February 12, 2025

Introducing Biofuels in R&D GREET®

2:00-3:00 p.m. CT

Instructors

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Argonne National Laboratory Subject Matter Experts

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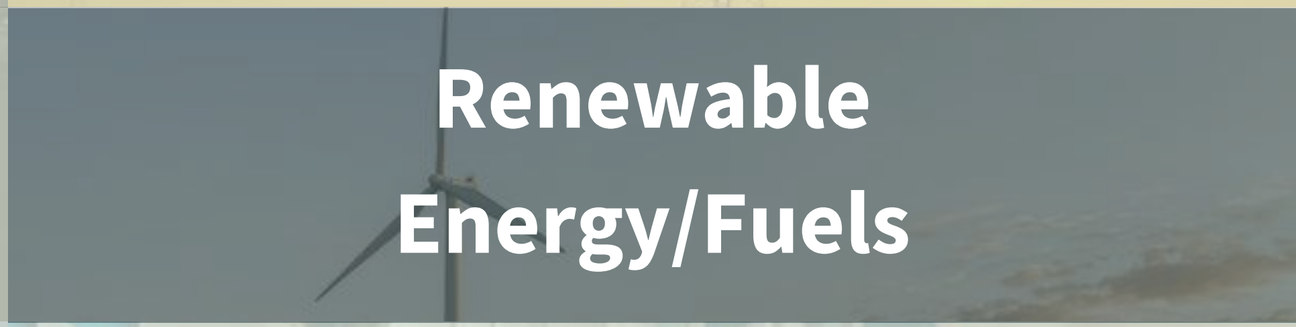
What Does R&D GREET Encompass?

R&D GREET covers many groups of energy systems

Petroleum

Electric Systems

Natural Gas



Renewable Energy/Fuels

Hydrogen

Electro-fuels

And More

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R&D GREET and biofuels

Corn
Soybean
Sorghum
Rapeseeds
Sugarcane
Dedicated Energy Crops
Crop Residues
Forest Residues
Municipal Solid Waste (MSW)
Animal Wastes
Algae
and More

Ethanol
Biodiesel
Renewable diesel
Renewable gasoline
Sustainable aviation fuel
Renewable natural gas
and more

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Common biofuel pathways in R&D GREET

Biofuels are renewable fuels derived from biomass

Common Biofuels

Ethanol
Biodiesel
Renewable diesel
Renewable natural gas

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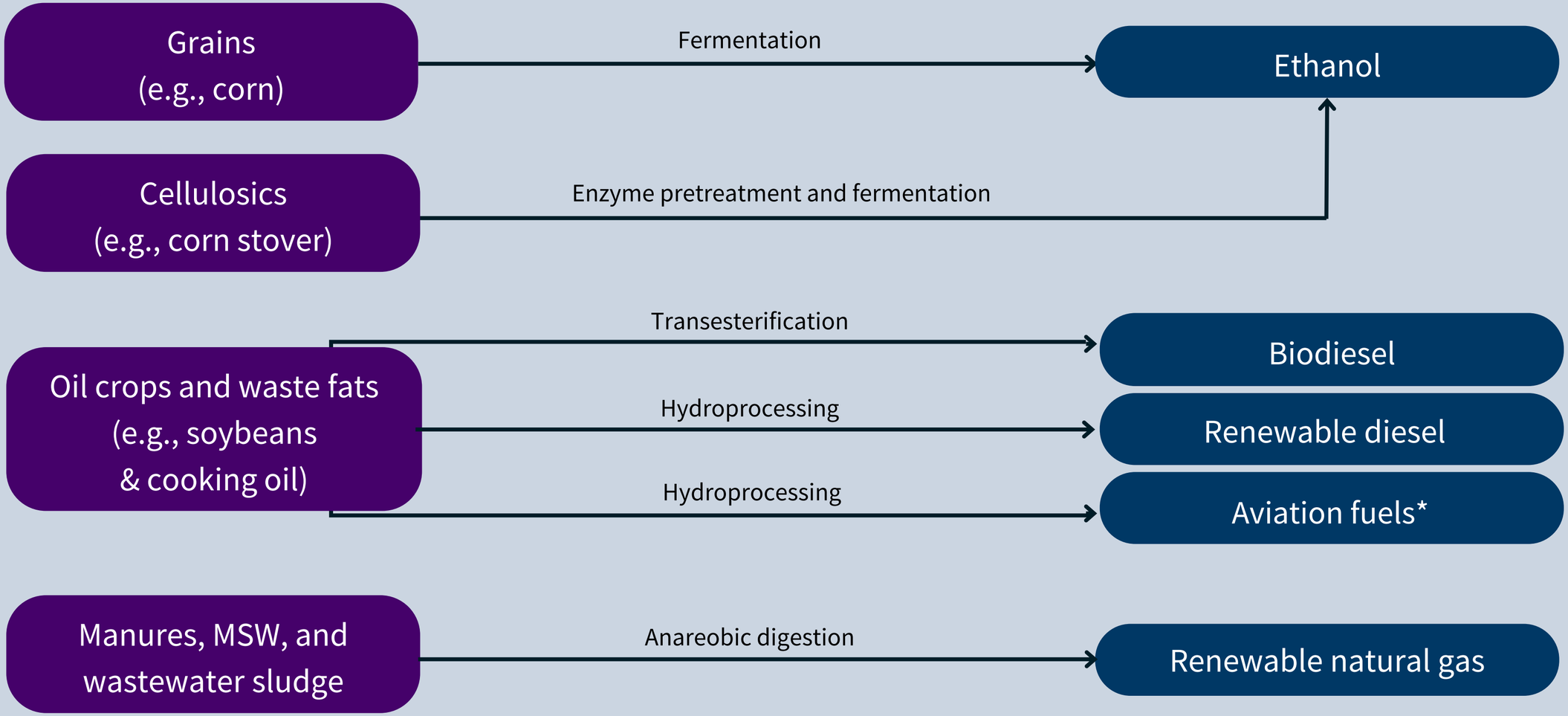
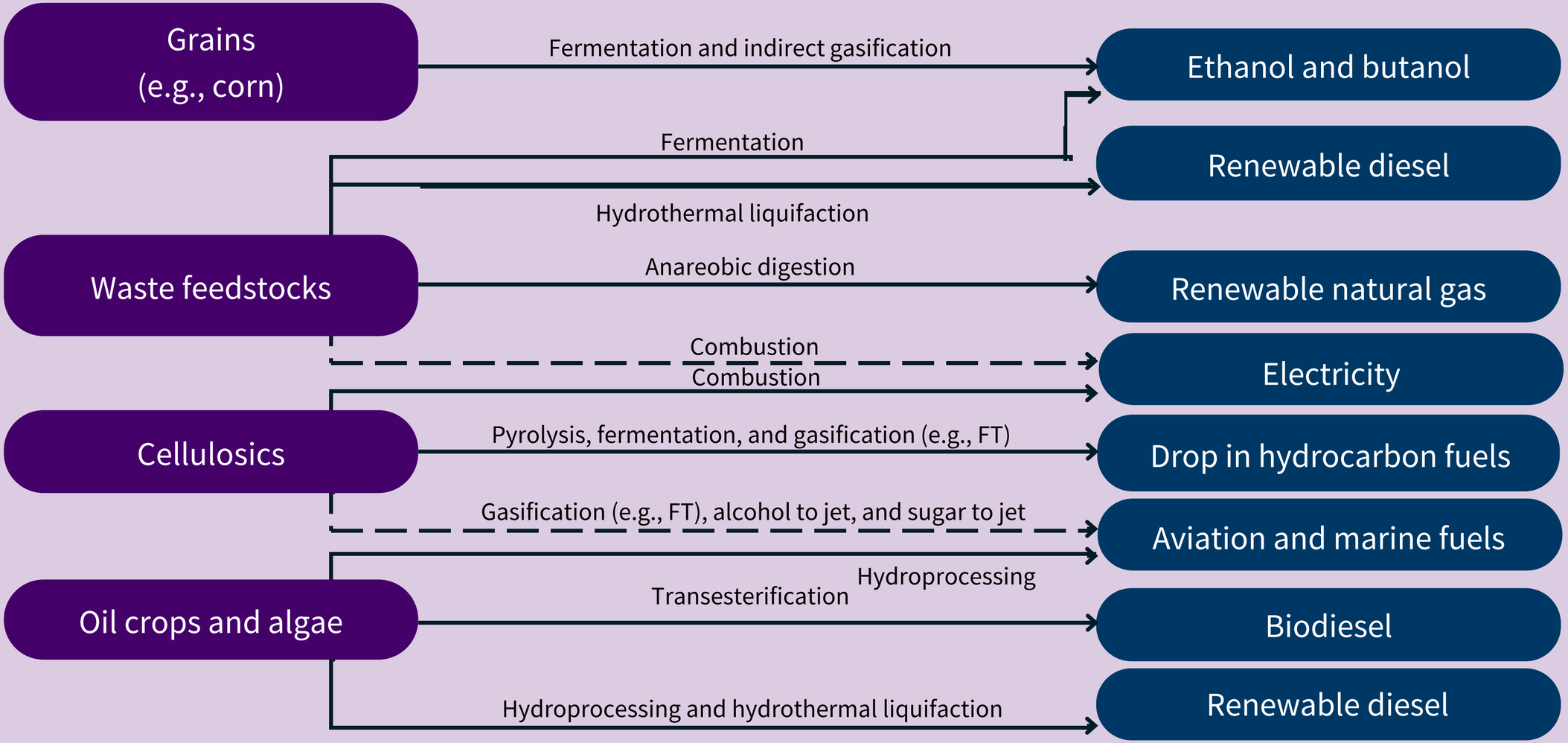
Common biofuel pathways in R&D GREET



*covered in a separate session
(Sustainable Aviation Fuel in R&D GREET)

More biofuels pathways in R&D GREET



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LCA of Biofuels in R&D GREET

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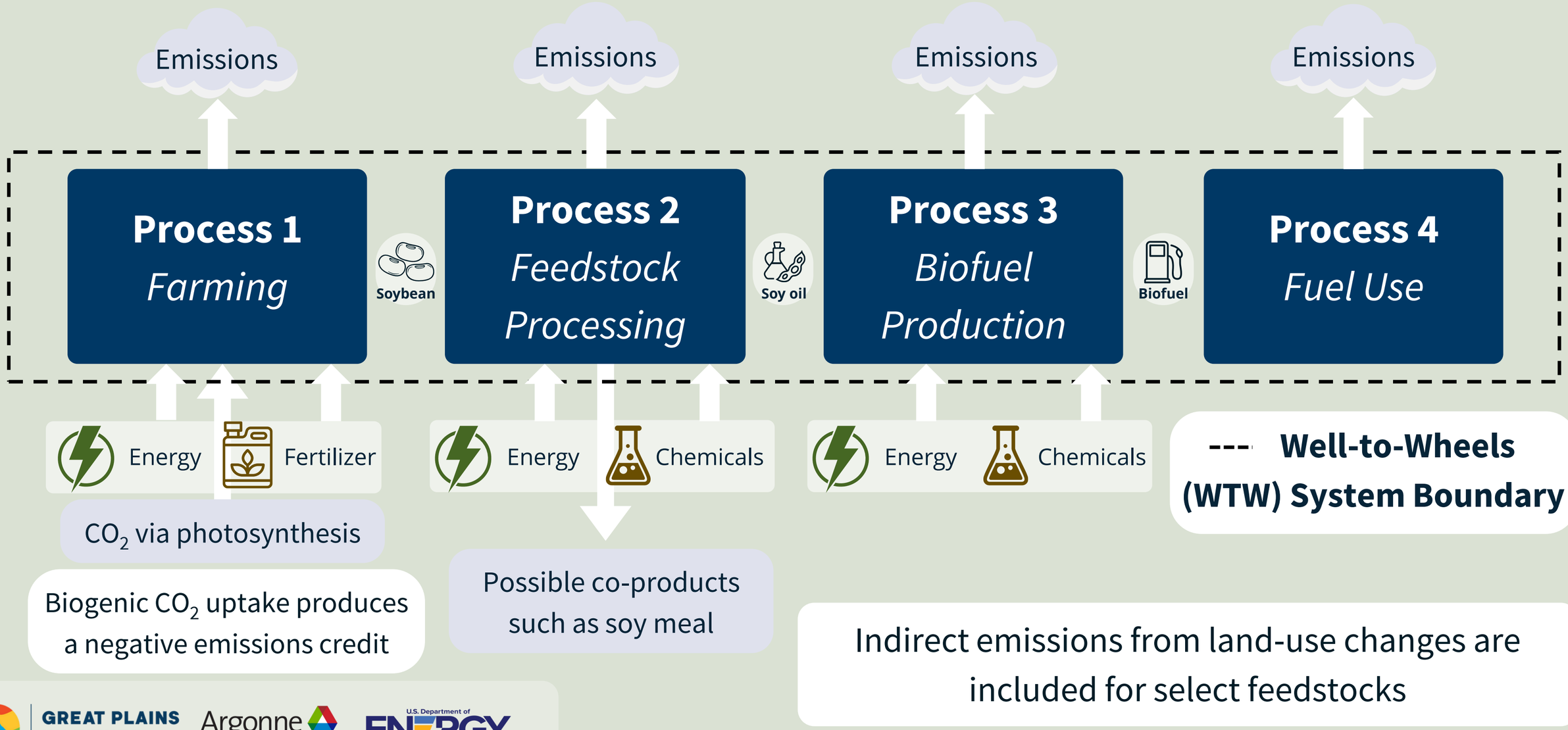
Life cycle of biofuels in R&D GREET: *example from soybeans*



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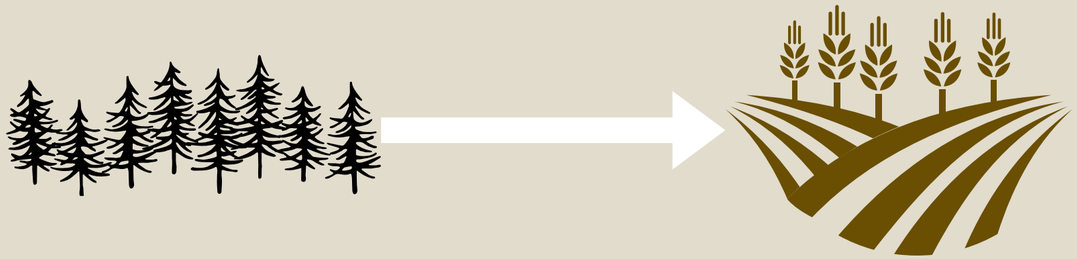
Land use change and induced land use change

Land Use Change (LUC)

GHG impact of converting land from its original use for specific agricultural production



Induced Land Use Change (ILUC)

GHG impact of land use that is induced by the economic demand for feedstocks and agricultural products as a result of domestic production changes

- Ravindranath et al., 2009, Biofuels: Environmental Consequences & Implications of Changing Land Use

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GREET land use change (iLUC) modeling

Biofuels Scenarios

Ethanol from corn, grain, stover, miscanthus, switchgrass, and soy biodiesel

GTAP-Bio CGE Model

Estimates land conversion over time associated with forest, grassland, cropland pasture, and feedstock land due to a prescribed "shock" volume of ethanol introduced to the market

Soil Carbon and N_2O Emission Factors Related to LUC

- Domestic emission factors (EFs) are modeled using U.S. county-level soil simulations
- International EFs include Winrock EFs (default), Agro-Economic Zone EFs, and Woods Hole EFs

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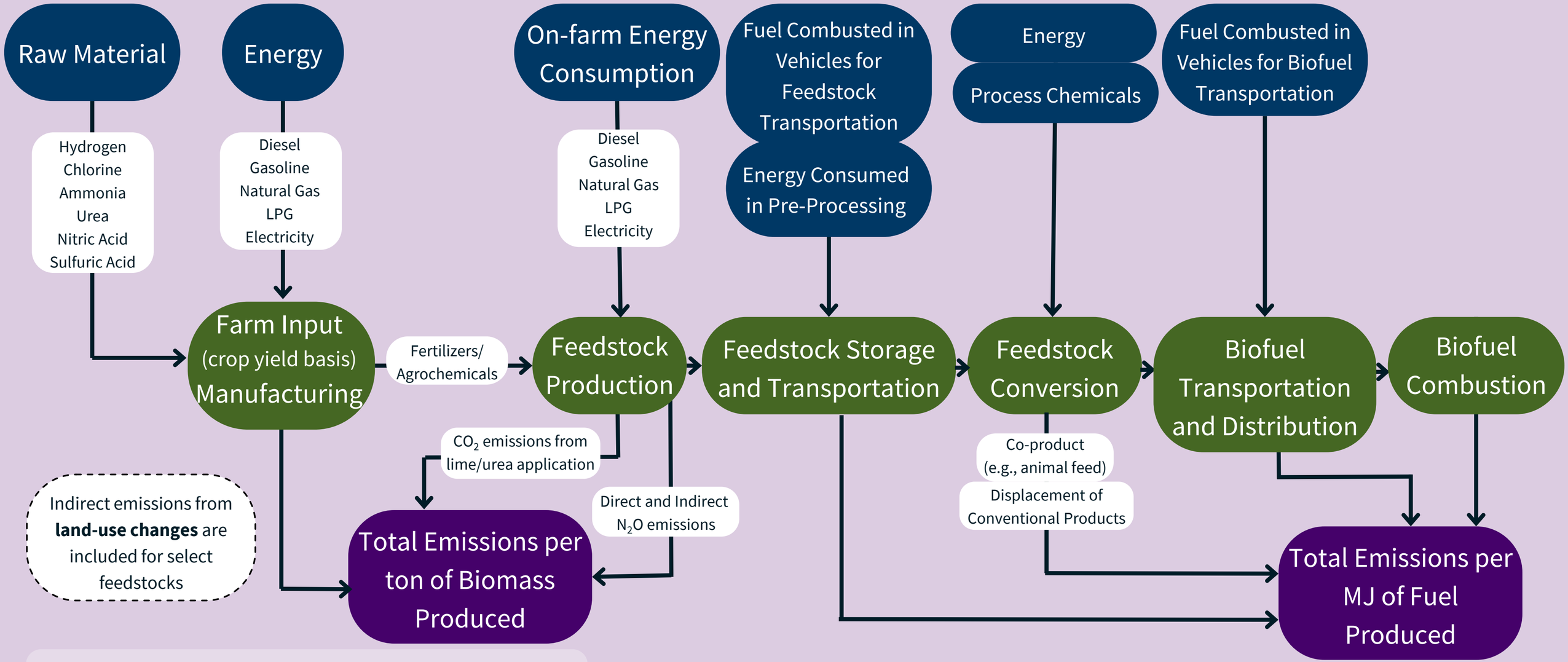
Life cycle of biofuels in more detail: *WTP emissions*



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LCA of Ethanol in R&D GREET

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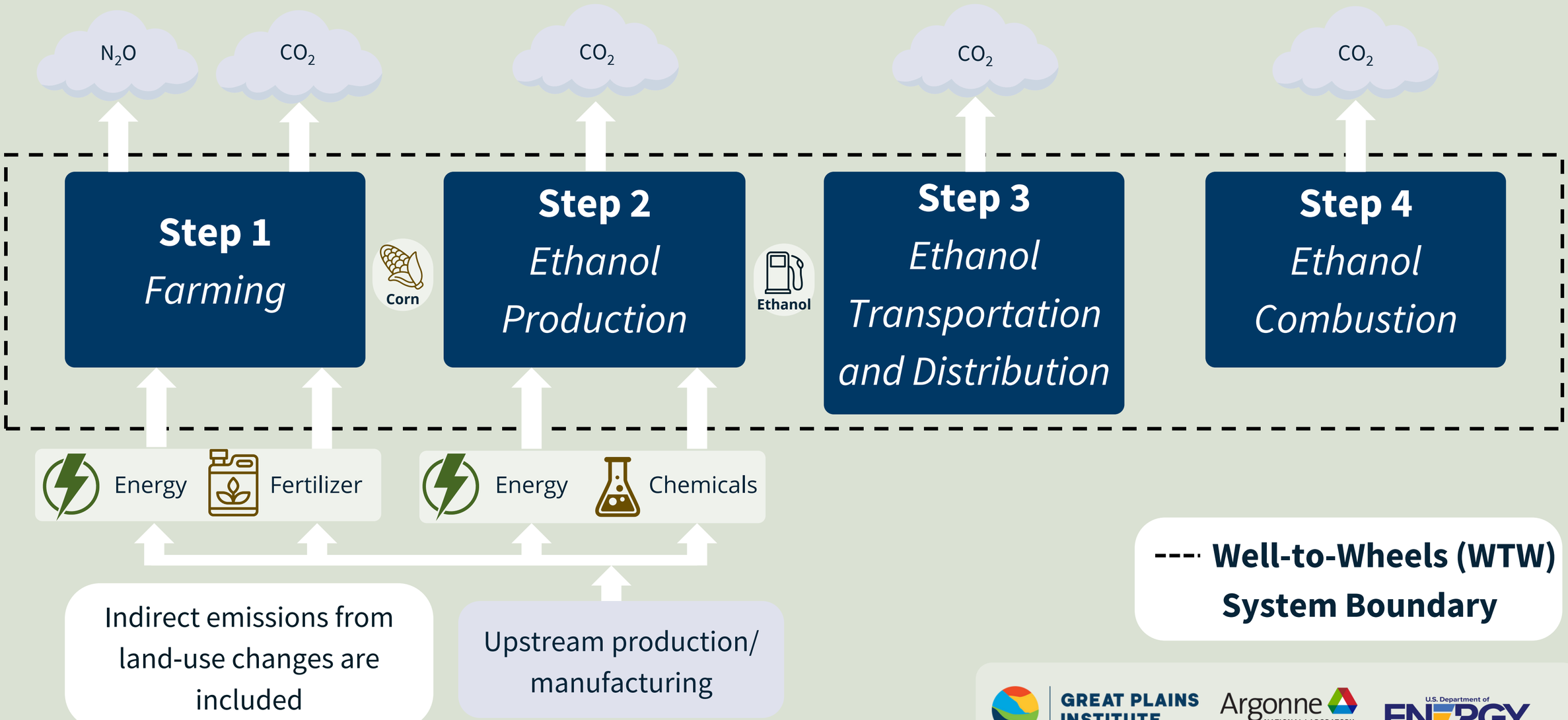
Simplified ethanol production process



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Ethanol emissions breakdown

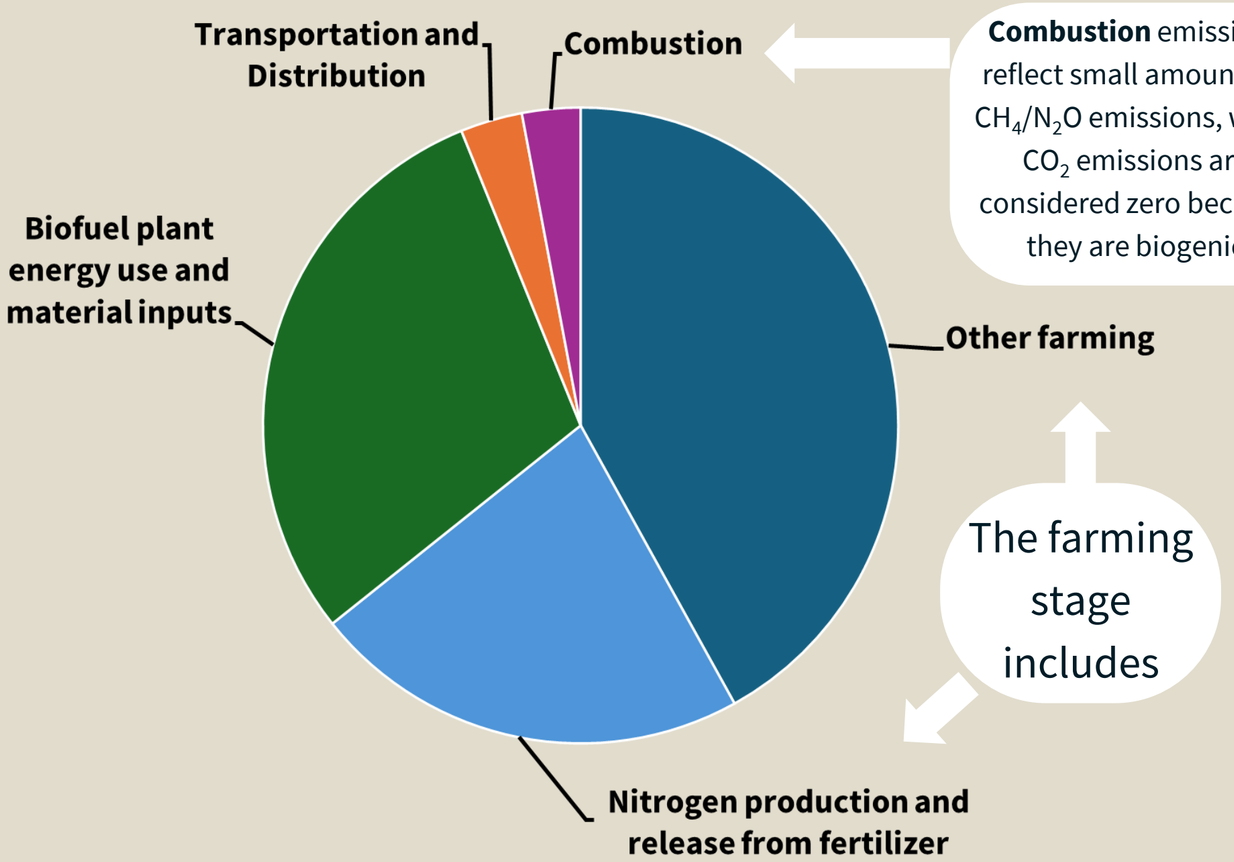
The largest GHG contributions to ethanol production

Farming (Feedstock Phase)

Nitrogen production and NO_2 emissions from fertilizers

Biofuel Production (Fuel Phase)

Plant energy consumption



Combustion emissions reflect small amounts of CH_4/N_2O emissions, while CO_2 emissions are considered zero because they are biogenic

The farming stage includes

Note: this figure was generated for illustrative purposes. As R&D GREET is updated, the values could change

- R&D GREET

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Nitrogen Production and Nitrous Oxide Emissions

Feedstock Phase - Agricultural Inputs

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Nitrogen Production

Corn production uses Nitrogen from fertilizers. Nitrogen is produced from a number of industrial processes

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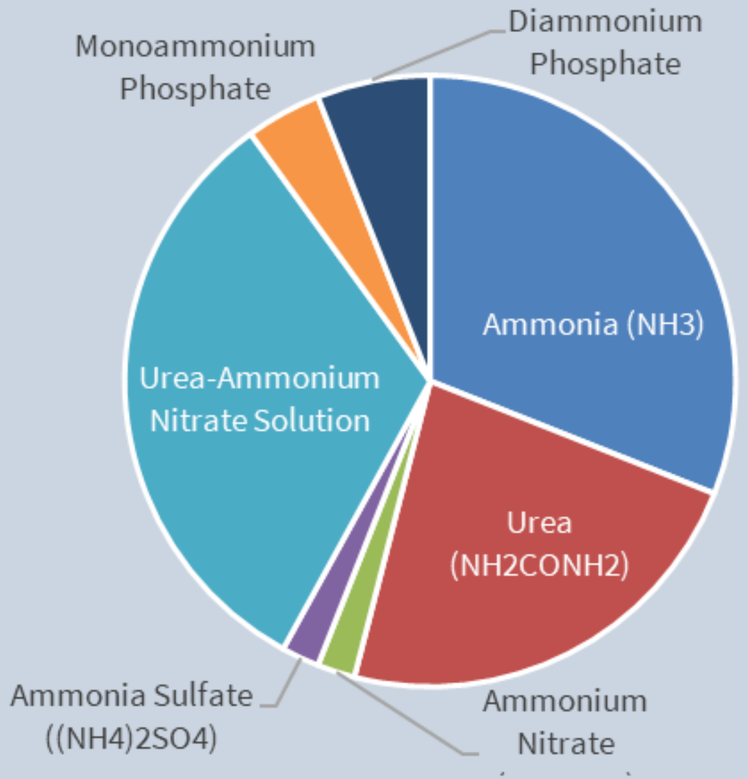
R&D GREET: *nitrogen production*

Nitrogen comes in many forms

The most prominent form is Ammonia (31%)

Upstream impacts associated with the production of Ammonia (e.g., Haber-Bosch) are accounted for in the total emissions of Nitrogen production

The emissions of Nitrogen production used in corn farming is averaged using this blend



- R&D GREET

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Nitrous Oxide Emissions

Nitrogen, released from fertilizer and crop residues as nitrous oxide emissions, produces one of the largest shares of ethanol GHG life cycle emissions

Nitrous oxide emissions (N_2O)

R&D GREET considers the direct release of nitrogen (N) as N_2O in fields, as well as indirect release on nitrogen as N_2O from leaching/runoff

Direct N_2O Emissions	*1% of nitrogen in fertilizer and residue*
Indirect N_2O Emissions	*~0.3% of nitrogen in fertilizer and residue*

Based on IPCC Tier 1 methodology and Argonne analysis

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Biofuel Production Emissions

Fuel Phase

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Biofuel production emissions

There are 2 types of ethanol production plants in GREET

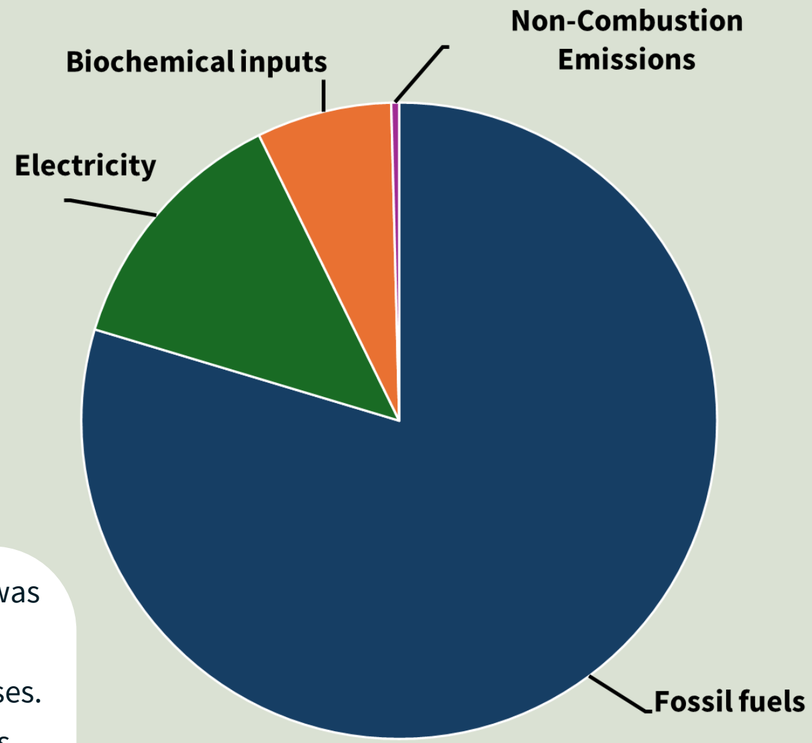
Dry Mill

Represents 90% share of corn ethanol plant types

Wet Mill

Represents 10% share of corn ethanol plant types

Emissions contributions for dry mill ethanol production



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- R&D GREET

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R&D GREET capabilities for LCA of ethanol

Feedstock Types

Corn, willow, poplar, switchgrass, miscanthus, corn stover, forest residue, sorghum, integrated corn/stover, solid waste, and sugarcane

Agricultural Feedstock Preparation Co-Products

- Distillers grains with solubles (DGS), both wet (WDGS) and dry (DDGS) - from dry milling ethanol production - displaces corn, soy bean meal, and urea used for animal feed
- Corn gluten meal and corn gluten feed - from wet milling ethanol production - displaces corn, soybean meal and urea used for animal feed
- Corn oil

Energy and Environmental Metrics

Energy intensities of total, fossil (petroleum, gas, coal), water use intensities, GHG emission intensities (total and CO_2, CH_4, and N_2O separately), air pollutants' emissions intensities of VOC, CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, BC, and OC

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Ethanol tabs

Primary

Ethanol

Some Secondary

Ag_Inputs

RNG

NG

Inputs

Results

Fuel_Prod_TS

Fuel_Specs

Electricity

Car_TS

Vehicles

EF

T&D

T&D Flowcharts

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LCA of Biodiesel and Renewable Diesel in R&D GREET

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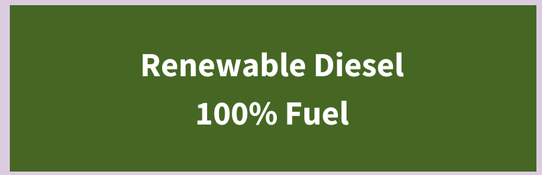
Biodiesel and renewable diesel

Biodiesel

- Made from renewable biomass resources (seed oils or animal fats) via transesterification
- Can be blended with conventional diesel fuel and used in diesel engines at designed blending levels

Renewable Diesel

- Made from seed oils, animal fats, and lignocellulosic feedstocks such as woody biomass
- Undergoes hydroprocessing to produce “drop-in diesel,” which is a petroleum diesel substitute



- Xu et al., 2022, Environmental Science and Technology

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R&D GREET capabilities for LCA of biodiesel and renewable diesel

Feedstock Types

Soybean, palm full fruit bunch (FFB), canola, jatropha, camelina, algae, tallow, corn oil, carinata, palm fatty acid distillate (PFAD) and used cooking oil (UCO)

Main Products

Biodiesel, renewable diesel, and renewable gasoline

Co-Products

Glycerin, propane, and soil co-products from agricultural feedstock oil extraction (meals, kernel, husks, and shells)

Energy and Environmental Metrics

Energy intensities of total, fossil (petroleum, gas, coal), water use intensities, GHG emission intensities (total and CO_2, CH_4, and N_2O separately), air pollutants' emissions intensities of VOC, CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, BC, and OC

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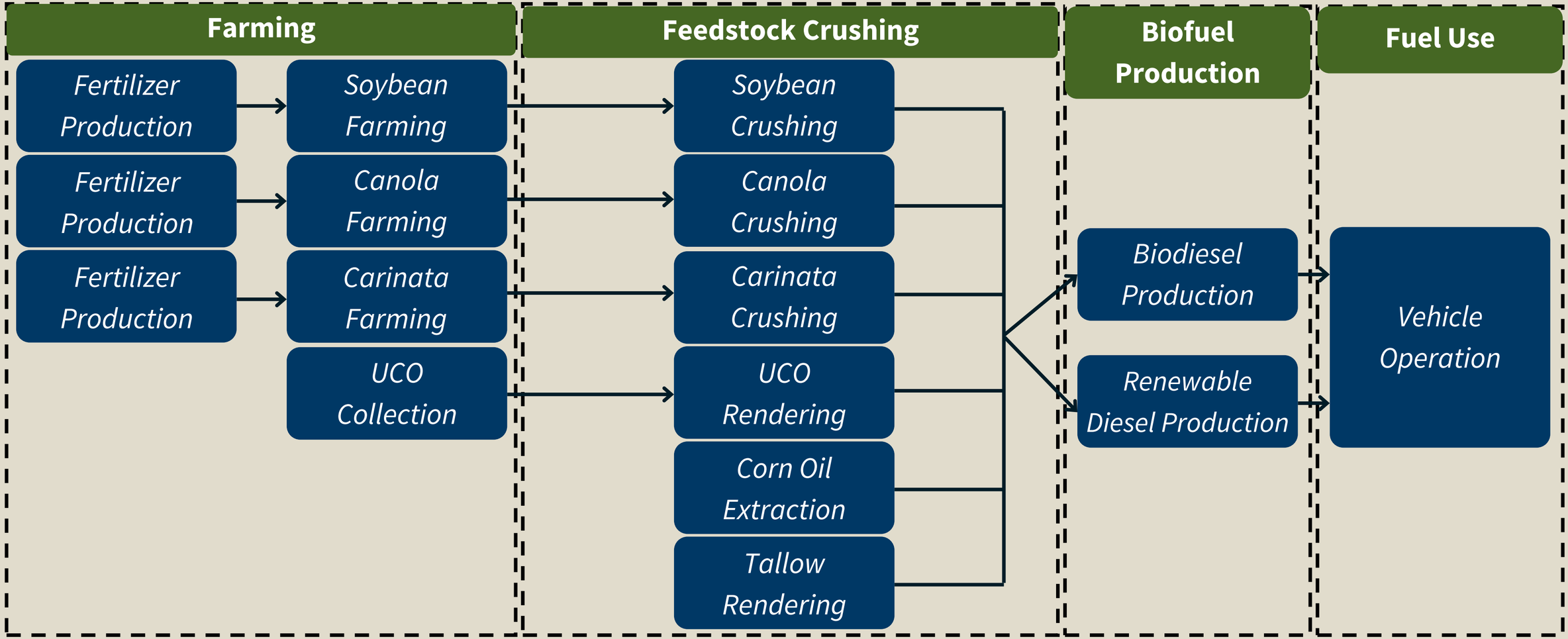
Example pathways for biodiesel and RD in R&D GREET

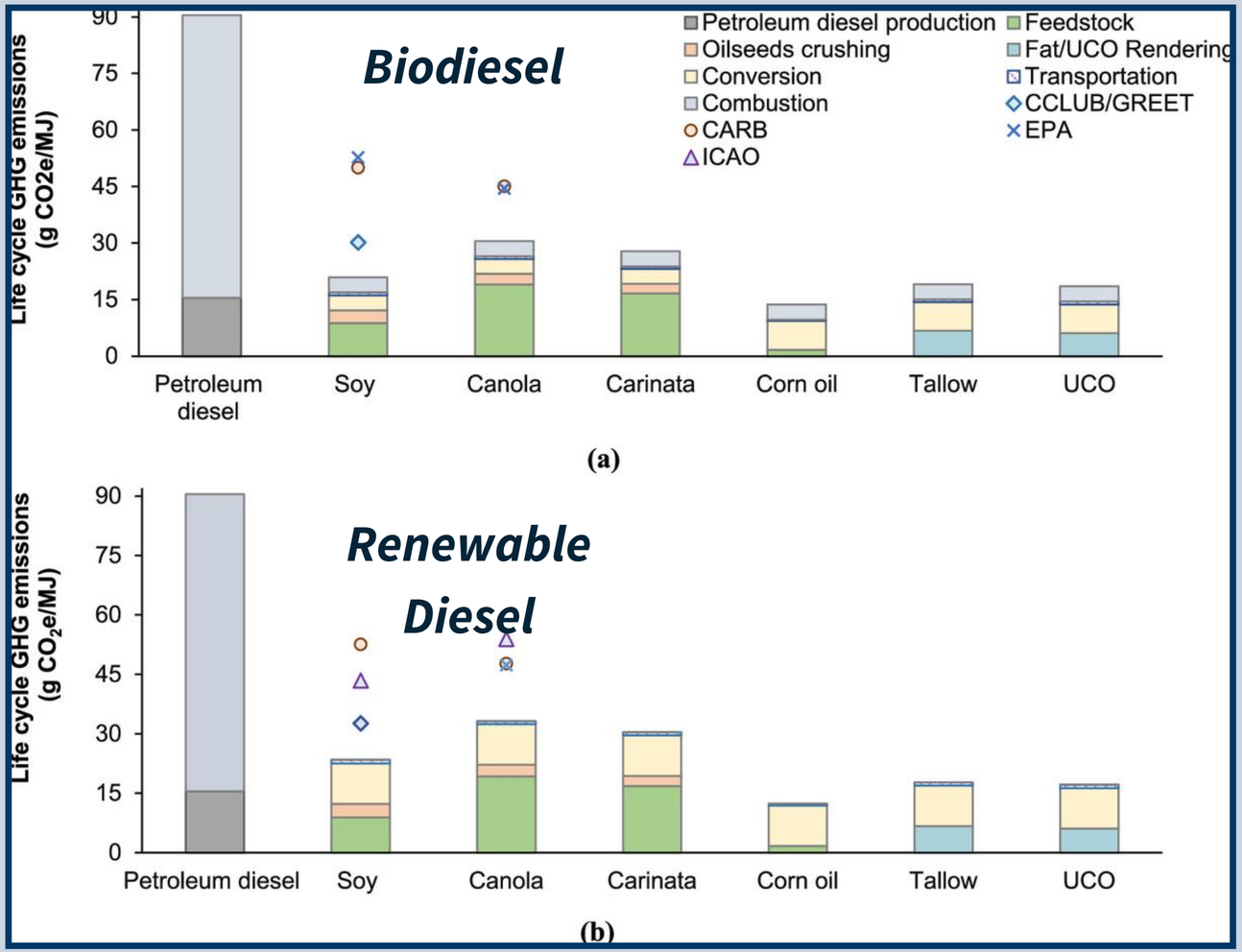


Sample results for biodiesel and RD in R&D GREET

Oil seed-based biodiesel and RD have high feedstock life cycle GHG emissions (e.g. farming/fertilizer)

Waste feedstocks (Corn oil, tallow, UCO) generally have lower GHG emissions than oil seed-based fuels

All fuels have greatly reduced life cycle GHG emissions compared with petroleum diesel



- Xu et al., 2022, Environmental Science and Technology

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Biodiesel and renewable diesel tabs

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T&D Flowcharts

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LCA of Renewable Natural Gas in R&D GREET

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The Counterfactual Scenario

What were the methane and overall GHG emission impacts associated with waste management before the waste was diverted to renewable natural gas production?

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Renewable natural gas

Renewable Natural Gas (RNG) is created when methane from biological material (typically waste) is converted into biogas and upgraded to pipeline quality before it is used in vehicles

Anaerobic Digestion (AD)

Microorganisms break down wastes and produce biogas

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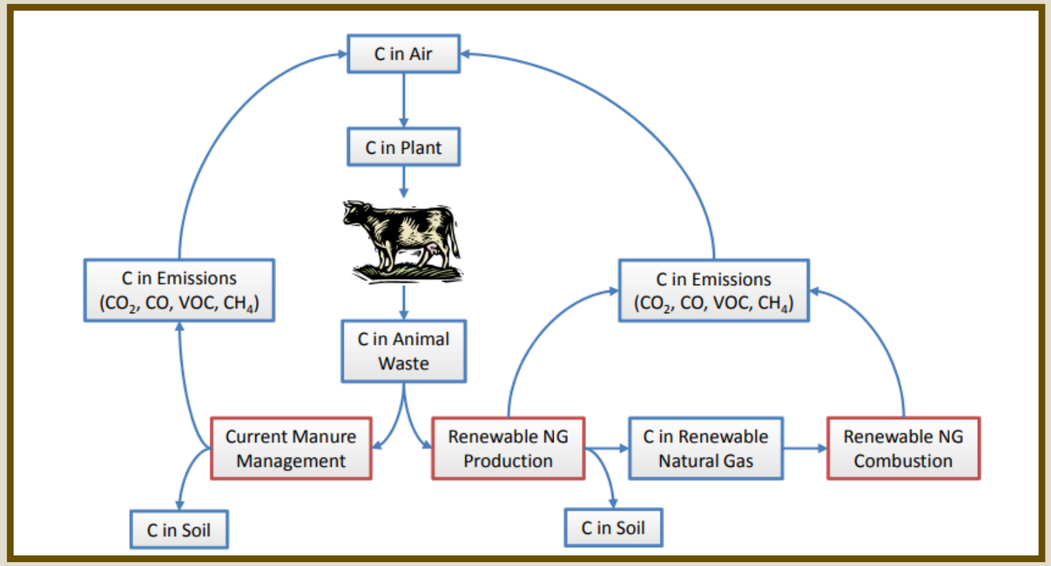
Renewable natural gas

The carbon intensity of RNG is most notably affected by

The counterfactual scenario

The magnitude of methane lost during the biogas upgrading process

The nitrogen nutrient in anaerobic digestion residue that could contribute to nitrous oxide emissions while substituting synthetic nitrogen fertilizers when the AD residue (digestate) is applied for soil amendment



- Han et al., 2011, Argonne National Laboratory

The amount of carbon from digestate that is sequestered from soil application

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R&D GREET waste management practices

Conventional Waste Practices

Practices must be known for the LCA of RNG

- Carbon in waste is partly sequestered to the soil
- Non-collected methane (CH_4) emissions influence climate change significantly

RNG Production

- Avoids emissions from conventional waste management
- Some carbon in waste is still released into the atmosphere but are considered carbon-neutral biogenic CO_2 emissions

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R&D GREET waste management practices

B-A: indicates the GHG impact of MJ of fuel produced and used

A: By diverting waste, emissions associated with the current waste management can be avoided

B: Fuel production and combustion emissions

Using waste avoids emissions from conventional waste management practices: counterfactual scenario

Waste is not intentionally produced

Waste management is regulated

R&D GREET capabilities for LCA of renewable natural gas

Waste Types

Landfills, animal manure, municipal solid waste (MSW), and waterwaste sludge (WWTP)

Default Counterfactual Scenarios

- *Animal manure gas*: weighted U.S. average of typical manure management methods without capturing methane from storage/management systems such as anaerobic lagoons
- *Landfill gas*: gas is collected and flared
- *WWTP*: a digester that aims to reduce waste by utilizing part of the biogas to sustain the digester while flaring the surplus biogas for emission mitigation purposes
- *MSW (food waste)*: U.S. average food waste management practices (including landfill, incineration, composting, and AD)

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R&D GREET capabilities for LCA of renewable natural gas

Products

Natural gas (NG), compressed NG (off-site and on-site refueling of vehicles), liquified NG, and methanol

Energy and Environmental Metrics

Energy intensities of total, fossil (petroleum, gas, coal), water use intensities, GHG emission intensities (total and CO_2, CH_4, and N_2O separately), air pollutants' emissions intensities of VOC, CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, BC, and OC

Regional Results

Animal manure management practices can be selected for specific states (e.g., CA)

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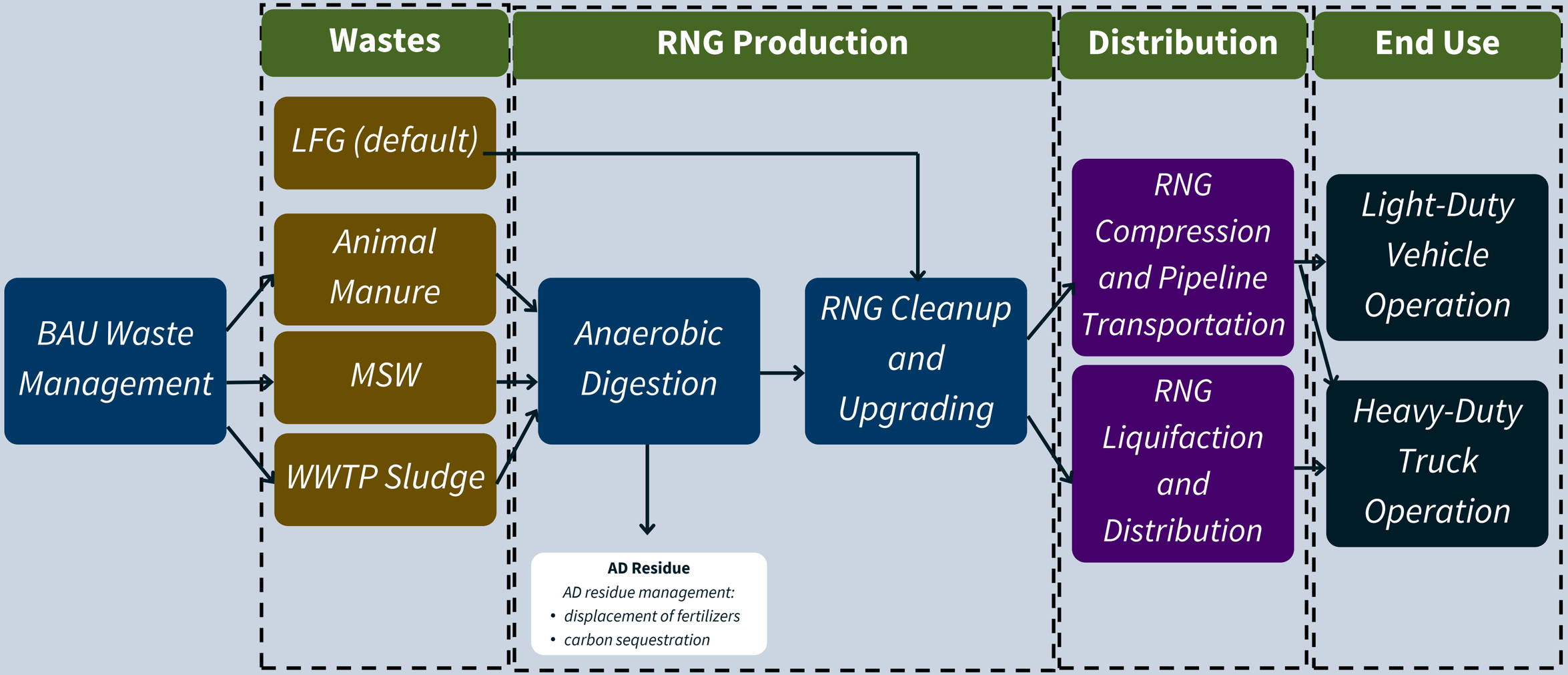
R&D GREET capabilities for LCA of renewable natural gas



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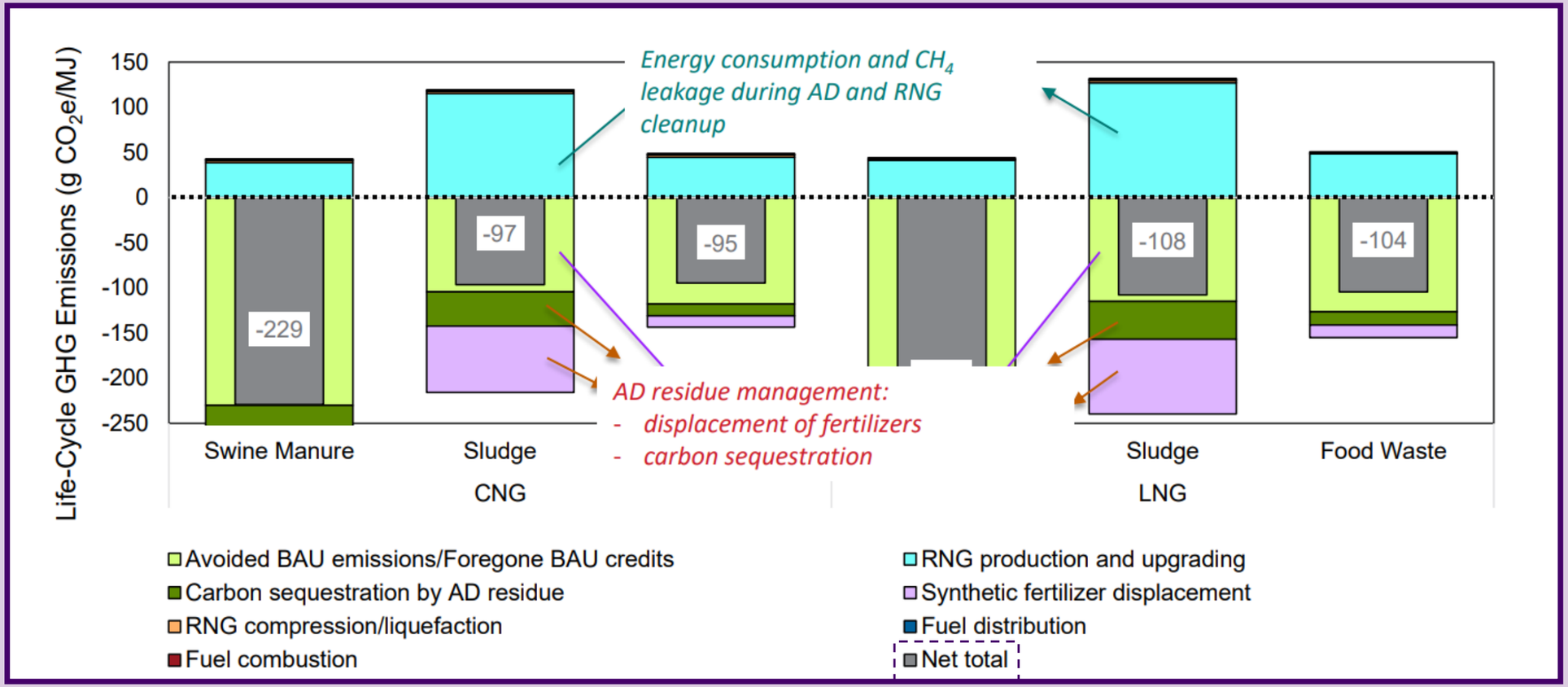
R&D GREET capabilities for LCA of renewable natural gas

Avoided emissions and displacement credits can be significant



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Renewable natural gas fuels tabs

Primary

Waste

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BioOil

MeOH_FTD

EtOH

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T&D

T&D Flowcharts

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