Uncertainty in Life Cycle Estimates of Greenhouse Gas Emissions from Biomass Energy Feedstocks

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Outline

- **Motivate the need for uncertainty analysis**

- **Introduce the Calculating Uncertainty in Biomass Emissions (CUBE) Model**

- **Discuss major factors that influence emissions from biomass production, and the policy implications of uncertainty in these emissions**

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Estimates of Uncertainty in Greenhouse Gas Emissions of Biomass Production Are Needed

- **Reducing greenhouse gas (GHG) emissions is increasingly viewed as necessary**

- **Biomass-based fuels and electricity can potentially lower GHG emissions**

- **Life cycle assessment (LCA) can provide estimates of emissions from production, processing, transport, and use of biomass**

- **LCA literature treats uncertainty inconsistently**

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GHG Emissions from Biomass Production Are Highly Uncertain

- **System boundaries are not defined consistently**

- **Different biomass production, transport, and processing scenarios are considered**

- **Land-use change emissions are large, uncertain, and dynamic**

- **Data and scientific understanding about some phenomena are limited**

- **Commercial biomass production for energy is a nascent, rapidly evolving activity**

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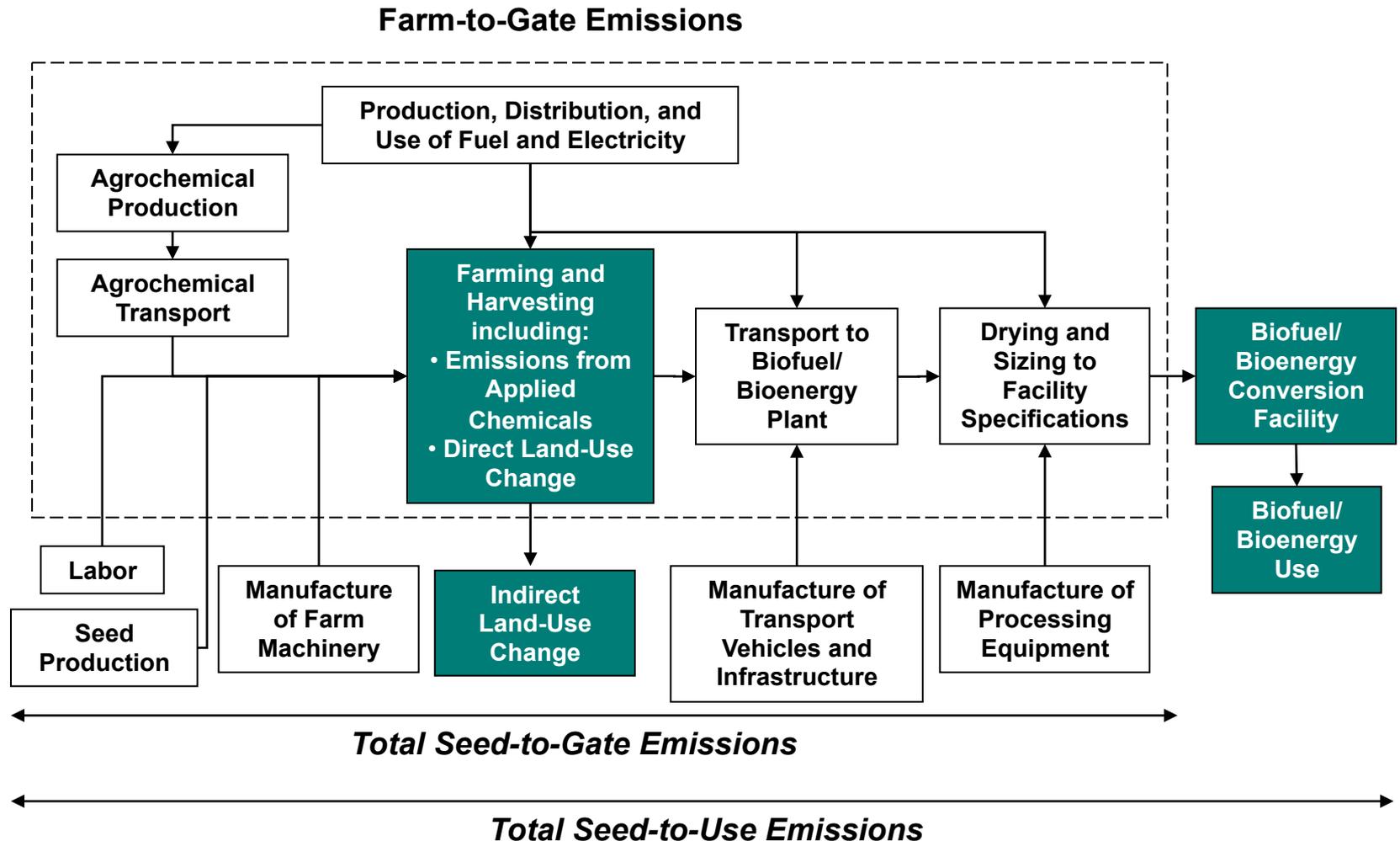
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Overview of CUBE Approach
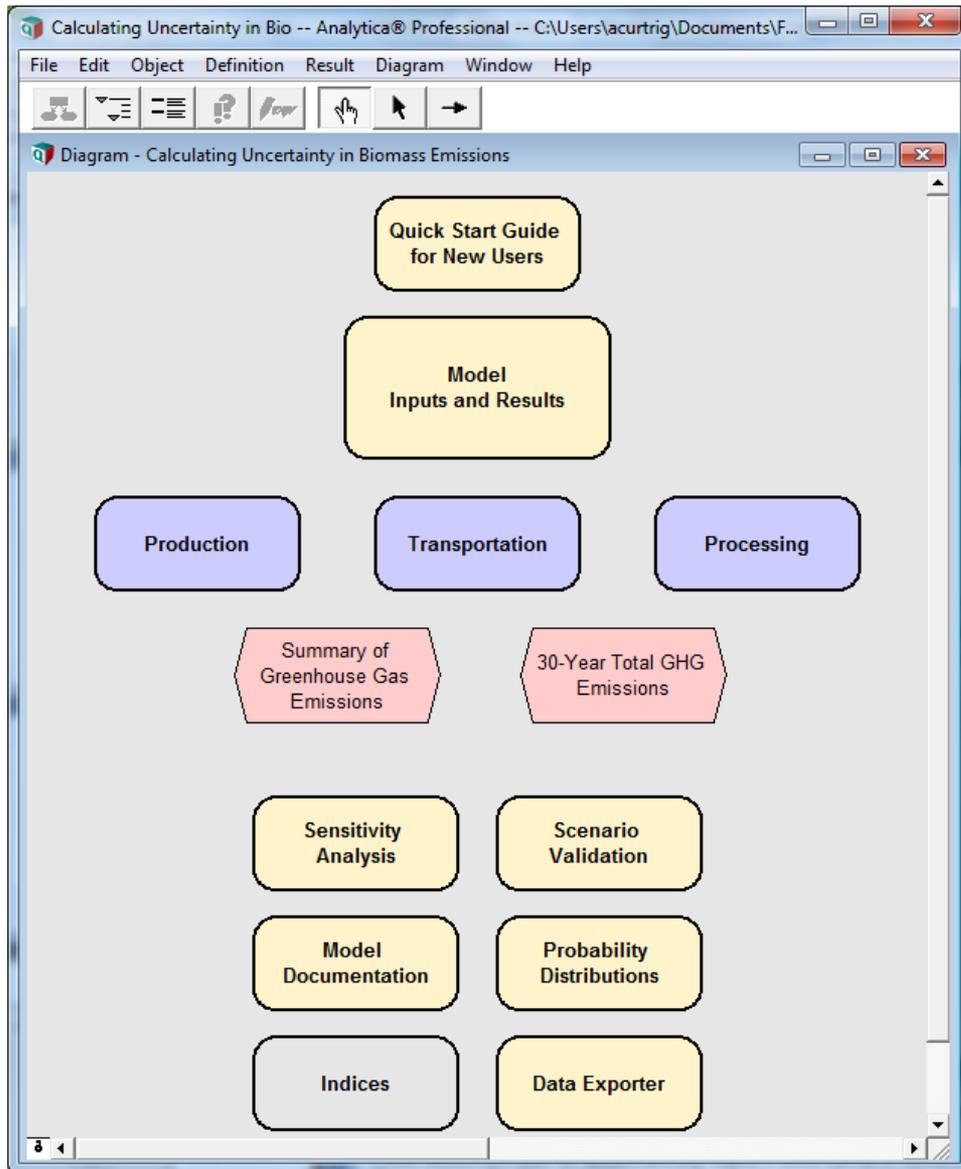
The Calculating Uncertainty in Biomass Emissions (CUBE) model:

- **Segments life cycle into production, transportation, and processing**

- **Includes seven feedstocks:**
  - **switchgrass, mixed prairie biomass, corn grain, corn stover, hybrid poplar**
  - **forest residue, mill residue**

- **Based on consultation with biomass-energy experts**
  - **Bruce Dale, Jason Hill, and Bill Berguson**

- **A tool for analyzing the life cycle inventory of emissions from biomass production**

- **Publicly available at:**
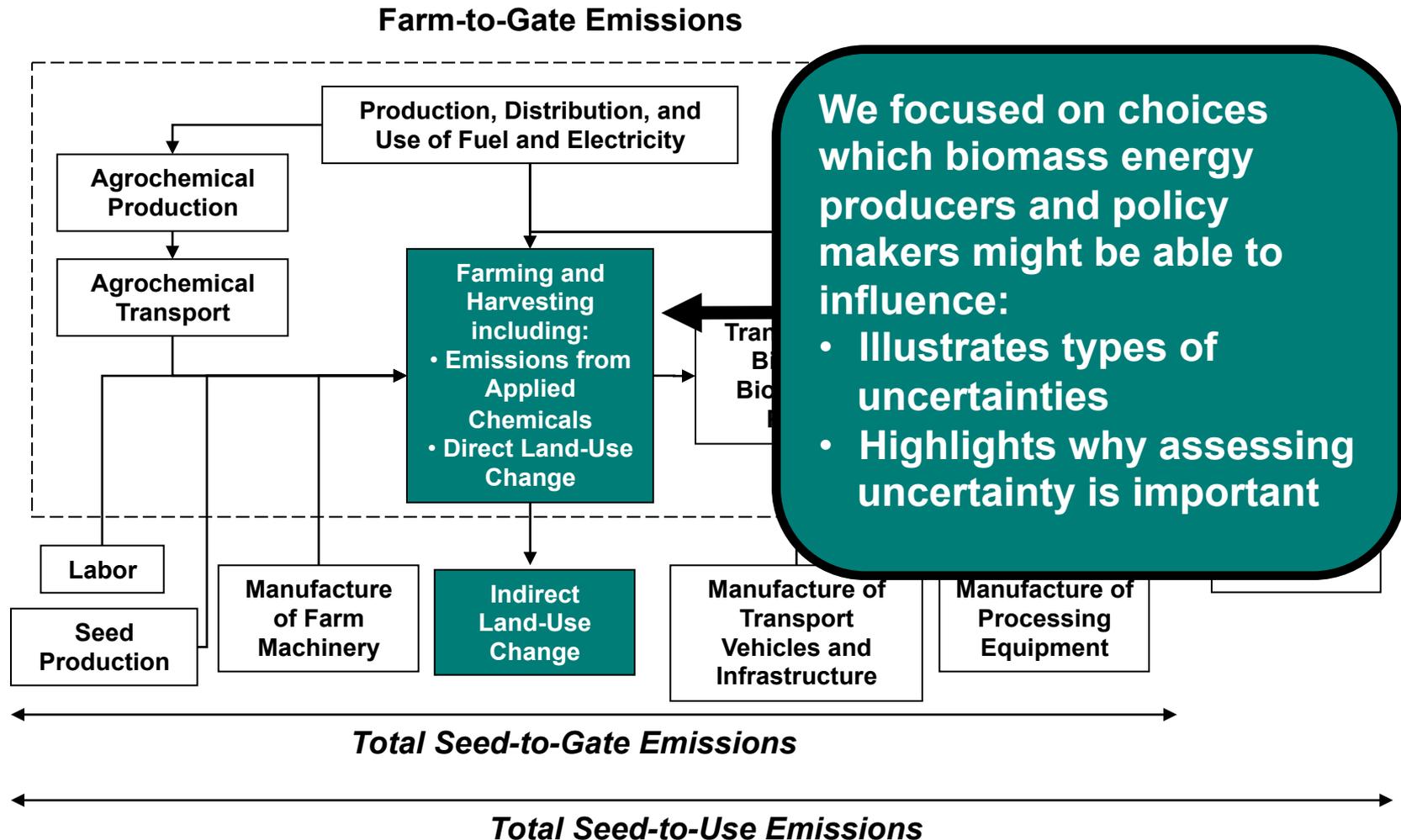 **www.rand.org/ise/projects/ bioemissions.html**

CUBE Captures Many of the Activities That Contribute to GHG Emissions

Farm-to-Gate Emissions

Total Seed-to-Gate Emissions

Total Seed-to-Use Emissions

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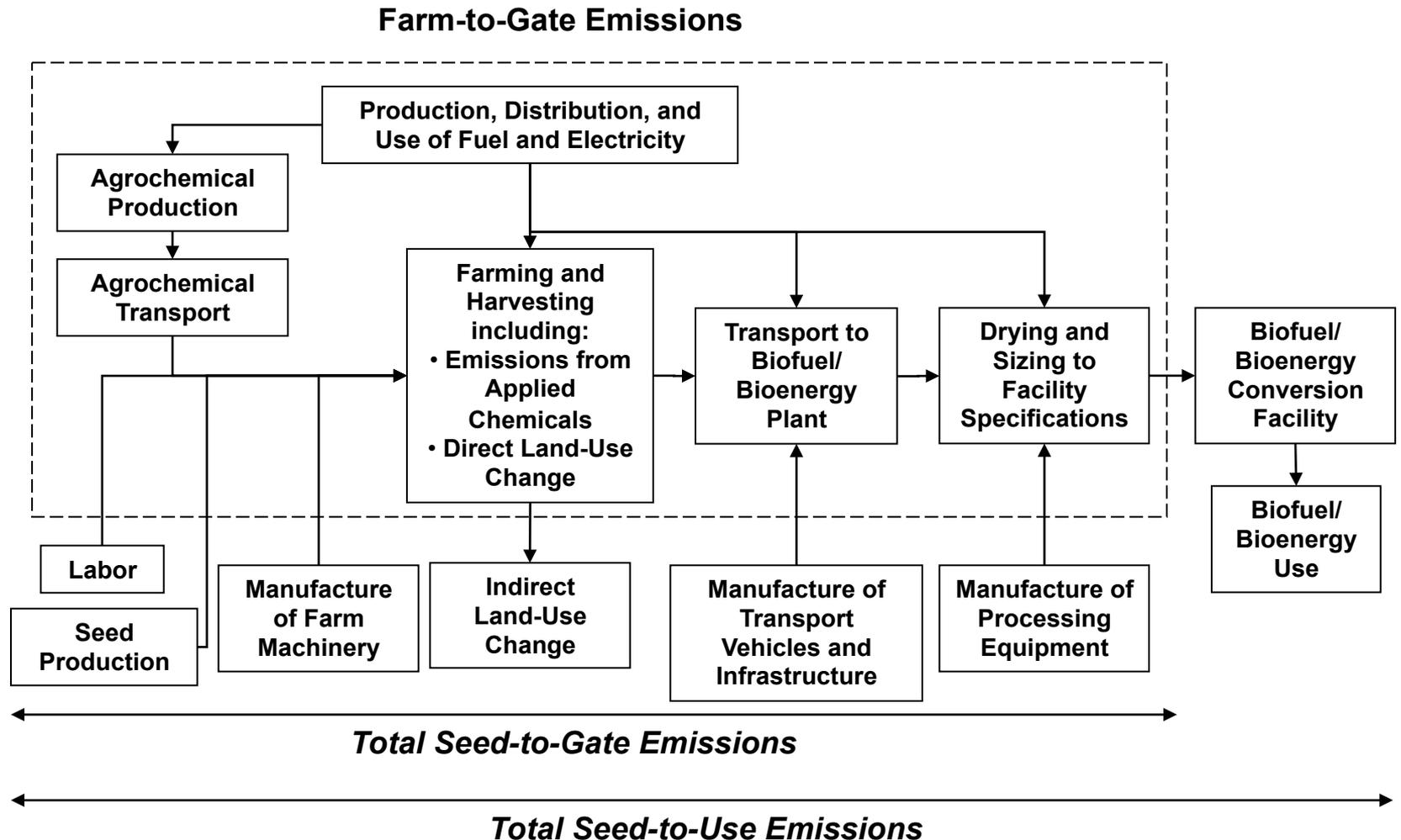
Four Categories Are Responsible for Most Emissions…

Farm-to-Gate Emissions

Total Seed-to-Gate Emissions

Total Seed-to-Use Emissions

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… Two of These May Still Be Uncertain Even After Biomass Conversion Decisions Have Been Made

Farm-to-Gate Emissions

Production, Distribution, and Use of Fuel and Electricity

Agrochemical Production

Agrochemical Transport

Farming and Harvesting including:
- **Emissions from Applied Chemicals**
- **Direct Land-Use Change**

Labor

Seed Production

Manufacture of Farm Machinery

Indirect Land-Use Change

Manufacture of Transport Vehicles and Infrastructure

Manufacture of Processing Equipment

We focused on choices which biomass energy producers and policy makers might be able to influence:
- Illustrates types of uncertainties
- Highlights why assessing uncertainty is important

Total Seed-to-Gate Emissions

*Total Seed-to-Use Emissions*

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Farming and Harvesting Emissions are Dominated by Direct Land Use Emissions
(Example 1: Switchgrass)

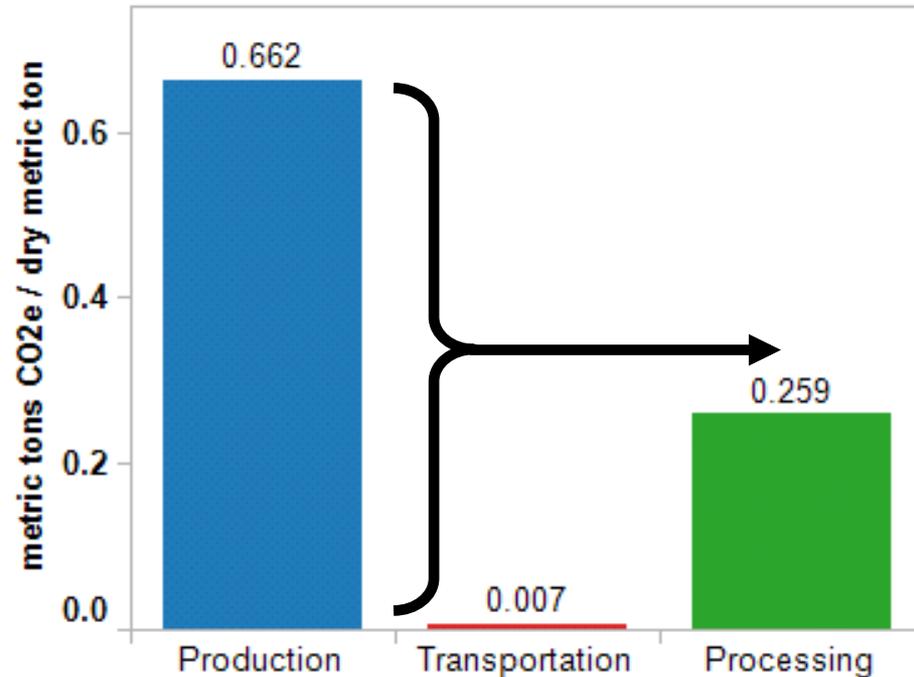(a) Switchgrass Farm-to-Hopper GHG Emissions by Life Cycle Stage
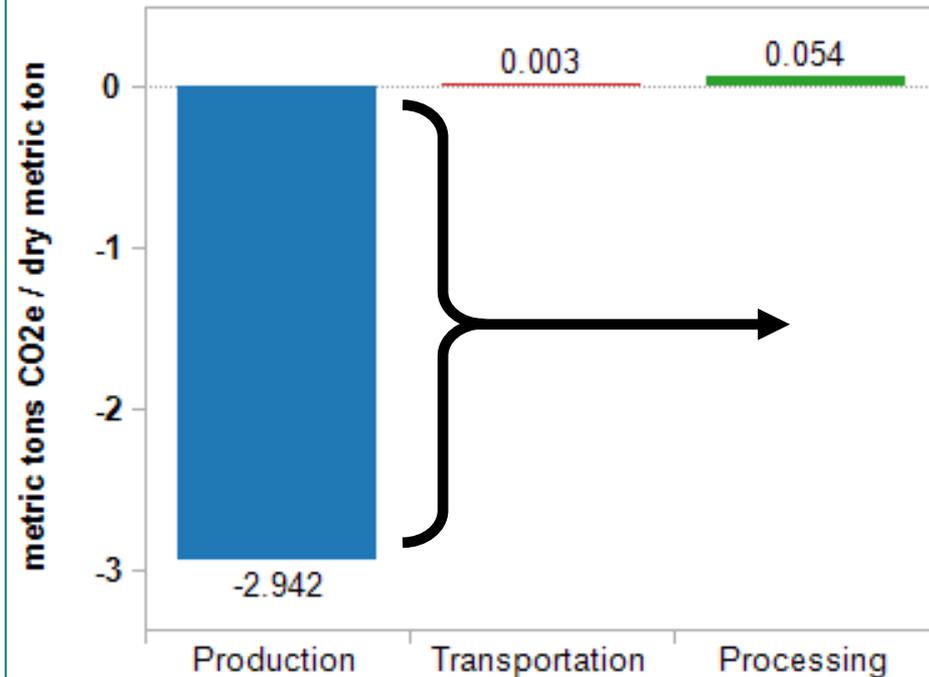
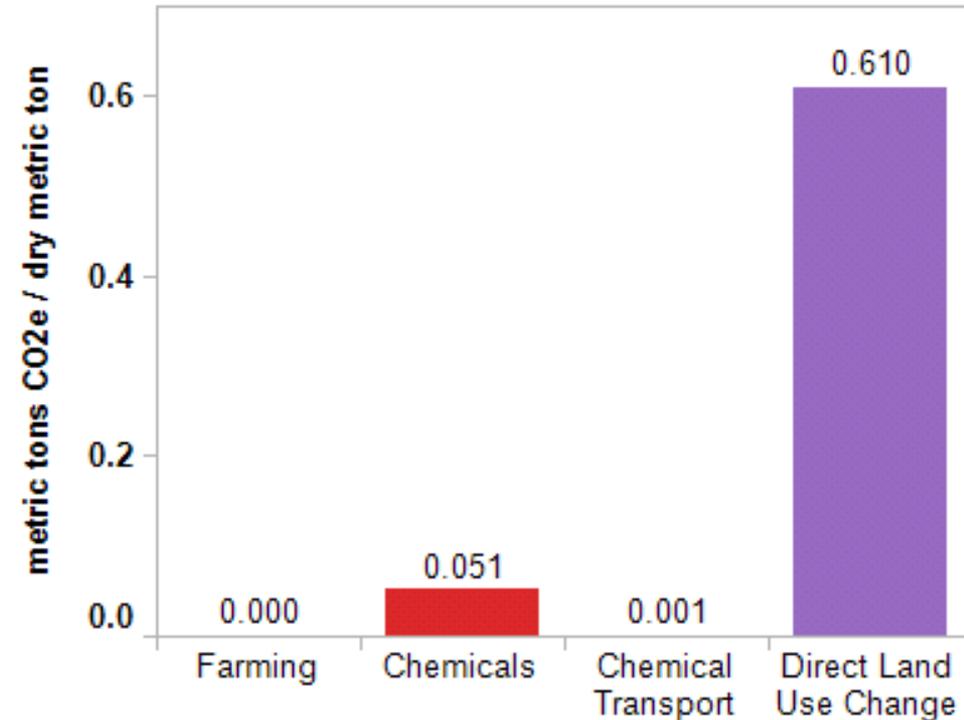(b) Switchgrass Production GHG Emissions by Source
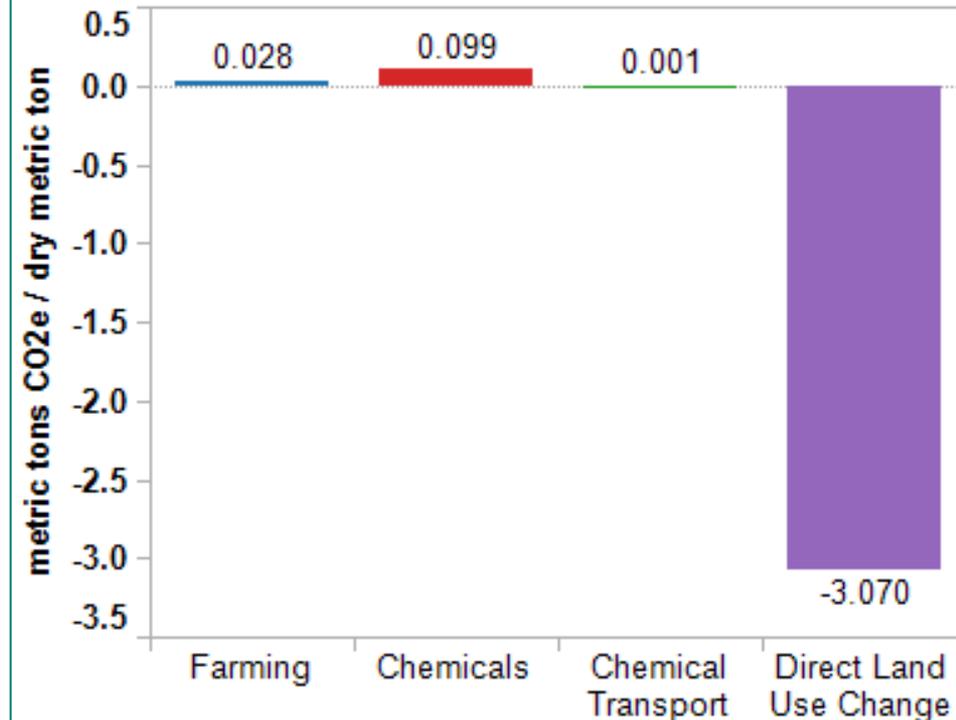
- **Switchgrass** grown on former row crops
- **Corn Belt region of U.S.**
- **Emissions in years 2-5**
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

Farming and Harvesting Emissions are Dominated by Direct Land Use Emissions
(Example 1: Corn Stover)

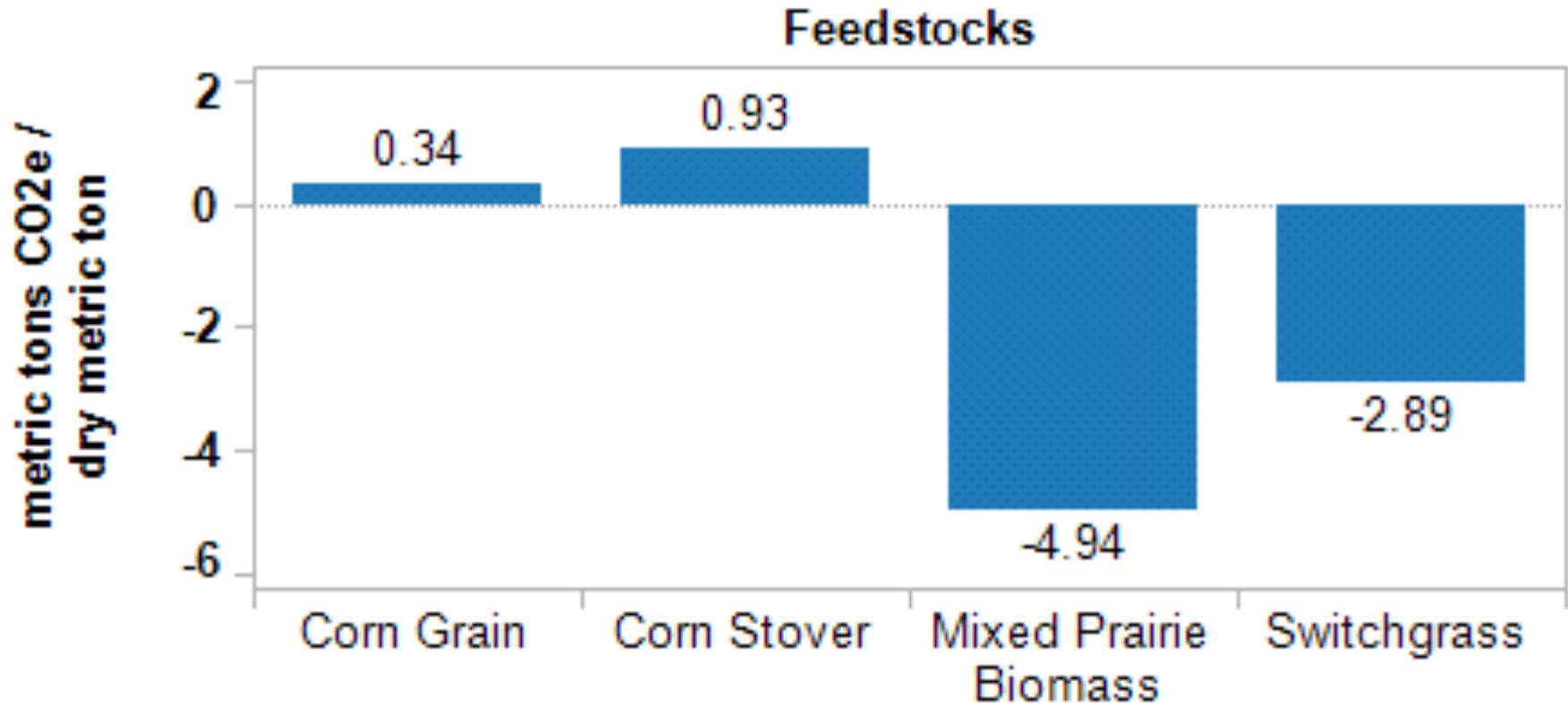(c) Corn Stover Farm-to-Hopper GHG Emissions by Life Cycle Stage

(d) Corn Stover Production GHG Emissions by Source

- **Corn stover** grown on former row crops
- Corn Belt region
- Emissions in years 2-5
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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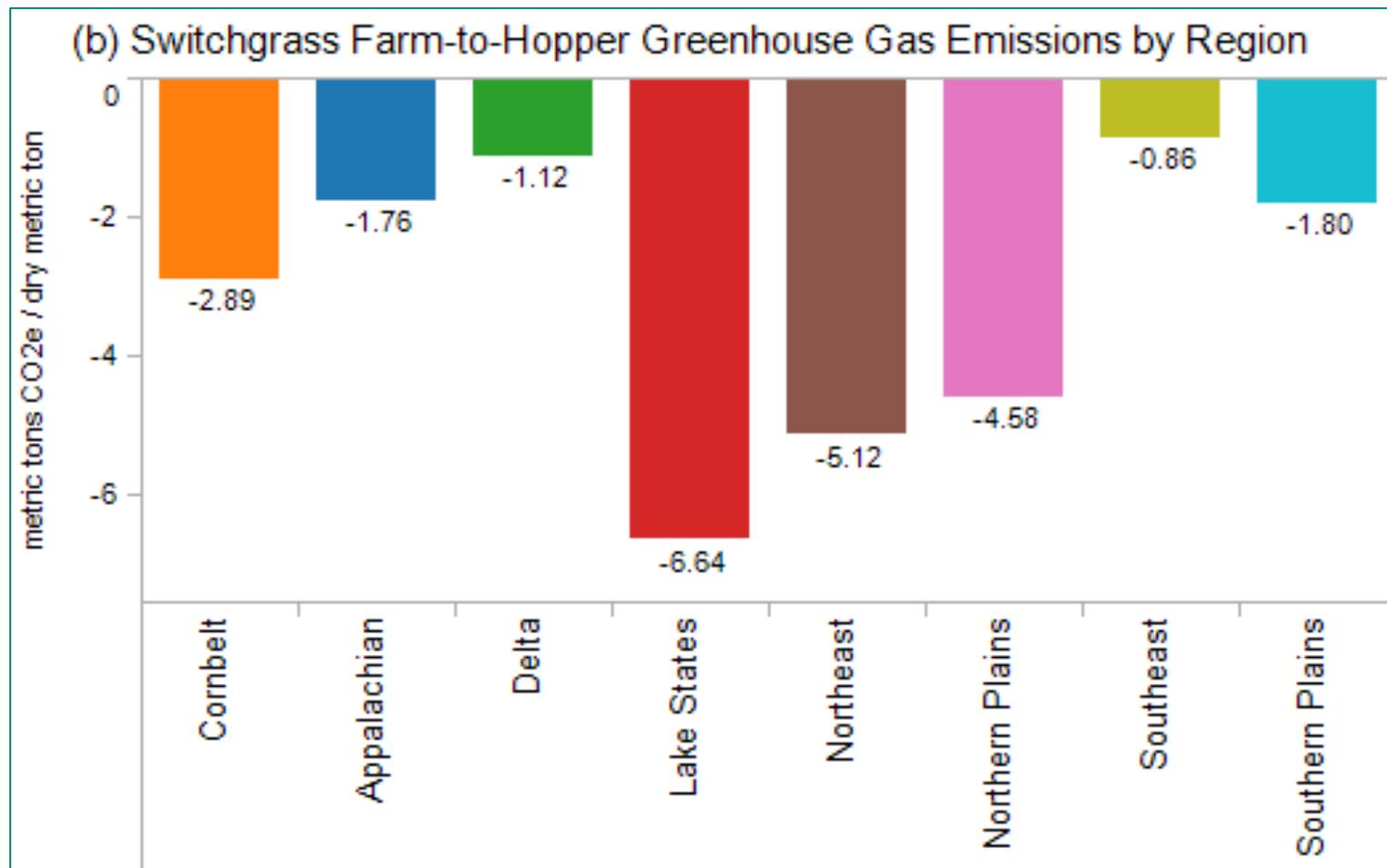# *Some Crops Are Carbon Sinks, Others Are Sources*

Total Farm-to-Hopper GHG Emissions

Feedstocks

- **All feedstocks** grown on former row crops
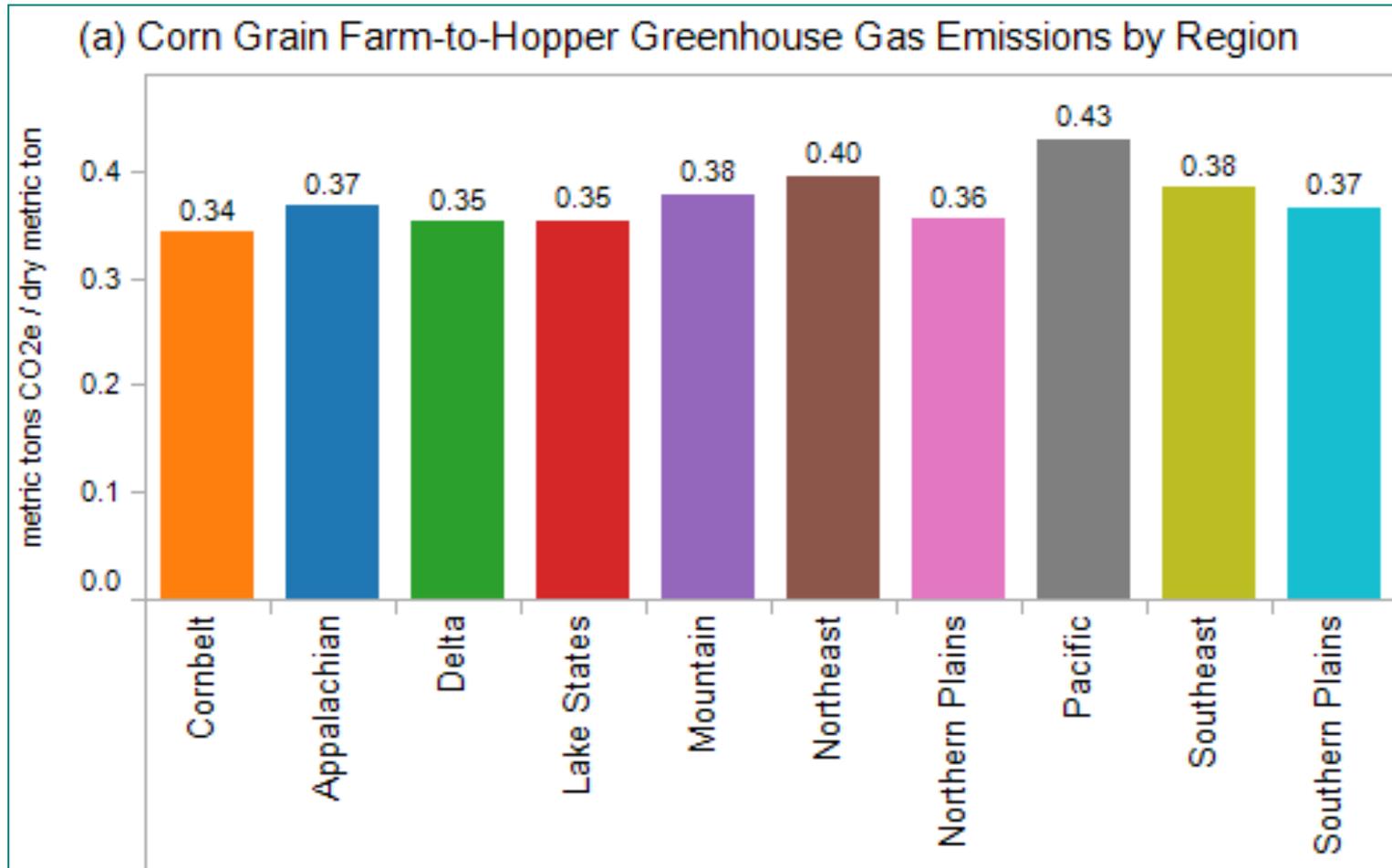- Corn Belt region
- Emissions in years 2-5
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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Geographic Region Matters
(Example 1: Switchgrass)

(b) Switchgrass Farm-to-Hopper Greenhouse Gas Emissions by Region

y-axis: metric tons CO_2e / dry metric ton

- Cornbelt: -2.89
- Appalachian: -1.76
- Delta: -1.12
- Lake States: -6.64
- Northeast: -5.12
- Northern Plains: -4.58
- Southeast: -0.86
- Southern Plains: -1.80

- **Switchgrass** grown on former row crops
- **Emissions in years 2-5**
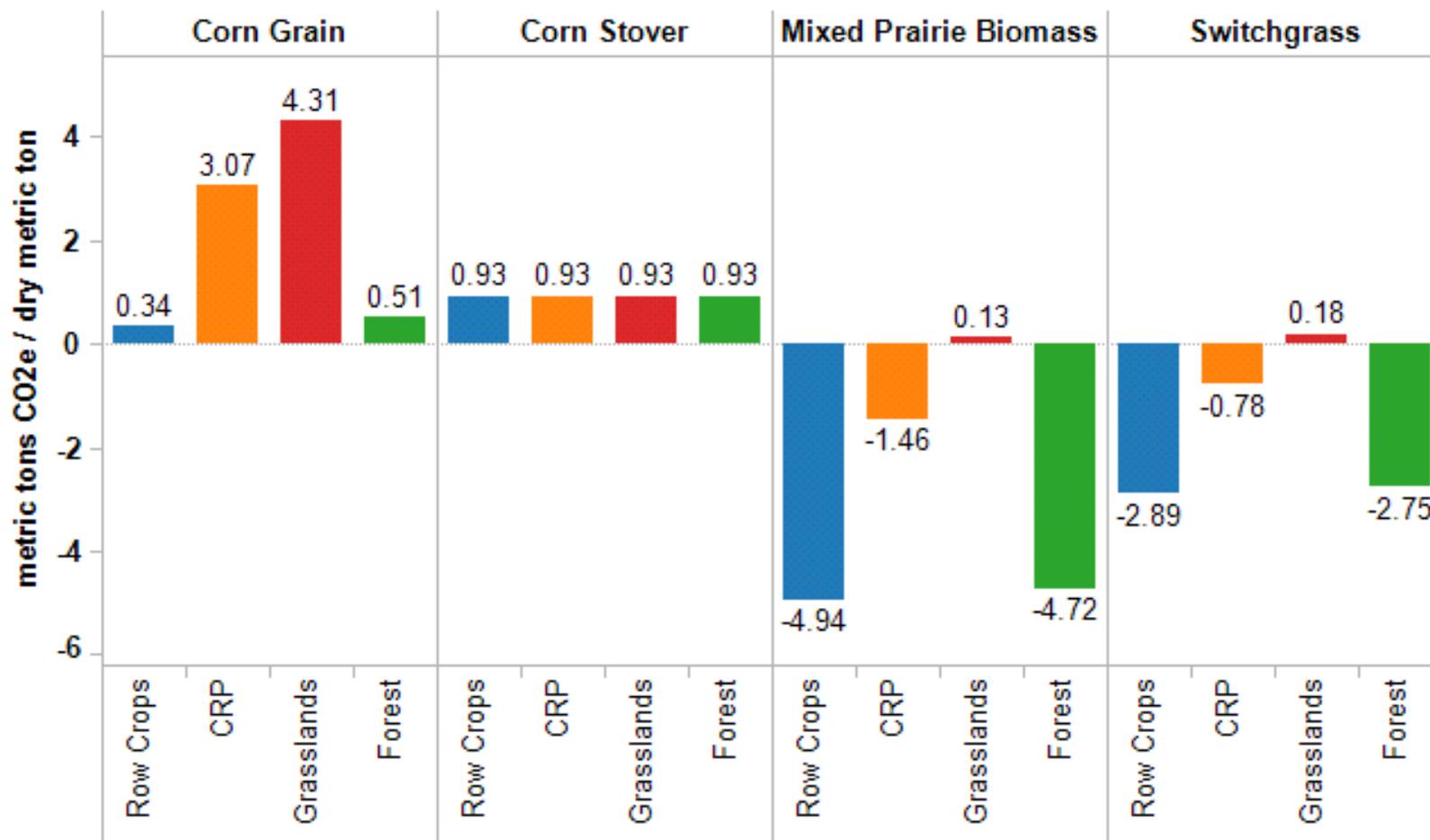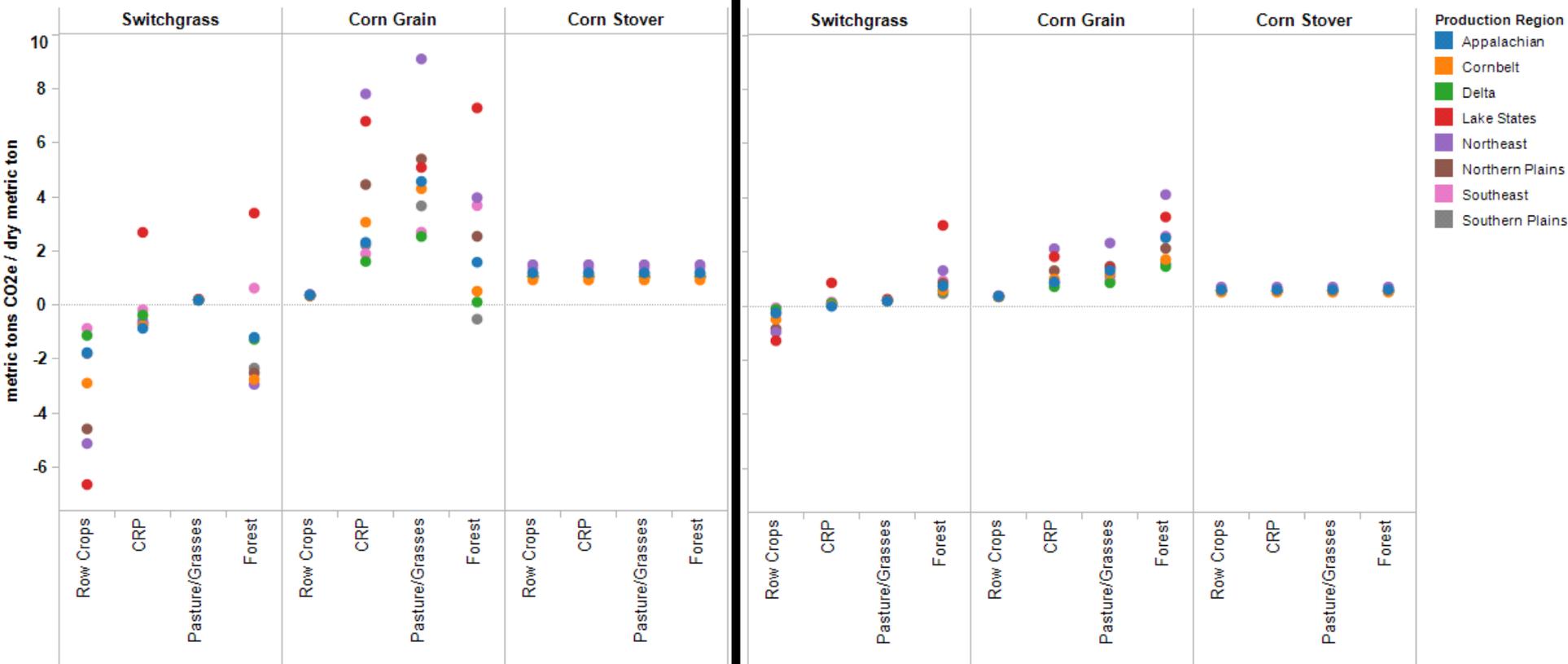- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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Geographic Region Matters
(Example 2: Corn Grain)

(a) Corn Grain Farm-to-Hopper Greenhouse Gas Emissions by Region

y-axis: metric tons CO2e / dry metric ton

Region	Value
Cornbelt	0.34
Appalachian	0.37
Delta	0.35
Lake States	0.35
Mountain	0.38
Northeast	0.40
Northern Plains	0.36
Pacific	0.43
Southeast	0.38
Southern Plains	0.37

- **Corn grain** grown on former row crops
- **Emissions in years 2-5**
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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… And Prior Land-Use May Matter Even More

Total Farm-to-Hopper Greenhouse Gas Emissions by Baseline Ecosystem

- **All feedstocks** grown in the Corn Belt region
- **Emissions in years 2-5**
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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Direct Land-Use Change Diminishes With Time

Total Farm-to-Hopper GHG Emissions by Feedstock and Baseline Ecosystem

- **All feedstocks** grown in the Corn Belt region
- **Emissions in years 2-5 AND average per metric ton emissions over 30 years**
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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Yields and Nitrogen Emissions Are the Most Critical Data Uncertainties In Most Scenarios
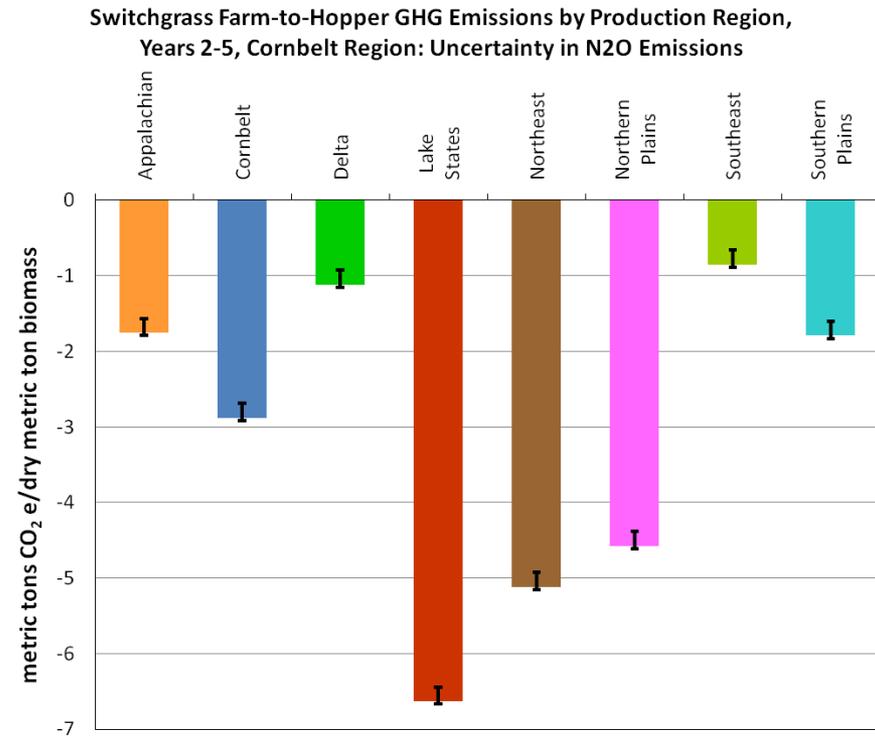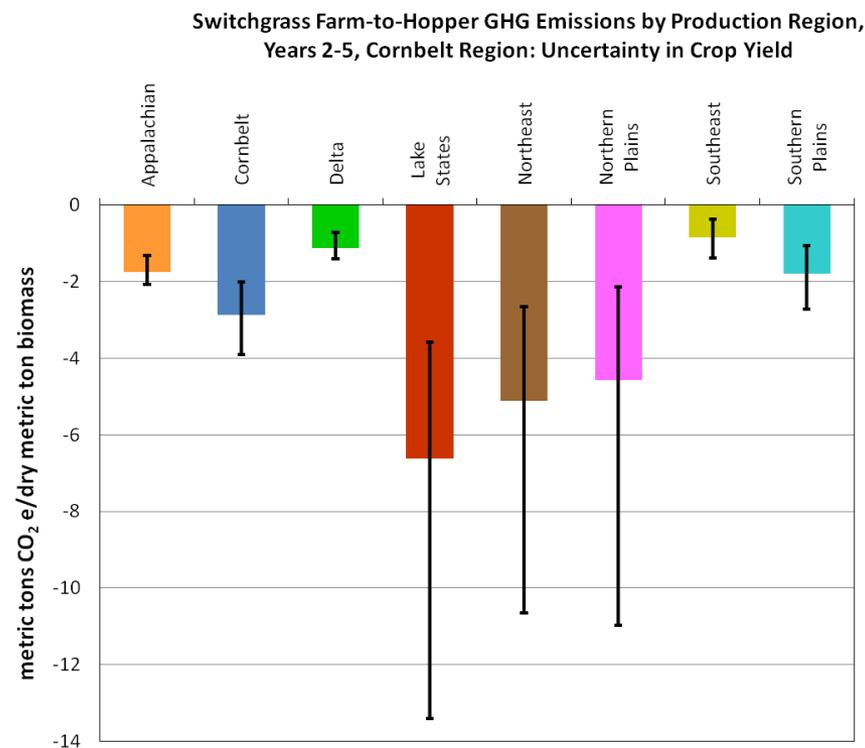
- **Switchgrass** grown on former row crops
- **Average annual emissions for years 2-5**
- *Positive values indicate net GHG emissions, negative indicate net carbon storage*

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Uncertainty in Farm-to-Gate Emissions Can Impact Net GHG Benefits of Biomass Use

Fuel Type	Life Cycle Stage	GHG Intensity (metric tons CO_2e/GJ)
Switchgrass	Total Farm-to-Hopper	**-0.116**
Corn Stover	Total Farm-to-Hopper	**0.0546**
Forest Residue	Total Farm-to-Hopper	**0.00333**
Subbituminous Coal	Full Life Cycle	**0.125**
Assumptions: switchgrass and corn stover grown in Corn Belt on former row crops; forest residue in Corn Belt.		

- **Under these specific scenarios**
    - **Corn stover reduces GHGs >50% relative to coal**
    - **Forest residue: 97% relative to coal**
    - **Switchgrass: 100%, and then sequesters 90% more**
- **Majority of scenarios produce a net GHG benefit relative to coal**
- **Scenario and data uncertainty will significantly change both the magnitude of the benefit and the associated *cost per metric ton of CO_2e avoided***

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Summary

- CUBE improves understanding about the potential GHG intensity of biomass-based energy
  - Formalizes a method of accounting for emissions
  - Supports comparison of different life cycle analyses

- Helps identify key areas of data uncertainty

  - Scientific inquiry into crop yields, nitrogen release rates, and soil-root carbon processes can reduce uncertainty

- Allows exploration of scenario uncertainty that is important to decision-making
  - Identify which scenarios can turn biomass from being a net sink to a source
  - Identify which biomass production scenarios meet mandates (e.g., RFS2, EISA)
  - Inform development of improved policies
  - Estimate the costs of mitigating climate change with biomass

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Acknowledgments

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- **CUBE 1.0 Review: Thomas Light (RAND), Bob Dilmore (NETL)**
- **CUBE 2.0: Justin Adder (NETL), Mike Griffin (Carnegie Mellon University), David Groves (RAND)**

- **Model and information: www.ise.rand/ise/projects/bioemissions.html**
- **Contact: acurtrig@rand.org**

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…But That Depends Heavily on the Prior Land Use
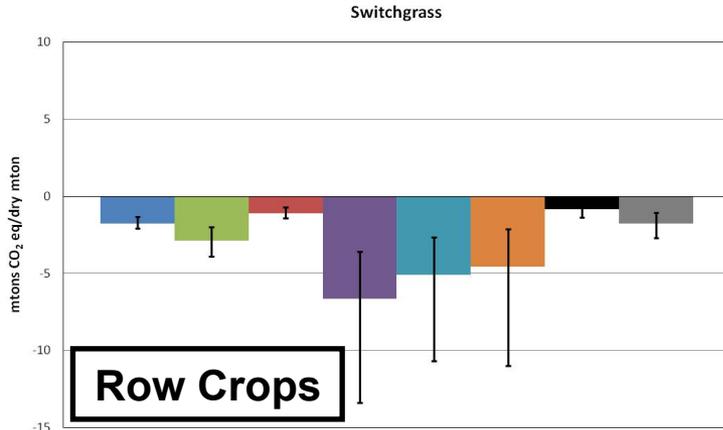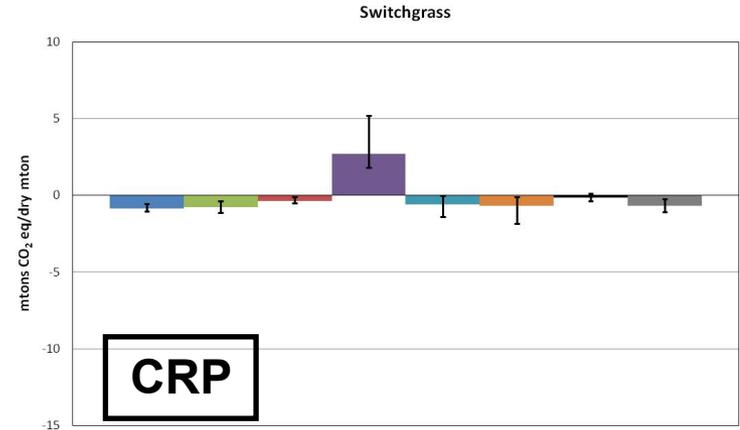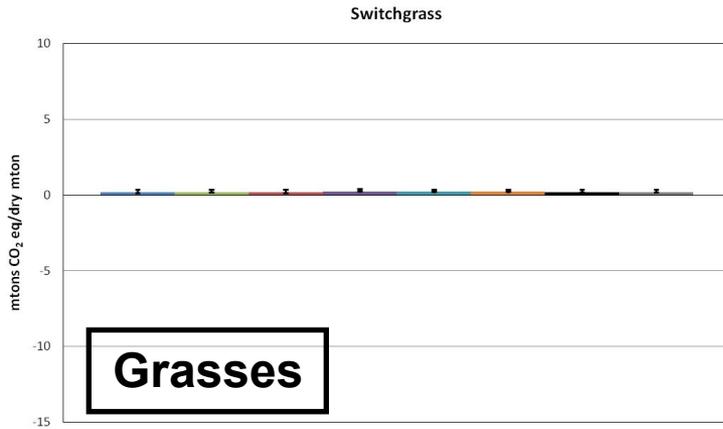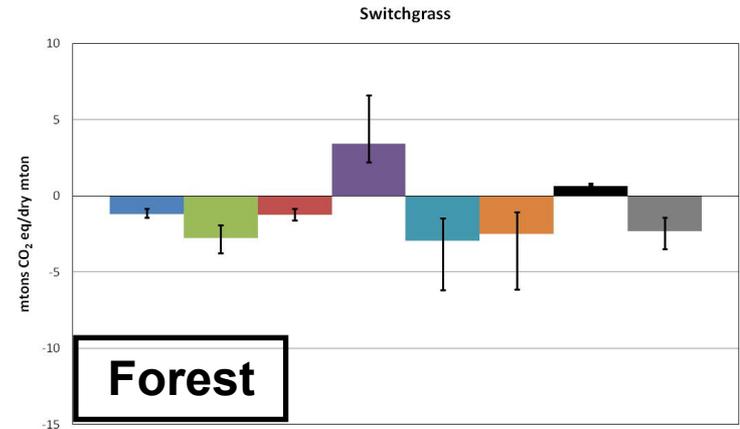
Average annual emissions for years 2-5

Yields and Nitrogen Emissions Are the Most Critical Data Uncertainties In Certain Scenarios

Greenhouse Gas Emissions from Switchgrass Production
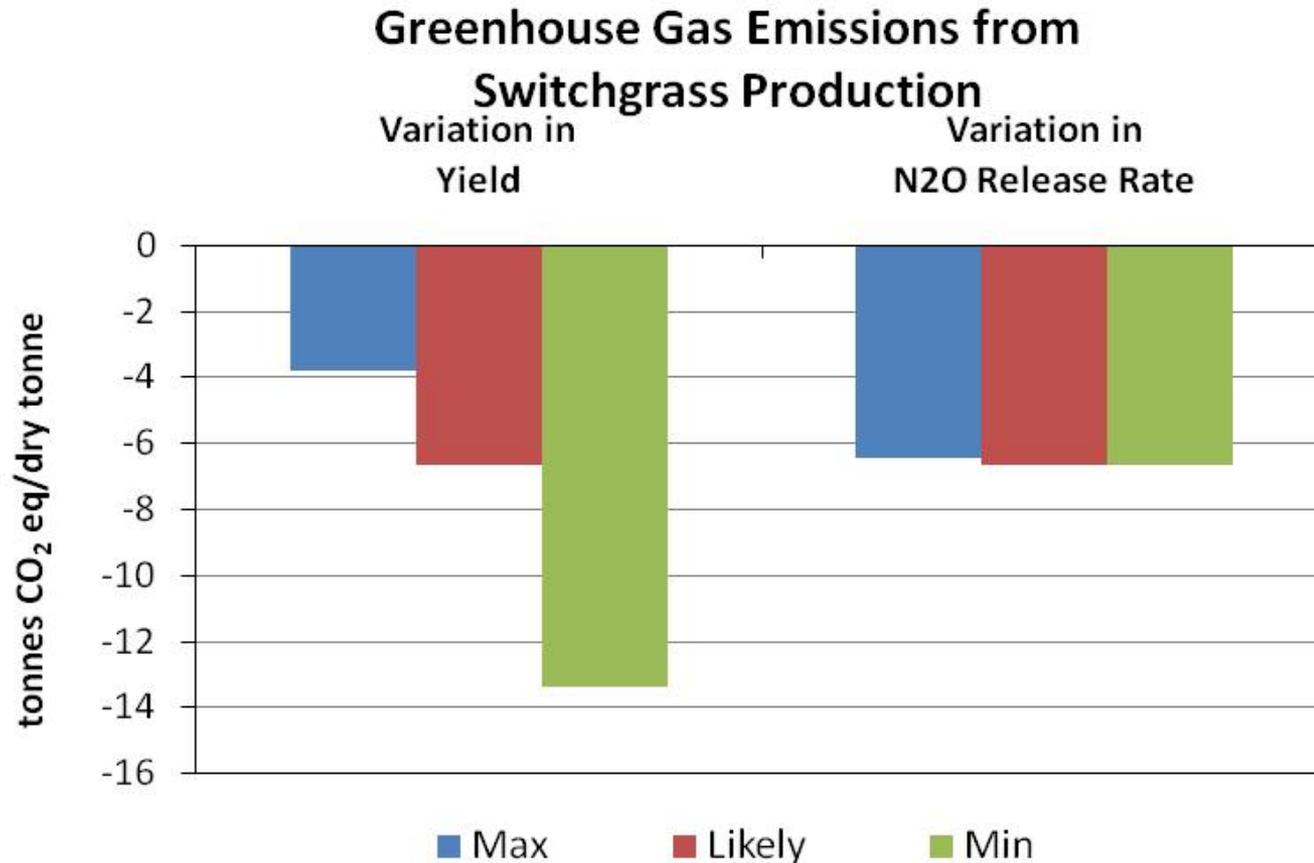
- Grown on row crops
- Lake States region
- Annual emissions for years 2-5