Life-Cycle Analysis of Bioethanol Fuel

Steffen Mueller, PhD, University of Illinois at Chicago
Energy Resources Center

UIC ENGINEERING

Seoul, Korea

May, 2017

THE UNIVERSITY OF ILLINOIS AT CHICAGO

UIC

Introduction

- University of Illinois at Chicago has 29,000 students
- One of the largest research universities in the state.
    - We conduct a lot of international research projects
    - I am managing the Bioenergy and Land Use Research Center

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

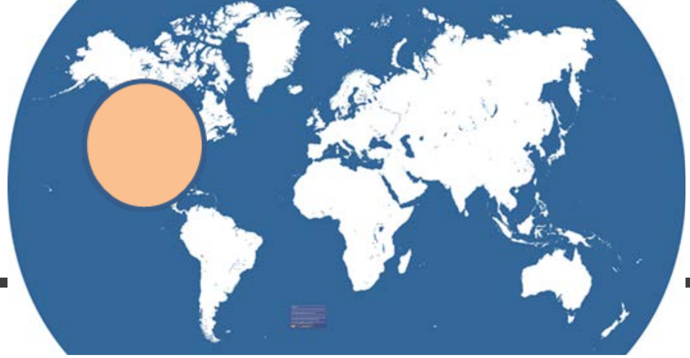
Presentation Overview

- Review of Regulations Around the World that Recognize Biofuels' Role in Reducing Greenhouse Gas Emissions
- Overview of Life Cycle Modeling
    - Why do Modern Ethanol Plant Technologies Provide Significant CO_2 Reductions
- Life Cycle Greenhouse Gas Modeling Results Around the World
- Summary Points

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Review of Regulations Around the World that Recognize Biofuels' Role in Reducing GHG Emissions

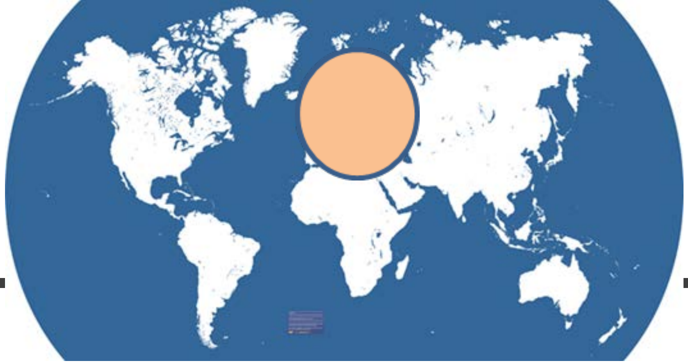
Biofuels and Climate: United States Efforts



- Many policy and regulatory structures around the globe recognize biofuels' potential to reduce global warming.
- In the US the **Low Carbon Fuel Standards (LCFS)** in California and Oregon as well as the expanded **Renewable Fuels Standard (RFS2)** have successfully reduced carbon emissions from transportation fuels.
  - RFS2 provides **volumetric blending requirements** for biofuels whereas
  - Fuel suppliers under the LCFS need to meet **performance based GHG reduction** targets from a fuel mix of their choice.
- The RFS2 creates GHG reduction categories for four types of fuels: biomass-based diesel, cellulosic biofuel, advanced biofuel, and renewable/conventional fuel. For example, corn ethanol must meet a 20% lifecycle GHG reduction threshold, while advanced biofuels produced from qualifying biomass must meet a 50% reduction in GHG emissions.
- The LCFS in California requires a 10% reduction in the carbon intensity of transportation fuels by 2020.
- Both RFS2 and LCFS consider emissions from land use change

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

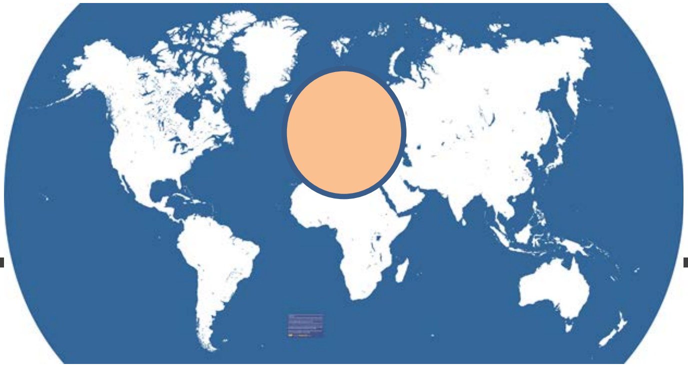
Biofuels and Climate: European Union Efforts



- The EU "Fuel Quality Directive" is similar to the California LCFS but with different GHG reduction targets, whereas Japanese efforts under the "Act on the Promotion of the Use of Nonfossil Energy Sources" are more in line with the RFS2 approach of volumetric blending requirements.
- Significant differences exist between these international efforts in the treatment of emissions related to land use change (LUC) prompted by biofuels production.
- In Europe, due to the evolving science and uncertainties associated with quantifying emissions from LUC, the Fuel Quality Directive does track but **does not include** emission from LUC in a fuel's GHG assessment.
- Corn ethanol must achieve a GHG reduction **of 35% over gasoline (with an increasing threshold starting in 2018 to 50% for existing plants and 60% for New Plants).**
- However, biofuels must be certified for sustainable production based on an EU-approved certification protocol.

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Biofuels and Climate: European Union Efforts

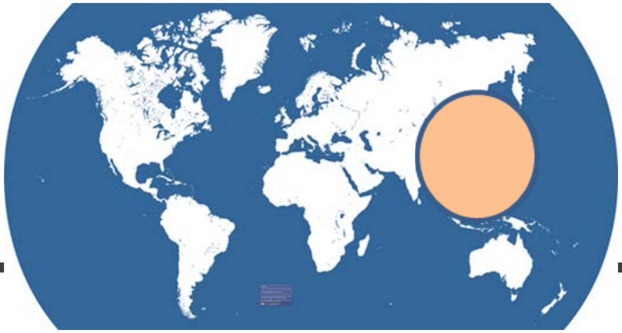


Sustainability Certification

- During the 2010-2011 time frame many US-based ethanol plants exported ethanol to the EU which also required a third party certification (e.g by International Sustainability and Carbon Certification – ISCC) of the greenhouse gas reductions and additional sustainability criteria such as feedstock sourcing from non-deforested land.
- **23 plants in the US were ISCC certified to export from US to Europe.** The certified plants span a wide range of technologies, owner entities, and geographic locations.
- Note that several other US-based plants would have met the EU GHG reduction threshold but may have chosen not to participate in the export markets to Europe

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

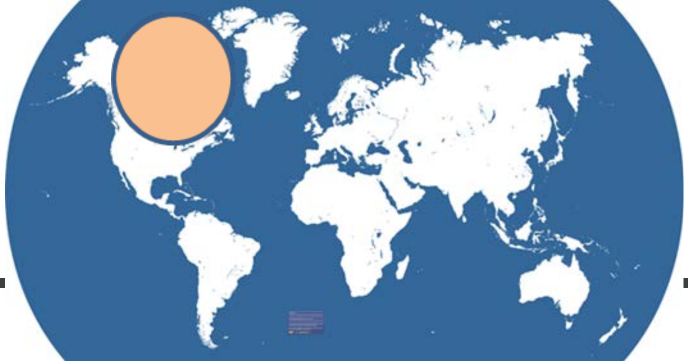
Biofuels and Climate: Asia Region



- Japan is increasing its biofuels blending volumes for gasoline over the next years.
- Imported ethanol and ETBE additives **must meet a 50% reduction threshold of biofuels over gasoline** set by the “Act on special accounts and the measures for the enhancement of the energy supply-demand structure.”
- Emissions from LUC are considered but only those associated with direct LUC have to be included in the life cycle modeling effort.
- We showed that large US produced ethanol volume would meet the Japanese GHG reduction threshold

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Biofuels and Climate: Canadian, Brazil, Columbia



- **<u>Canada</u>** is Developing **<u>Federal Clean Fuel Standard (CFS)</u>**
    - Similar to California Low Carbon Fuel Standard
- **<u>Columbia</u>** is Developing Guidelines to Include Ethanol from Sugarcane and Corn in their Decarbonization Strategy
- **<u>Brazil</u>** has long history of ethanol use from sugarcane (and qualifying it under carbon regulations around the world)

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Overview of Life Cycle Modeling

Decarbonization is a Metric of Efficiency

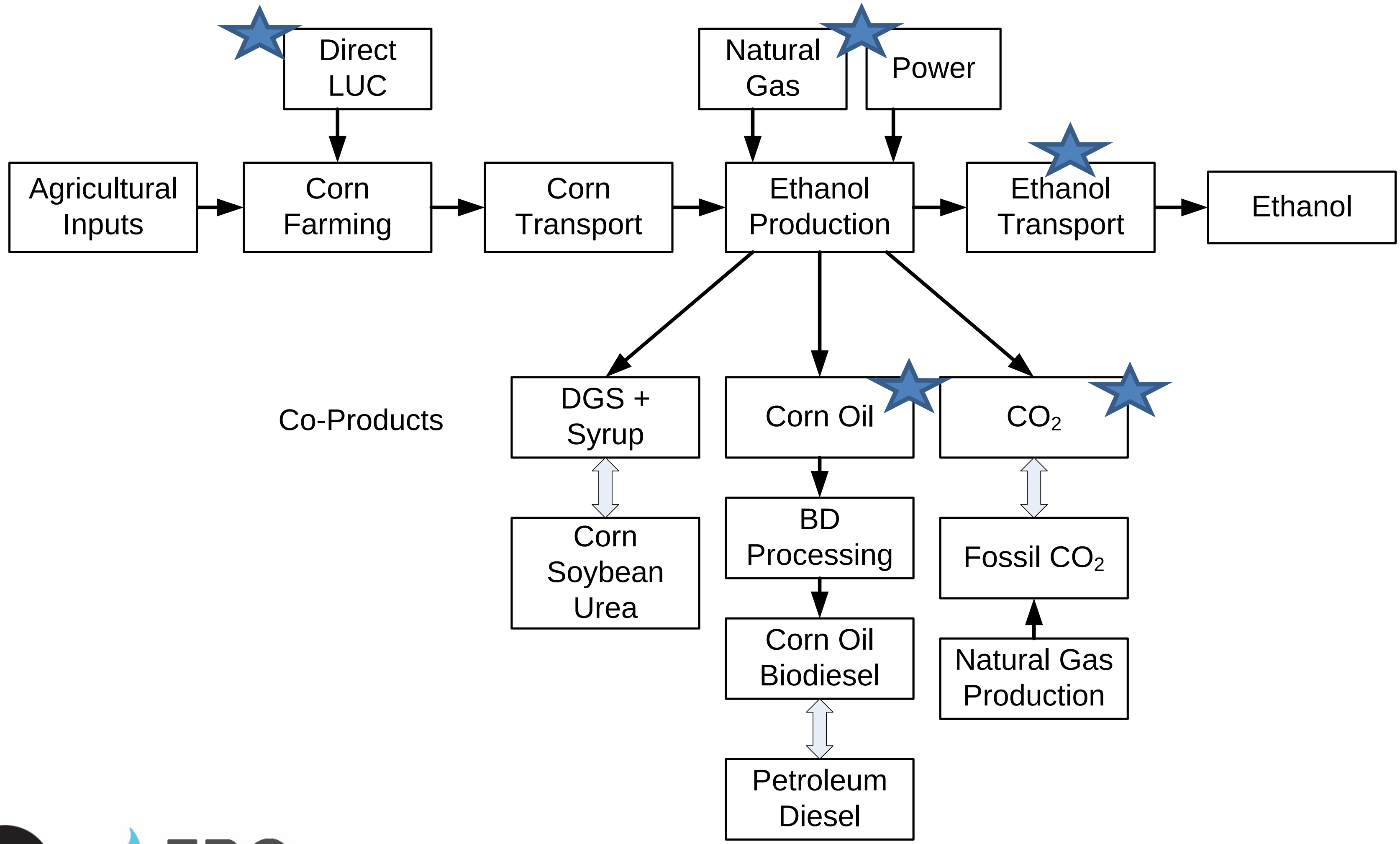
Climate Change:
Greenhouse Gas Life Cycle Assessment

- When comparing the energy, efficiency and emissions impact of different fuels and vehicle technologies researchers around the world use what is called life cycle models.
  - In the US the dominant and most updated life cycle model is the **GREET** model developed by Argonne National Laboratory.
  - In Canada, the dominant model is **GHGenius**
  - In Europe a common life cycle model is called **Biograce**
- While several different life cycle models exist around the world the basic concept is always the same
- We look at the individual emissions released during the different production stages to make a fuel followed by the emissions incurred during the combustion of this fuel.

Corn Ethanol

- For ethanol, for example, we look at the emissions
  - incurred during the growing of the corn or sugarcane feedstock including
  - tractor emissions,
  - nitrogen and other nutrient emissions,
  - emissions from feedstock conversion at the ethanol plant and
  - emissions from combustion of ethanol in the vehicle.
- However, emissions credits are given for
  - co-products produced at the biorefineries such as
  - animal feed produced with corn ethanol
  - and cogenerated electricity often produced at sugarcane ethanol plants.
- The international metric is grams of carbon dioxide emitted per megajoule (gCO_2/MJ)

Introduction to Life Cycle Modeling: System Boundary for Selected Corn Ethanol Pathway



UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Modern Ethanol Plant Technologies Provide Significant CO_2 Reductions

Selected New Technologies that Provide CO_2 Reductions

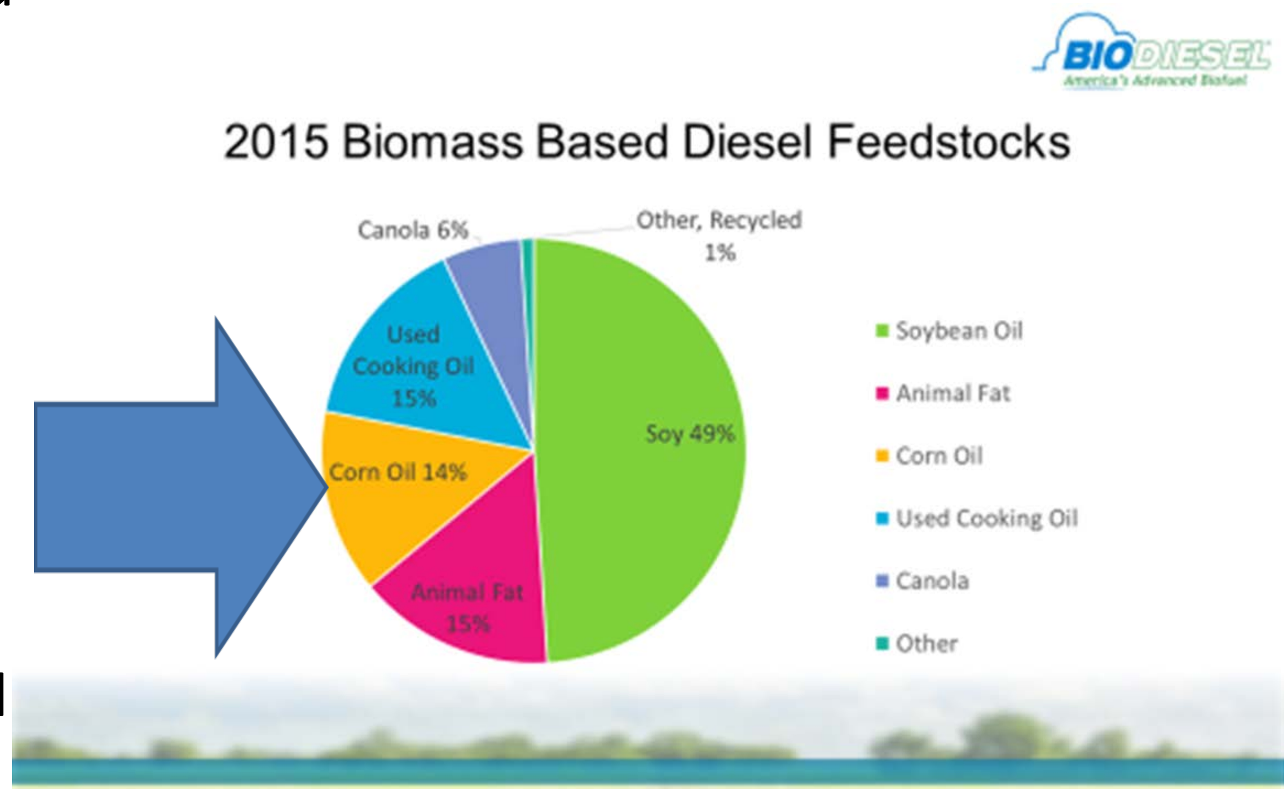
- Modern plants not only produce **ethanol** but **also corn oil** which often goes into biodiesel production or animal feed
- Many ethanol plants **recover CO_2 for Food Industry** or Enhanced Oil Recovery
- Ethanol plants have become very **energy efficient**
  - Use of heat integration, combined heat and power
  - Use of Enogen corn trait
- Many ethanol plants sell at least some of their animal feed (distillers grains) in wet form which saves drying energy
- Some ethanol plants look at Anaerobic Digesters to generate their own energy
- **High corn rotatio**ns on corn land supplying ethanol plants accumulate carbon over time: **Soil Carbon Sequestration**

Technologies will be detailed in the following slides

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Corn Oil to Biodiesel

- Corn oil separated at ethanol plants provides feedstock for biodiesel production
- Two Uses:
  - Sale into Animal Feed Markets
  - Substitution for petroleum based diesel fuel



Life Cycle Associates

Enogen

- Syngenta's Enogen product has directly incorporated enzymes into its corn traits.
- The technology is now used by 18 plants producing 1.3 billion gallon of corn ethanol (EPM 12/2015).
- According to Syngenta Enogen raises ethanol yield per bushel by up to 3%, reduces electricity use up to 3%, and lowers natural gas use up to 10%.
- Example: Western Plains Energy

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

CO_2 Recovery at Ethanol Plants for Food Industry Use and Enhanced Oil Recovery

- About 40 percent of the North American merchant market for CO_2 is sourced from ethanol plants.
- Each bushel of corn produces 17 lbs of CO_2 during fermentation
- Ethanol plants produce CO_2 for both:
  - Food/Beverage Industry as well as for
  - Enhanced Oil Recovery
- If not recovered as a by-product CO_2 must be produced in conventional CO_2 and Dry Ice Production Plants:
  - Fuel source: low Sulphur content diesel, kerosene or natural gas.

Conventional CO2 plant fired by fossil fuels

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Wet DDG and Anaerobic Digesters

Wet DDG

- Nebraska Plants collocated with feed lots
- Skip the drying step of Distillers Dried Grains and ship feed wet to feedlots
- Significant energy savings

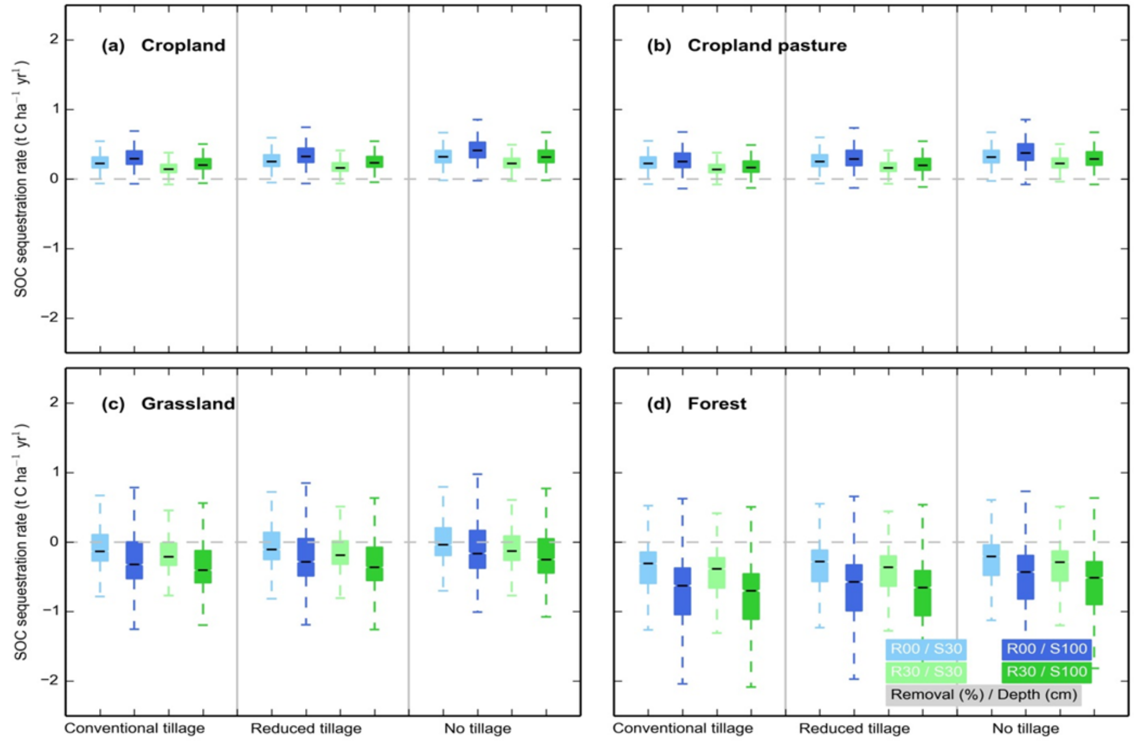
Anaerobic Digesters

- Anaerobic digestion of syrup, DGS, and manure
- Digester produces biogas for energy production offsetting onsite energy use
- Example: Western Plains Energy LLC in Kansas (also uses Enogen)

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Direct Land Use Change

- Direct land use change to high corn on corn rotations around plants provide annual carbon sequestration
- GREET CCLUB Model has a database of regional carbon sequestration factors



Source: Argonne GREET Group (Qin et al., *GCB Bioenergy)*

Transportation Emissions to Ship Ethanol

Transport from United States

Rail Shipment of Ethanol to US Port (1750 miles) followed by Vessel to Korea

Very Small Contribution to Greenhouse Gas Life Cycle (less than 10 percent)

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Life Cycle Greenhouse Gas Modeling Results Around the World

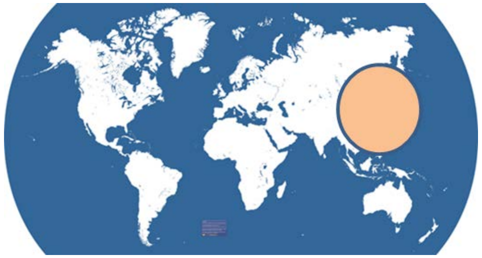
Life Cycle Greenhouse Gas Modeling Results Around the World

- Different regions and GHG regulations use **different life cycle models** (discussed earlier)
- Different GHG regulations use **different baseline emissions for gasoline** depending on the gasoline composition and modeling approach
- Different GHG regulations use **different allocation methods for credits from coproducts**

However, one thing in common: Ethanol is Generally Shown to Reduce Greenhouse Gas Emissions and it is Generally Shown to Provide a Large Contribution towards Decarbonization of the Transportation Fuel Sector

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

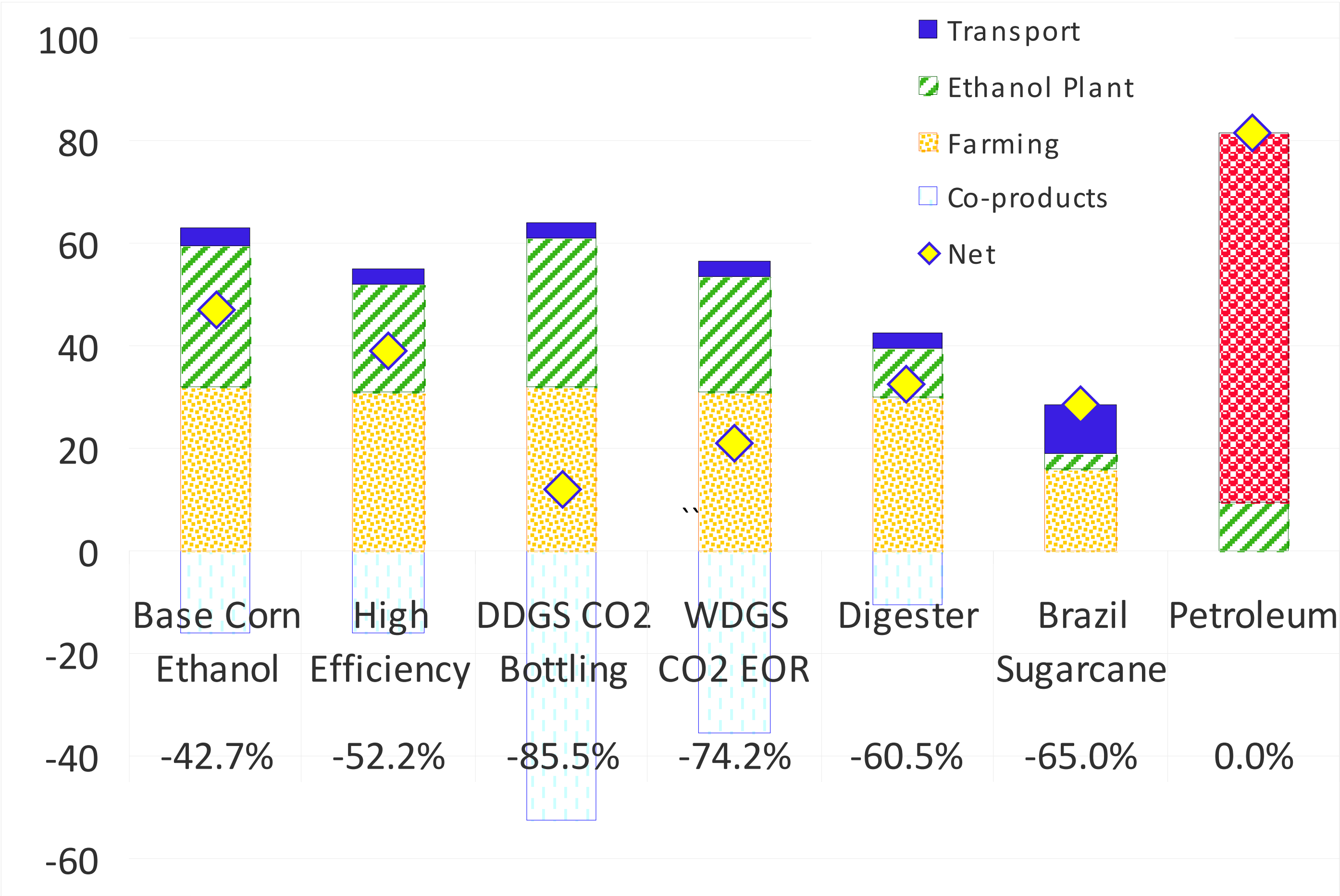
Ethanol Modeled Under Japanese Guidelines



- We showed in a recent study that a large volume of US produced ethanol can meet the **50% GHG reduction requirements set by Japan**
- The "Judgment Criteria for Oil Refiners on the Use of Non-Fossil Energy Sources (Ministry of Economy, Trade and Industry Public Notice No. 242 of 2010) regulations" detail the life cycle modeling (LCA) requirements including the ultimate **emissions reduction threshold for ethanol of 50%** (41 gCO_2/MJ) compared with LCA-based GHG emissions from gasoline (81.7 gCO_2/MJ)."
  - Many of the LCA guidelines from that document are closely in line with the European Union's Renewable Energy Directive (RED)
  - For past exports of US ethanol to the EU the achieved greenhouse gas reductions were often assessed using the Argonne GREET life cycle model funded by the US Department of Energy.

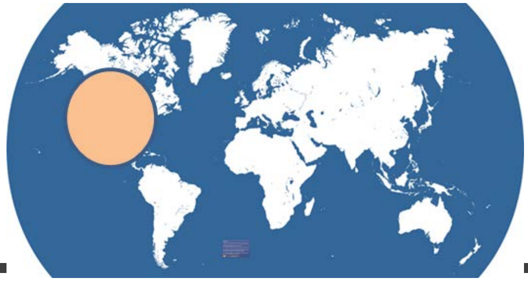
UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Modeled under European/Japanese LCA Framework
81.7 gCO_2/MJ Petroleum Basecase
Without Land Use Credit



UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

New United States Data from US Department of Agriculture



- USDA report, titled “A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol,” finds that greenhouse gas (GHG) emissions associated with producing corn-based ethanol in the United States are about 43 percent lower than gasoline
- “GHG profile of corn ethanol will be almost 50 percent lower than gasoline in 2022 if current trends in corn yields, process fuel switching, and improvements in trucking fuel efficiency continue.
- On-farm conservation practices, such as reduced tillage, cover crops, and nitrogen management, are estimated to improve the GHG balance of corn ethanol by about 14 percent.

Analysis relies heavily on and cites repeatedly:
J. Dunn, Z. Qin, S. Mueller, H-Y. Kwon, M. Wander, M. Wang ; Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) Manual; October 07, 2016; https://greet.es.anl.gov/publication-cclub-manual

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Ethanol Modeled Under European and Canadian Guidelines

- **EU:** We have certified many US ethanol plants under European Union regulations for export into EU market
  - Many plants meet 50% reduction threshold (required starting 2018)
  - We have also shown that many existing plants will meet a 60% reduction threshold already (60% reduction is required in 2018 in EU for new ethanol plants)
- **Canada:** Using Both GREET Model and GHGenius we showed that US-Produced Corn Ethanol provides 40-50 percent reduction of Greenhouse Gas Emissions over gasoline

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Summary Points

- Many regulations around the world recognize that biofuels and ethanol help reduce GHG emissions (US, EU, Canada, Japan, Brazil, Columbia) over gasoline use.
- Modeling results differ because of different country specific models and modeling guidelines but ethanol generally is shown to significantly reduce GHG emissions
- Ethanol Provides a Large Contribution in the Effort to Decarbonize the Transportation Sector

Appendix:
Selected Publications

University of Illinois at Chicago Selected publications

- Qin, Z., Dunn, J. B., Kwon, H., Mueller, S. and Wander, M. M. (2016), Influence of spatially-dependent, modeled soil carbon emission factors on life-cycle greenhouse gas emissions of corn and cellulosic ethanol. GCB Bioenergy. Accepted Author Manuscript. doi:10.1111/gcbb.12333
- Qin, Z., Dunn, J. B., Kwon, H., Mueller, S. and Wander, M. M. (2015), Soil carbon sequestration and land use change associated with biofuel production: empirical evidence. GCB Bioenergy. doi: 10.1111/gcbb.12237
- Elliott, J., Sharma, B., Best N., Glotter., M., Dunn, J., Foster, I., Miguez, F., Mueller, S., Wang, M., A Spatial Modeling Framework to Evaluate Domestic Biofuel-Induced Potential Land Use Changes and Emissions, Environ. Sci. Technol., 2014, 48 (4), pp 2488–2496 DOI: 10.1021/es404546r
- J. B. Dunn, S. Mueller, H. Kwon Land-use change and greenhouse gas emissions from corn and cellulosic, M. Wander, M. Wang. Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) Manual, ANL/ESD/12-5, Rev. 2, May 2014.
- Ho-Young Kwon, Steffen Mueller, Jennifer B. Dunn, Michelle M. Wander; Modeling state-level soil carbon emission factors under various scenarios for direct land use change associated with United States biofuel feedstock production; Biomass and Bioenergy (2013), http://dx.doi.org/10.1016/j.biombioe.2013.02.021
- Jennifer B Dunn, Steffen Mueller, Ho-young Kwon and Michael Q Wang; Land-use change and greenhouse gas emissions from corn and cellulosic ethanol; Biotechnology for Biofuels 2013, 6:51 doi:10.1186/1754-6834-6-51; Published: 10 April 2013
- Dunn, Jennifer and Steffen Mueller, Michael Wang, Jeongwoo Han. Energy consumption and greenhouse gas emissions from enzyme and yeast manufacture for corn and cellulosic ethanol production; Biotechnol Lett DOI 10.1007/s10529-012-1057-6, October 2012.
- Mueller, S. 2008 National dry mill corn ethanol survey; Biotechnol Lett DOI 10.1007/s10529-010-0296-7, May 15, 2010.
- Mueller, S. Research investigation for the potential use of combined heat and power at natural gas and coal fired ethanol plants; US Department of Energy; 2006.

UIC ERC ENERGY RESOURCES CENTER Life Cycle Associates

Contact

Steffen Mueller, PhD
Principal Economist
Energy Resources Center
The University of Illinois at Ch
1309 South Halsted Street
Chicago, IL 60607
(312) 316-3498
muellers@uic.edu