Life-Cycle Greenhouse Gas Emissions of Corn Ethanol with the GREET Model

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GREET includes more than 100 fuel production pathways from various energy feedstock sources

**Feedstock**

**Petroleum**
- Conventional
- Oil Sands

**Coal**

**Natural Gas**
- North American
- Non-North American
- Shale gas

**Renewable Natural Gas**
- Landfill Gas
- Animal Waste
- Waste water treatment
- Coke Oven Gas
- Petroleum Coke
- Nuclear Energy

**Fuel**

**Petroleum**
- Gasoline
- Diesel
- Jet Fuel
- Liquefied Petroleum Gas
- Naphtha
- Residual Oil

**Coal**

**Natural Gas**
- Compressed Natural Gas
- Liquefied Natural Gas
- Liquefied Petroleum Gas
- Methanol
- Dimethyl Ether
- Hydrogen

**Renewable Natural Gas**
- Fischer-Tropsch Diesel
- Fischer-Tropsch Jet
- Methanol
- Dimethyl Ether
- Fischer-Tropsch Diesel
- Fischer-Tropsch Jet
- Fischer-Tropsch Naphtha
- Hydrogen

**Cellulosic Biomass**
- Switchgrass
- Willow/Poplar
- Crop Residues
- Forest Residues
- Miscanthus

**Feedstock**

**Corn**

**Sugarcane**

**Soybeans**
- Palm
- Rapeseed
- Jatropha
- Camelina
- Algae

**Cellulosic Biomass**

**Residual Oil**

**Coal**

**Natural Gas**

**Biodiesel**

**Renewable Diesel**

**Renewable Gasoline**

**Hydroprocessed Renewable Jet**

**Electricity**

**Renewable Natural Gas**

**Landfill Gas**

**Animal Waste**

**Waste water treatment**

**Coke Oven Gas**

**Petroleum Coke**

**Nuclear Energy**

**Renewables**

**Ethanol**

**Butanol**

**Biodiesel**

**Renewable Diesel**

**Renewable Gasoline**

**Hydroprocessed Renewable Jet**
Life-Cycle Analysis System Boundary: Corn to Ethanol
Trend of 35 Studies in the Past 35 Years: Energy Use in U.S. Corn Ethanol Plants Has Decreased Significantly

Historical Ethanol Plant Energy Use: Btu/Gallon

Dry Mill
Wet Mill
Average
Fertilizer Use in U.S. Corn Farming Has Reduced Significantly in the Past 40 Years
GHG Emission Sources for Corn Ethanol

Corn Ethanol: 60 g CO2e/MJ
(DGS Credit: -13)

From Wang et al. (2012), *Environ. Research Letters*
Carbon Calculator for Land-Use Change from Biofuels Production (CCLUB) in GREET

Amount and type of land use change (from GTAP etc.)

Soil carbon change (from CENTURY etc.)

Original Land Types
- Forest (including YF-Shrub), Grassland, Cropland-Pastureland

Land Management Options
- Conventional Till
- Reduced Till
- No Till

Feedstock Options
- Corn Grain
- Corn Grain and Stover
- Switchgrass
- Miscanthus
Estimates of LUC GHG emissions for corn-to-ethanol pathway

Critical factors for LUC GHG emissions:
- Economic models are used for global simulations
- Crop yields: exist cropland vs. new cropland; global yield differences and potentials
- Available land types: cropland, grassland, forestland, wetland, etc.
- Price elasticities
  - Crop yield response to price
  - Food demand response to price
- Animal feed modeling
- Soil organic carbon changes from land conversions
LCA GHG emissions of gasoline and bioethanol pathways

Biofuels achieve positive fossil energy balance

Biofuel energy balance = energy output - fossil energy input
Biofuel energy ratio = energy output/fossil energy input

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Sugar-cane</th>
<th>Corn Stover</th>
<th>Switch-grass</th>
<th>Miscanthus</th>
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<tbody>
<tr>
<td>Energy balance:</td>
<td></td>
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<tr>
<td>MJ/liter(^a)</td>
<td>10.1</td>
<td>16.4</td>
<td>20.4</td>
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<tr>
<td>Energy ratio</td>
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<td>4.32</td>
<td>4.77</td>
<td>5.44</td>
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</table>

\(^a\) A liter of ethanol contains 21.3 MJ of energy (lower heating value). Values close to or greater than 21.3 MJ are caused by co-produced electricity.
New trends of ethanol production

Corn oil extraction for biodiesel production

Co-production of corn grain ethanol and stover ethanol
Life-Cycle Analysis system boundary: petroleum to gasoline
Argonne has been addressing petroleum fuel pathways

- Petroleum refining to gasoline, diesel, jet fuel, and others with LP modeling to address refinery efficiency and emissions
  - Two journal articles document findings

- Oil sands production
  - Energy use and GHG emissions of recovery activities (with Stanford U.)
  - Land disturbance GHG emissions (with UC Davis)

- Other crude types being analyzed
  - Light crude recovery in Bakken and Eagle Ford Plays
Petroleum product energy efficiencies based on simulations of 43 US refineries

Gasoline greenhouse gas emissions simulated in GREET: grams/MJ
25 oil sands projects were analyzed for their emissions and land disturbance

<table>
<thead>
<tr>
<th></th>
<th>Mining + SCO (58%)</th>
<th>Mining + Bitumen (4%)</th>
<th>In-Situ + SCO (6%)</th>
<th>In-Situ + Bitumen (32%)</th>
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<td><strong>GREET2013</strong></td>
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<td>4.1</td>
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<td>Land Disturbance</td>
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<td></td>
<td>NE</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>31.7</strong></td>
<td><strong>35.0</strong></td>
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<td><strong>GREET2014 Update</strong></td>
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<td><strong>31.0</strong></td>
<td><strong>51.0</strong></td>
<td><strong>43.2</strong></td>
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- NE – not estimated
- Refining GHG emissions for GREET2014 are estimated by assuming API gravity of 32 for SCO and 21 for bitumen
- Combustion GHG emissions are 73.3 g/MJ for gasoline and 75.0 g/MJ for diesel

Based on Englander and Brandt (2014) and Yeh et al. (2014)
Conclusions

- Technology improvements in ethanol production and corn farming have helped reduce corn ethanol GHG emissions.
- Land use change modeling for corn ethanol has improved in the past 6 years with reduced modeled LUC GHG emissions, but uncertainties and confusions remain and debate continues.
- Transition to cellulosic biofuels will result in greater GHG reductions.
Additional Information:

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