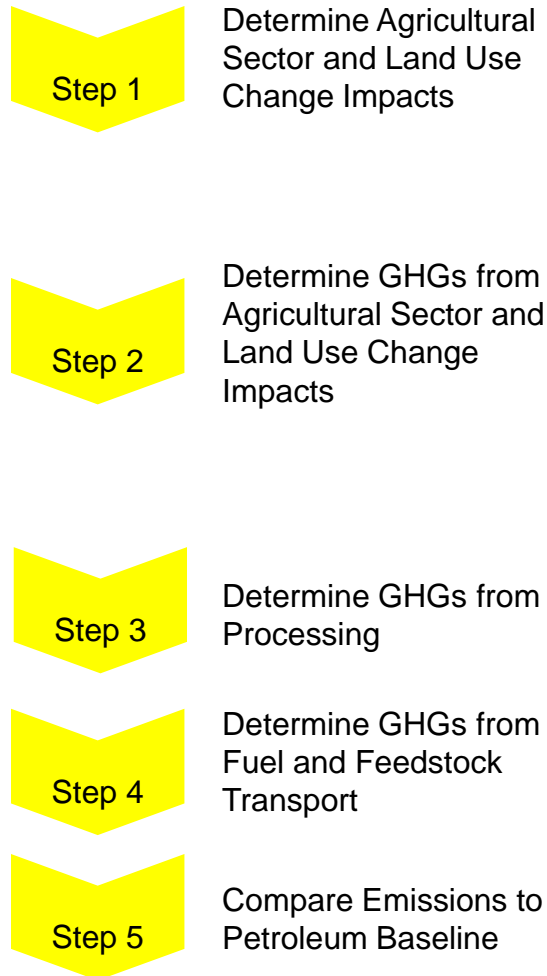


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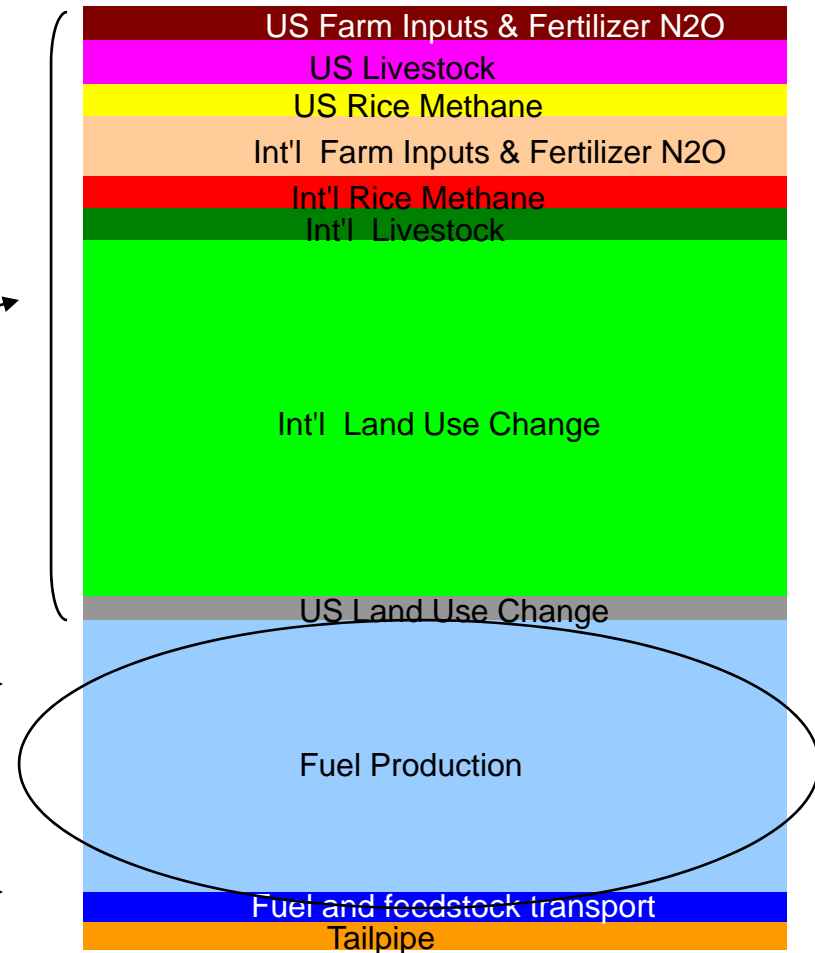
# Biofuel Technologies' Contribution to Life Cycle Emissions

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## Steps in Lifecycle Analysis



## Lifecycle GHG Emissions



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# Overview

- For each biofuel technology:
  - Present information source and methodology used for the life cycle analysis (LCA)
  - Present LCA information used in proposed rule and how it was applied
  - Discuss future work
- Discuss other technologies to be evaluated

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# List of Biofuels Analyzed in RFS2 Proposal

- LCA of ethanol-producing technologies
  - Corn ethanol
  - Cellulosic ethanol
  - Sugarcane ethanol (i.e., from Brazil)
- LCA of diesel-based biofuels
  - FAME biodiesel
  - Renewable diesel

# Corn Ethanol Process Energy Use and Projections

- Estimated 2007 corn ethanol plant baseline energy use
- The lifecycle analysis is based on projected energy use of corn ethanol plants in 2022
- Three types of adjustments incorporated from 2007 to 2022
  - Primary fuel type (Natural Gas, Coal, or Biomass) and combined heat and power (CHP) usage
    - CHP improves plant efficiency by utilizing the normally wasted heat from electricity production
  - Process efficiency improvements (more efficient boilers, motors, turbines, etc.) were applied to all corn ethanol plants
  - New energy saving technology (corn oil extraction, corn fractionation, raw starch hydrolysis, and membranes for ethanol dehydration)
    - All dry mill ethanol plants, regardless of fuel type, were considered to be eligible for energy saving technologies

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# Corn Ethanol Process Energy Use and Projections – data sources

- 2007 (baseline) corn ethanol performance based on several surveys of current ethanol production facilities analyzed by Steffen Mueller, University of Illinois at Chicago (UIC)
- Projected energy use of corn ethanol plants in 2022 based on two sources
  - An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010 – 2030); Steffen Mueller, UIC
  - Conversations with technology providers

# Corn Ethanol Projected Fuels Source and CHP Usage for Dry Mill Plants

|                 | 2007 (Baseline) | <b>2022</b> |
|-----------------|-----------------|-------------|
| Natural Gas     | 88%             | <b>49%</b>  |
| Natural Gas CHP | 4%              | <b>12%</b>  |
| Coal Boiler     | 0%              | <b>0%</b>   |
| Coal CHP        | 4%              | <b>4%</b>   |
| Biomass Boiler  | 2%              | <b>11%</b>  |
| Biomass CHP     | 1%              | <b>10%</b>  |
| Biogas Boiler   | 1%              | <b>14%</b>  |

# Corn Ethanol Process Efficiency Improvements for Dry Mill Plants

|  | 2007 Baseline | 2022  | % Improvement |
|--|---------------|-------|---------------|
| Boiler Efficiency  | 82%           | 91.6% | 10.5%         |
| Motor Efficiency   | 90%           | 93.8% | 4%            |
| Turbine Efficiency at Ethanol Plant or Central Power Plant             | 31%           | 34%   | 8.8%          |
| Total Electricity Improvement  |               |       | 12.8%         |
| Total Plant Improvement (weighted electricity and fossil energy input) |               |       | 11%           |

# Corn Ethanol New Energy Saving Technology Descriptions

- Raw Starch Hydrolysis - different enzymes are used which do not require heat for the conversion of starches to sugars.
  - lowers thermal energy demands
- Corn Fractionation – the germ and bran are removed from the endosperm (contains the starch) before fermentation
  - This technology reduces the drying energy demand, as the germ and bran no longer require drying.
  - Ethanol production capacity is also increased and corn oil can be recovered from the germ.
- Corn Oil Extraction - uses centrifuges or other mechanical devices to extract corn oil from the thin stillage or DGS.
  - This process recovers a salable corn oil and also reduces the drying energy demand.
- Membrane Separation - molecular sieve units are replaced by membranes for ethanol dehydration; the membranes do not have to be regenerated, reducing recycle of the ethanol/water mixture
  - Saves energy required for molecular sieve regeneration.

# Corn Ethanol - Percentage of Dry Mill Plants Adopting Technologies

|                                 | 2007<br>(Baseline) | 2022 |
|---------------------------------|--------------------|------|
| Raw Starch Hydrolysis (No Cook) | 5%                 | 22%  |
| Corn Fractionation              | 1%                 | 20%  |
| Corn Oil Extraction             | 5%                 | 22%  |
| Membrane Separation             | 0%                 | 5%   |

Technology penetration rates based on Mueller paper.

# Corn Ethanol - Energy Changes from New Technologies in Dry Mill Plants

|  |            | 2007 (Baseline) | 2022   |
|--|------------|-----------------|--------|
| Raw Starch Hydrolysis<br>(Based on Mueller Paper and Poet)     | Thermal    | -16%            | -16%   |
|  | Electrical | 0%              | 0%     |
| Corn Fractionation*<br>(Based on Mueller Paper)                | Thermal    | -31%            | -31%   |
|  | Electrical | 10%             | 9%     |
| Corn Oil Extraction*<br>(Based on Mueller Paper)               | Thermal    | -4%             | -4%    |
|  | Electrical | 9%              | 9%     |
| Membrane Separation<br>(Based on Vaperma and Leland Vane; EPA) | Thermal    | N/A             | -29%   |
|  | Electrical | N/A             | 0%     |
| Weighted Energy Savings from New Technologies                  | Thermal    | -1.3%           | -12.1% |
|  | Electrical | 0.5%            | 3.8%   |

Weighted energy reductions omit potential double counting

\* To be accounted for in the FRM

# Corn Ethanol - Energy Use for Dry Mill Natural Gas Plants (2022)

|   | Dry DGS; BTU/gal             |                           | Wet DGS; BTU/gal            |                           |
|---|------------------------------|---------------------------|-----------------------------|---------------------------|
|   | Thermal                      | Electrical                | Thermal                     | Electrical                |
| 2007 Baseline Plant   | 32,000                       | 2,558                     | 19,072                      | 2,558                     |
| 2022 Base Plant*  | 28,660                       | 2,251                     | 17,081                      | 2,251                     |
| Base with CHP   | 30,898                       | 512                       | 19,320                      | 512                       |
| Base with CHP and Fractionation   | 22,014                       | 714                       | 15,594                      | 714                       |
| Base with CHP, Fractionation, and Membranes   | 17,994                       | 714                       | 11,574                      | 714                       |
| Base with CHP, Fractionation, Membranes, and Raw Starch Hydrolysis (Best Case Scenario) | 13,408<br>58.1%<br>reduction | 714<br>72.1%<br>reduction | 8,841<br>53.6%<br>reduction | 714<br>72.1%<br>reduction |

\*2022 Base Plant includes all efficiency improvements but no new technologies

# Corn Ethanol - Energy Use for Dry Mill Coal Plants (2022)

|   | Dry DGS; BTU/gal             |                           | Wet DGS; BTU/gal             |                           |
|---|------------------------------|---------------------------|------------------------------|---------------------------|
|   | Thermal                      | Electrical                | Thermal                      | Electrical                |
| 2007 Baseline Plant   | 40,000                       | 3,069                     | 23,840                       | 3,069                     |
| 2022 Base Plant*  | 35,824                       | 2,694                     | 21,351                       | 2,694                     |
| Base with CHP   | 39,407                       | 205                       | 24,934                       | 205                       |
| Base with CHP and Fractionation   | 28,301                       | 447                       | 20,277                       | 447                       |
| Base with CHP, Fractionation, and Membranes   | 23,276                       | 447                       | 15,252                       | 447                       |
| Base with CHP, Fractionation, Membranes, and Raw Starch Hydrolysis (Best Case Scenario) | 17,545<br>56.1%<br>reduction | 447<br>85.4%<br>reduction | 11,836<br>50.4%<br>reduction | 447<br>85.4%<br>reduction |

\*2022 Base Plant includes all efficiency improvements but no new technologies

# Corn Ethanol - Energy Use for Dry Mill Biomass Plants (2022)

|   | Dry DGS; BTU/gal |                           | Wet DGS; BTU/gal |                           |
|---|------------------|---------------------------|------------------|---------------------------|
|   | Thermal          | Electrical                | Thermal          | Electrical                |
| 2007 Baseline Plant   | 0                | 3,069                     | 0                | 3,069                     |
| 2022 Base Plant*  | 0                | 2,694                     | 0                | 2,694                     |
| Base with CHP   | 0                | 205                       | 0                | 205                       |
| Base with CHP and Fractionation   | 0                | 447                       | 0                | 447                       |
| Base with CHP, Fractionation, and Membranes   | 0                | 447                       | 0                | 447                       |
| Base with CHP, Fractionation, Membranes, and Raw Starch Hydrolysis (Best Case Scenario) | 0                | 447<br>85.4%<br>reduction | 0                | 447<br>85.4%<br>reduction |

\*2022 Base Plant includes all efficiency improvements but no new technologies

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# Cellulosic Biofuel

- LCA based solely on biochemical ethanol process.
  - BTL diesel fuel or other processes not estimated.
  - LCA will consider others for final rule.
- Our LCA is based on NREL projections - based on Aspen modeling.
- Provided year 2010 efficiency, and projected efficiency in 2015 and 2022.
  - Significant efficiency improvement in the future.
  - Individual plant LCA based on 2015 plant efficiency and electricity sales information
  - Overall LCA impacts based on projected year 2022 cellulosic ethanol plant.

# Cellulosic Ethanol Plant Efficiency

|  | 2010   | 2015   | 2022   |
|--|--------|--------|--------|
| Plant Size<br>(mmgals/yr)                  | 55     | 70     | 71     |
| Plant Yield<br>(gals/dry ton)              | 72     | 90     | 92     |
| Thermal<br>Efficiency (%)                  | 44     | 49     | 58     |
| Total Electricity<br>Produced<br>(BTU/gal) | 16,000 | 12,600 | 12,300 |
| Electricity Sales<br>(BTU/gal)             | 8900   | 8050   | 12,300 |
| Plant Steam<br>Use (BTU/gal)               | 31,700 | 31,700 | 22,900 |

# Improved Efficiency of Cellulosic Ethanol Plants

- Cellulosic ethanol efficiency improvements projected by NREL:
  - Ethanol yields improve from increased conversion of cellulose to sugar, and increased conversion of sugar to ethanol
  - Process will tolerate higher ethanol concentration in the liquor, from 5% to 8%
- Both of these changes increase yields which lowers operating and capital costs

# Imported Sugarcane Ethanol

- Assumed sugarcane ethanol facility only produces ethanol, (i.e., no co-production of sugar)
- LCA primarily based on GREET inputs
  - Wang, et. al, “Life-cycle energy use and greenhouse gas emission implications of Brazilian sugarcane ethanol simulated with the GREET model,” International Sugar Journal 2008, Vol. 110, NO. 1317.
- Exceptions include updating assumptions on excess electricity from bagasse and yields for 2022
  - OECD, “Biofuels: Linking Support to Performance,” ITF roundtables No. 138, 2008.
  - FAPRI modeling
- Assumes use of bagasse, but not the “straw”

# Key Assumptions for Sugarcane Ethanol Plants

|  |        |
|--|--------|
| Electricity Use (BTU/gal)                            | 1703   |
| Mechanical Use (BTU/gal)                             | 2271   |
| Thermal Use (BTU/gal)                                | 46,836 |
| Chemical & Lubricant Use (BTU/gal)                   | 251    |
| Ethanol yield (gal/ton)                              | 27     |
| Excess electricity for export from bagasse (BTU/gal) | 6070   |

# FAME Biodiesel Overview

- Two versions modeled for the proposal
  - Soy oil model assumes minimal fatty acid content, uses typical base-catalyzed methanol transesterification
  - Yellow grease model includes acid pretreatment step upstream of base-catalyzed transesterification
- Two components: process modeling and steam generation
  - Process modeling (material & energy balances) conducted with SuperPro by USDA; all heat inputs are from steam
  - Steam generation modeling conducted in spreadsheet by USDA provided to EPA (conventional generation only)

# FAME Biodiesel

- GHG impacts of production process were derived from the process and steam models
  - Btu/gal based on fuel type and plant configuration
  - Specific technology and fuel-source factors were weighted together according to projected mix of plant types

Energy Consumption for Biodiesel Production (BTU/gallon)

|               | Natural Gas | Electricity |
|---------------|-------------|-------------|
| Soy Oil       | 20,091      | 3080        |
| Yellow Grease | 21,051      | 494         |

# Renewable Diesel

- Renewable diesel production was based on survey of information from vendors and other sources
- Based on petroleum hydrotreating technologies, via three options:
  - Revamping/repurposing part of an existing refinery process train
  - New construction of a processing unit on-site at an existing refinery
  - New construction of a stand-alone facility

Energy Consumption for Renewable Diesel Fuel Production (BTU/gallon)

|               | Natural Gas | Electricity | Other |
|---------------|-------------|-------------|-------|
| Soy Oil       | 14,532      | 3578        | 9796  |
| Yellow Grease | 0           | 838         | 9796  |

# Calculating LCA with Biofuel Production Information

- Biofuel production efficiency is key (i.e., gallons per dry ton)
  - It relates the feedstock with its land use, harvesting and transportation impacts
  - to fuel production and transportation, and the extent that it offsets petroleum consumption
- Account for fossil fuel consumption, co-products produced and excess electricity produced
  - GREET usually used for these lifecycle impacts

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## Next Steps

- Updates of these LCAs for the FRM
  - Incorporate technology improvements
  - Based on comments received, or on our own revised assessments
- Will assess the LCAs of additional biofuel production technologies

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# Examples of Potential Biofuel Technologies to be Assessed

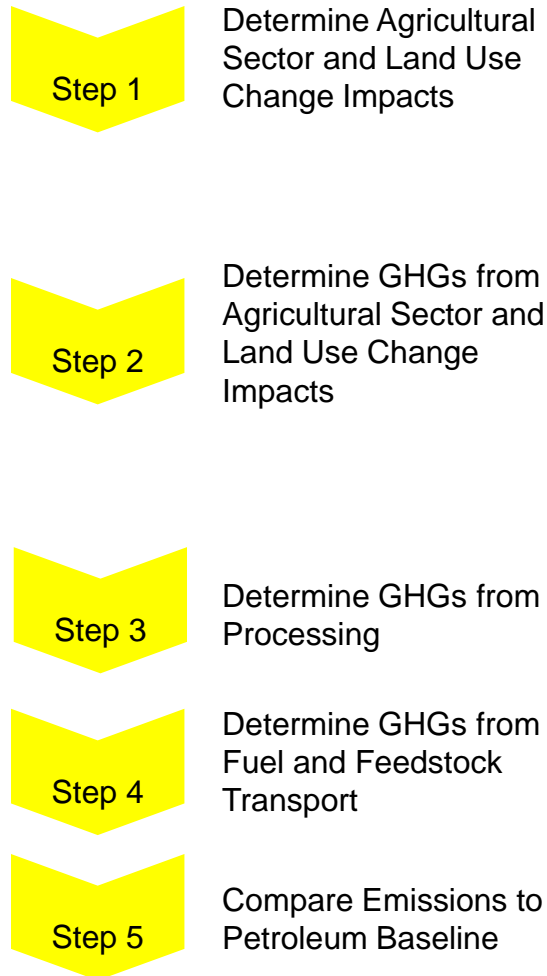
- Diesel-based biofuels
  - Cello Energy, Bell Bioenergy
  - FT Diesel: Flambeau River Biofuels, Choren, Beard
  - Sugar sourced: Amyris, Gevo,
  - Algae: Solazyme
- Other Ethanol Processes
  - Range, Zechem, Algenol
- Naphtha
  - UOP, Virent, Swift
- Butanol
  - DuPont/BP

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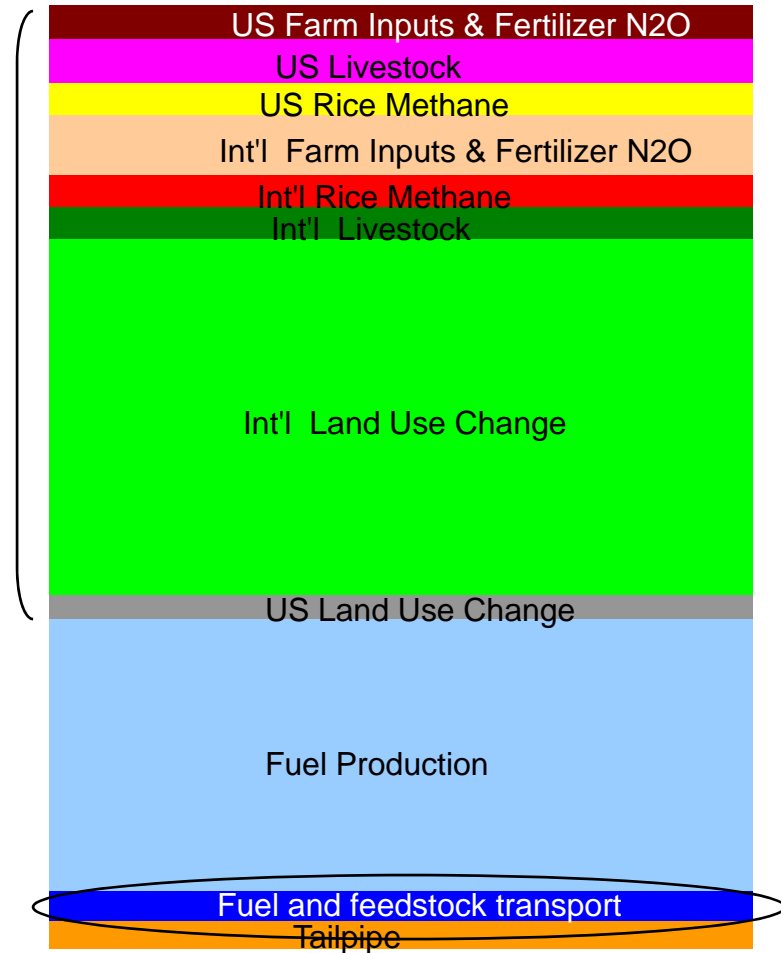
# Fuel and Feedstock Transport

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## Steps in Lifecycle Analysis



## Lifecycle GHG Emissions



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# Determining GHG Emissions From Transport

- Calculate emissions based on:
  - Transportation distances
  - Modes of transport (i.e., truck, barge, etc.)
    - Each mode has assumed efficiency
  - Can be used to determine overall fuel used for transport
  - Transport fuel use multiplied by GHG emissions factor for producing and combusting that fuel

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# Key Assumptions

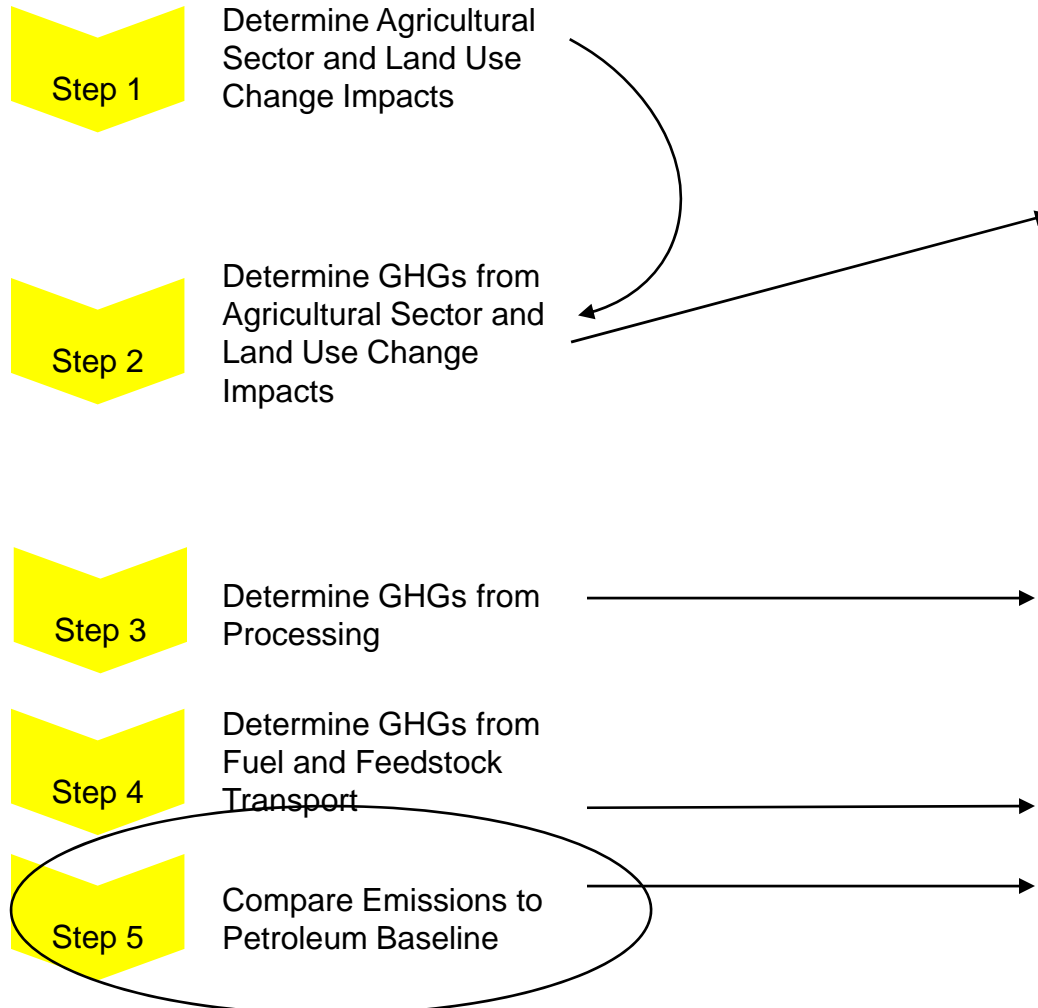
- Feedstock Transport
  - 50 miles by truck from field to plant
- Fuel Transport
  - Current fuel distribution analysis based on GREET defaults for distances and modes of transport
  - Working to incorporate analysis done as part of this rulemaking that considers infrastructure impacts of increased biofuel volumes
- Crude transport part of petroleum baseline

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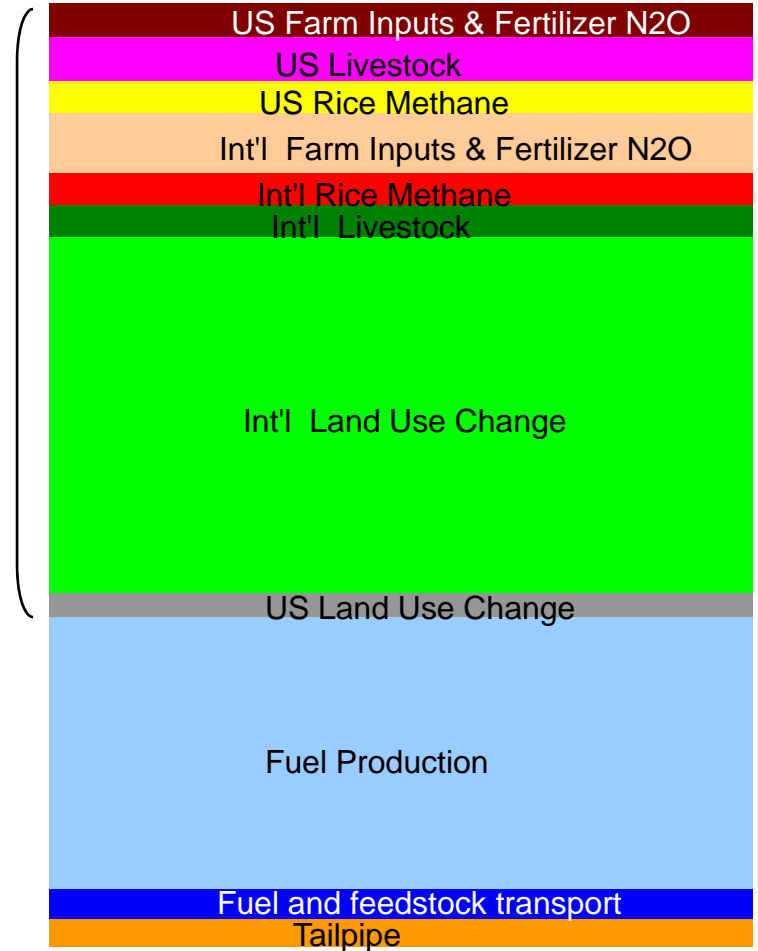
# Petroleum Baseline

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## Steps in Lifecycle Analysis



## Lifecycle GHG Emissions



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# Petroleum Baseline

“(C) BASELINE LIFECYCLE GREENHOUSE GAS EMISSIONS.— The term ‘baseline lifecycle greenhouse gas emissions’ means the average lifecycle greenhouse gas emissions, as determined by the Administrator, after notice and opportunity for comment, for gasoline or diesel (whichever is being replaced by the renewable fuel) sold or distributed as transportation fuel in 2005.

# Petroleum Life Cycle Modeling

- Based on GREET (Version 1.8)
- Calculated using an energy efficiency metric for the different processes involved (measure of how many Btus of input energy are needed to make a Btu of product)
  - GREET also has assumptions on the mix of energy sources used to provide the energy input
  - The GHG emissions based on the emissions from producing and combusting the input energy sources (with non-combustion sources added in where applicable)
- Processes included
  - Crude oil extraction
  - Crude oil transport
  - Refining
  - Fuel transportation and distribution
  - Tailpipe combustion (based on MOVES results)

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# Life Cycle Boundaries

- Using same system boundaries for both petroleum and biofuel lifecycle
  - Infrastructure-related activities are not included (e.g., emissions associated with the production of tractor or farm equipment)
  - Construction-related emissions are also not included (e.g., steel or concrete needed to construct a refinery)
- Elements excluded were determined based on internationally accepted life cycle assessment standards, developed by the International Organization for Standardization (ISO), using environmental significance as the cut-off criteria
- For biofuels compared marginal 2022 production to average 2005 petroleum baseline
  - EISA mandate for average 2005 petroleum fuels

# Crude Oil Extraction

- GREET has assumptions for different types of crude oil extraction
  - Conventional crude oil (assumed to represent average crude oil extraction, including domestic and foreign production and onshore, offshore and enhanced oil recovery processes)
  - Oil sands recovery was used in this analysis to represent Canadian oil sands recovery
- Assumed 2005 mix of crude
  - Tar Sands
  - Developed emissions factors for those crude types (not currently included in GREET)
    - Venezuela crude 2.4 times emissions as conventional
    - Heavy crude 1.07 time conventional emissions

|                                       |       |
|---------------------------------------|-------|
| International Light Crude             | 41.8% |
| Domestic Light Crude                  | 30.2% |
| Bitumen (Canadian, Surface mining)    | 2.5%  |
| Bitumen (Canadian, In-situ)           | 2.0%  |
| Extra Heavy Oil/Syncrude (Venezuelan) | 1.0%  |
| Heavy Crude                           | 22.5% |

# Crude Oil Refining

- GREET default allocation values
  - 60–65% of total refining process energy use (and emissions) allocated to gasoline production
  - 18–22% to diesel production
  - Remaining 13–22% to other petroleum products
- GREET has different values for different types of gasoline and diesel fuel (based on different refining requirements)
  - Conventional gasoline and diesel fuel
  - Reformulated gasoline blendstock
  - California reformulated gasoline blendstock
  - Low sulfur diesel fuel

# Types of Fuels Modeled

- To represent baseline gasoline we considered the types of gasoline used in 2005
- Based on EIA data on sales of gasoline to end users in 2005
  - 57.4% was conventional gasoline
  - 28.4% was reformulated gasoline
  - 14.2% was California reformulated gasoline
- We also considered imported finished product vs. domestically produced gasoline
- According to EIA data, in 2005
  - 6.0% of conventional gasoline used was imported
  - 7.7% of reformulated gasoline was imported
- To represent baseline diesel fuel use we used a similar analysis and assumed 100% low-sulfur diesel fuel and 8.0% imported finished product

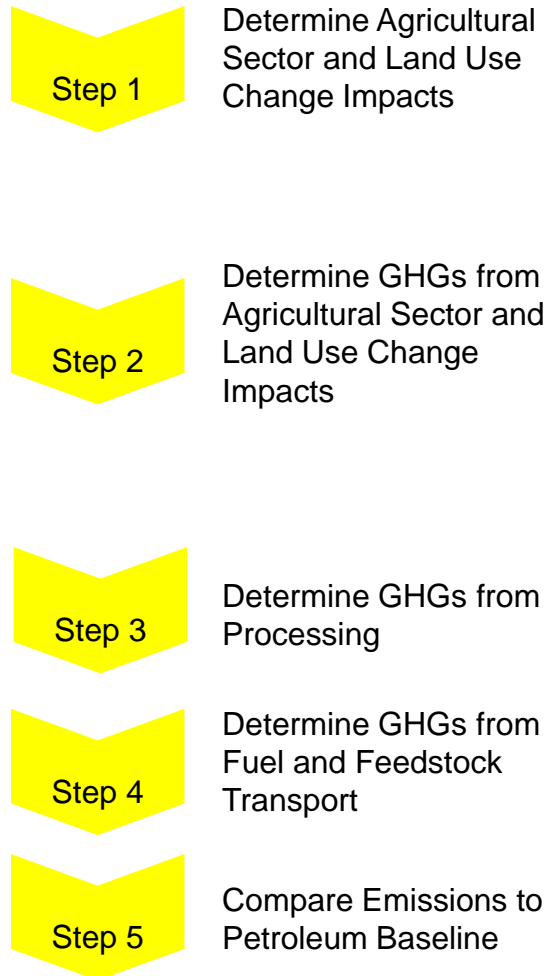
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# Next Steps

- Comparison to December 2008 Department of Energy's National Energy Technology Laboratory (NETL) report that estimates the average lifecycle GHG emissions from petroleum-based fuels sold or distributed in 2005
  - More specification on foreign crude production
- Other studies looking at well specific crude oil extraction emissions

# Steps for Determining Lifecycle GHG Emissions

## Steps in Lifecycle Analysis



## Lifecycle GHG Emissions

