (1/2011)
- LCA: Existing Pulverized Coal Power Plant (12/10)
- LCA: Integrated Gasification Combined Cycle Power Plant (12/10)
- LCA: Natural Gas Combined Cycle Power Plant (12/10)
- LCA: Supercritical Pulverized Coal Power Plant (12/10)
- Alternative Liquid Fuels Simulation Model (3/10)
- Balancing Climate Change, Energy Security, and Economic Sustainability: A LC Comparison of Diesel Fuel from Crude Oil and Domestic Coal and Biomass Resources (4/09)
- Framework and Guidance for Estimating GHG Footprints of Aviation Fuels (4/09)
- Consideration of Crude Oil Source in Evaluating Transportation Fuel GHG Emissions (3/09)
- Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass (1/09)
- Development of Baseline Data and Analysis of LC GHG Emissions of Petroleum-Based Fuels (11/08)

Forthcoming

- Cofiring Coal & Biomass in the U.S.
- Technology Assessments (Comb. LCA, LCC & Resource Projection)
  - Nuclear
  - Cofiring
  - Wind
  - Natural Gas
  - Hydro
  - Geothermal
  - Solar Thermal
- Updated Baseline LCAs
  - NGCC
  - IGCC
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