Biofuel analysis with the GREET model

Michael Wang

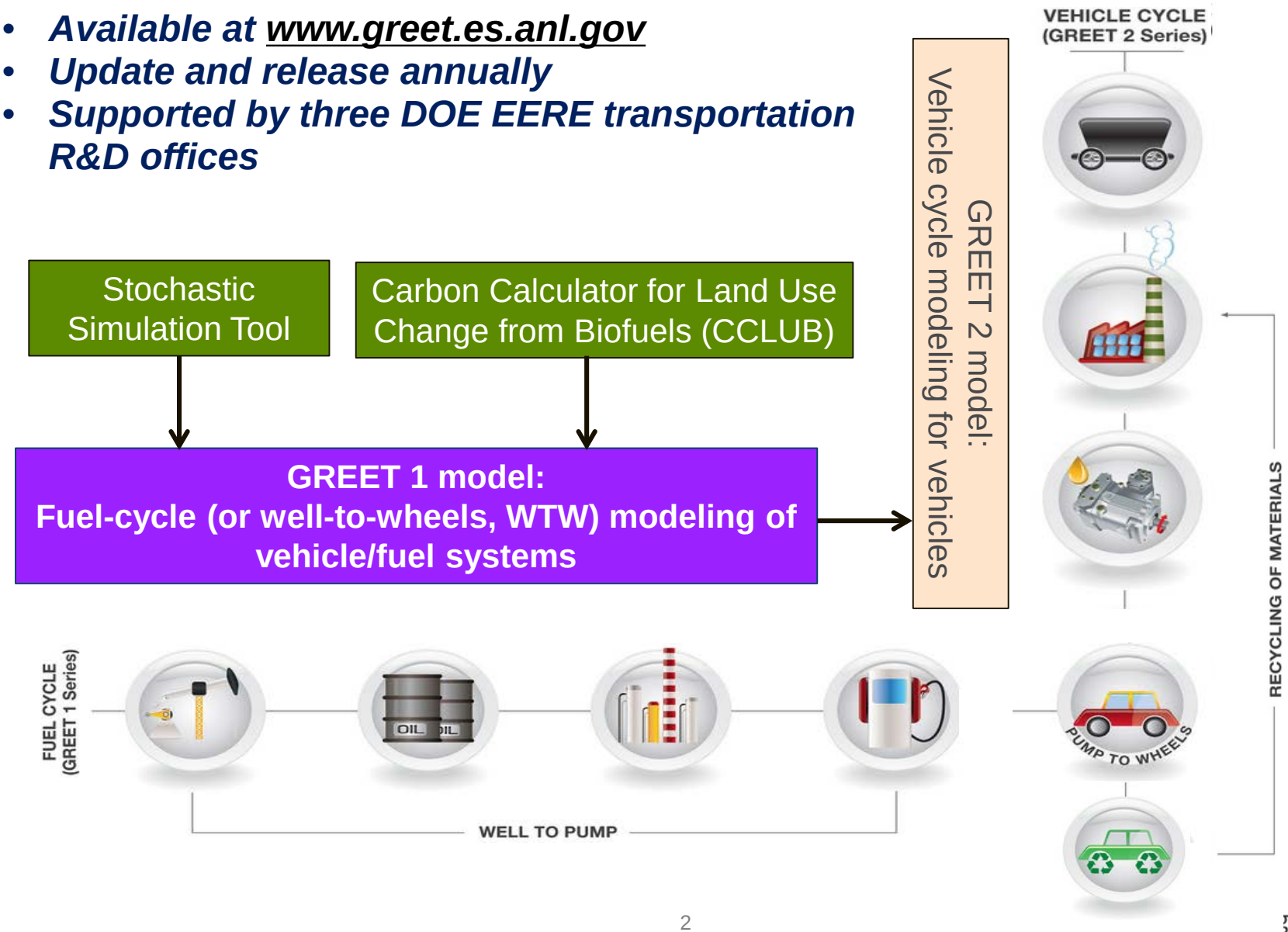
Systems Assessment Group
Energy Systems Division
Argonne National Laboratory

ARPA-E Energy-Smart Farm Workshop
Phoenix, AZ, Feb. 14, 2018

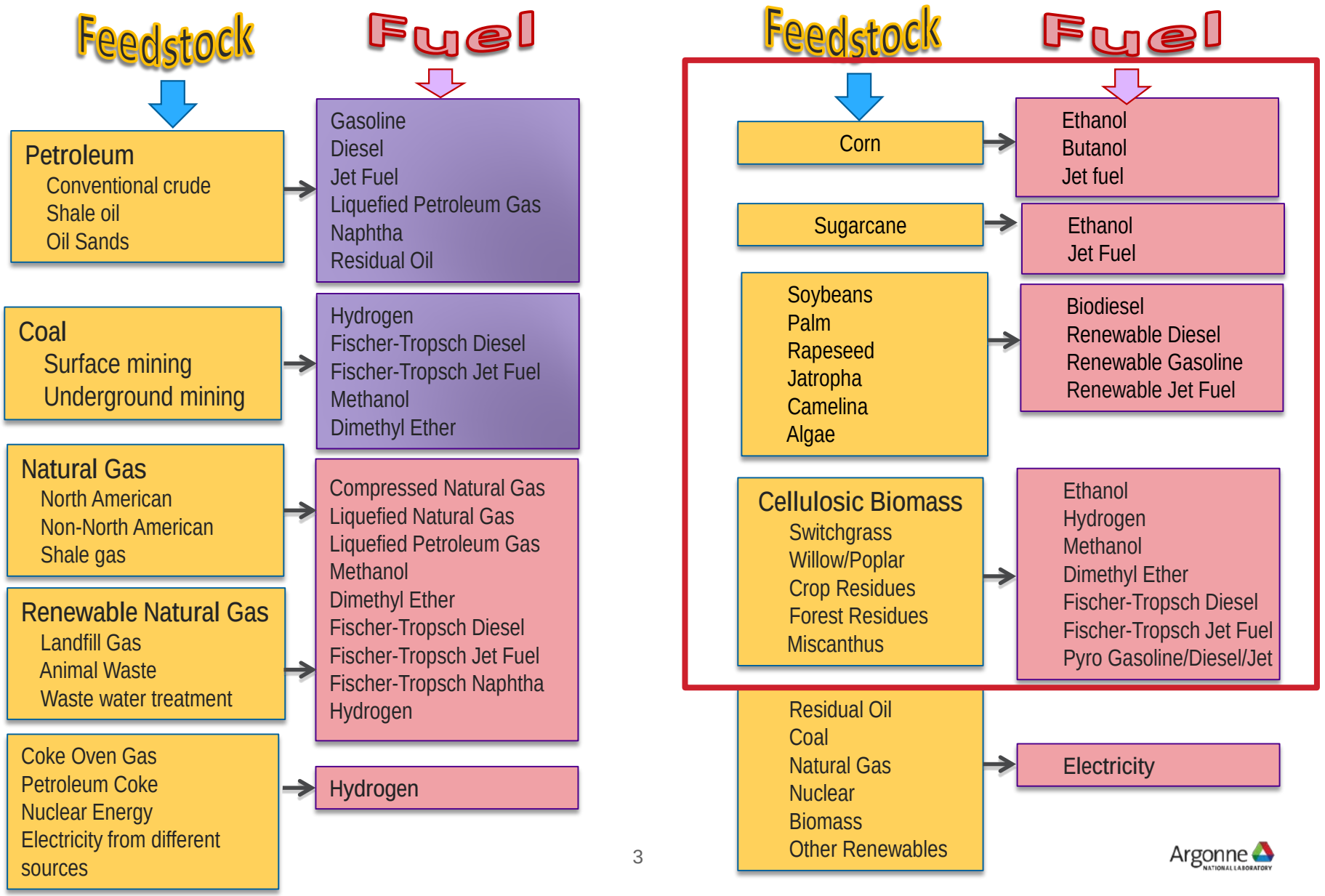
Argonne NATIONAL LABORATORY

The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model

- ***Available at www.greet.es.anl.gov***
- ***Update and release annually***
- ***Supported by three DOE EERE transportation R&D offices***



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

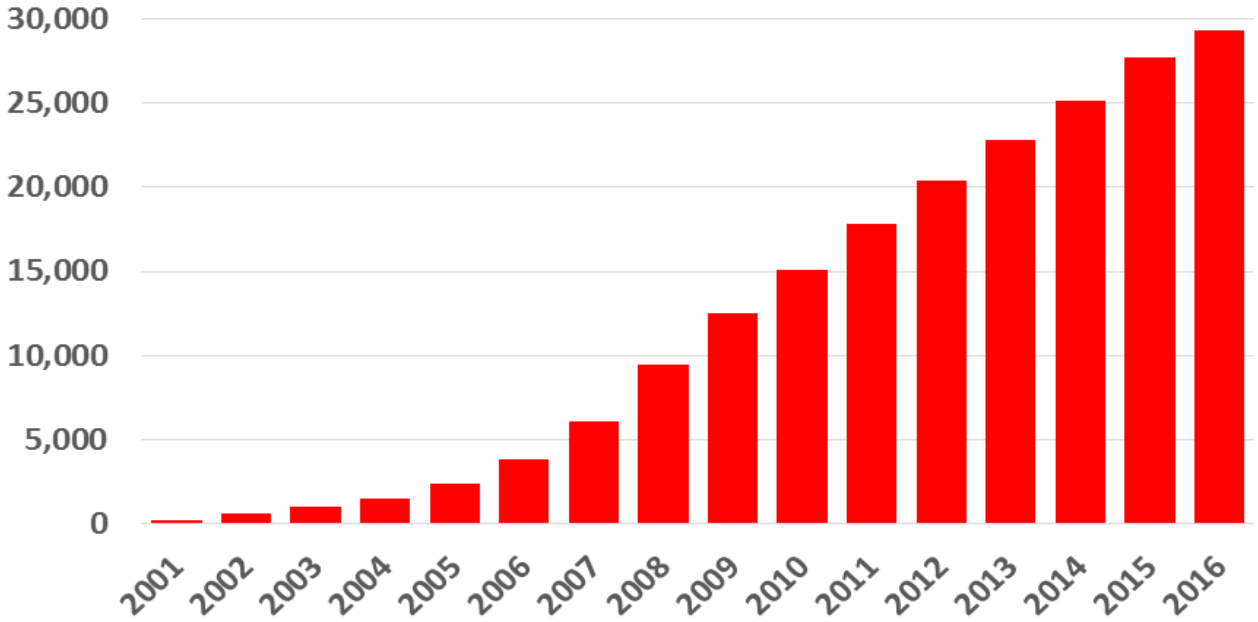


Argonne NATIONAL LABORATORY

GREET outputs include energy use, greenhouse gases, criteria pollutants and water consumption for vehicle and energy systems

- **Energy use**
  - Total energy: fossil energy and renewable energy
    - Fossil energy: petroleum, natural gas, and coal (they are estimated separately)
    - Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy
- **Greenhouse gases (GHGs)**
  - CO_2, CH_4, N_2O, black carbon, and albedo
  - CO_{2e} of the five (with their global warming potentials)
- **Air pollutants**
  - VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
  - They are estimated separately for
    - Total (emissions everywhere)
    - Urban (a subset of the total)
- **Water consumption**
- **GREET LCA functional units**
  - Per service unit (e.g., mile driven, ton-mi)
  - Per unit of output (e.g., million Btu, MJ, gasoline gallon equivalent)
  - **Per units of resource (e.g., per ton of biomass)**

There are nearly 30,000 registered GREET users globally



- Geographically, 71% in North America, 14% in Europe, 9% in Asia
- 57% in academia and research, 33 % in industries, 8% in governments

GREET approach and data sources

❑ Approach

- ➢ Build a consistent LCA platform with reliable, widely accepted methods/protocols
- ➢ Address emerging LCA issues
- ➢ Maintain openness and transparency of LCAs by making GREET publicly available
- ➢ Primarily process-based LCA approach (the so-called attributional LCA); some features of consequential LCA are incorporated

❑ Data sources

- ➢ Open literature and results from other researchers
- ➢ DOE and other agencies R&D results
- ➢ Fuel producers and technology developers for fuels and automakers for vehicles
- ➢ Simulations with models such as ASPEN Plus for fuel production and ANL Autonomie and EPA MOVES for vehicle operations
- ➢ Baseline technologies and energy systems: EIA Annual Energy Outlook (AEO) projections, EPA eGrid for electric systems, etc.
- ➢ Use of real-time data from agricultural fields for each season?

GHG reduction requirements of EPA's Renewable Fuel Standard (RFS) are on LCA basis

- Compliance of fuel with RFS determined by EPA based on lifecycle greenhouse gas emissions
- Use of suite of models, including GREET for LCA
- Land use change (LUC) emissions included for biofuels

Renewable fuel (D6) – 20% GHG reduction

- Plants existing before 2008
- Corn ethanol
- Corn starch butanol
- Sorghum ethanol w/NG process energy

Advanced biofuels (D5) – 50% GHG reduction

- Sugarcane ethanol
- Naphtha and LPG from camelina
- Sorghum ethanol w/ bioenergy

Biomass-based diesel (D4) – 50% GHG reduction

- Biodiesel (BD) and renewable diesel (RD) from soy, corn, rapeseed, camelina, algal and waste oils, fats and greases
- BD produced using esterification
- RD w/ electricity and NG process energy
- BD produced using glycerolysis and transesterification

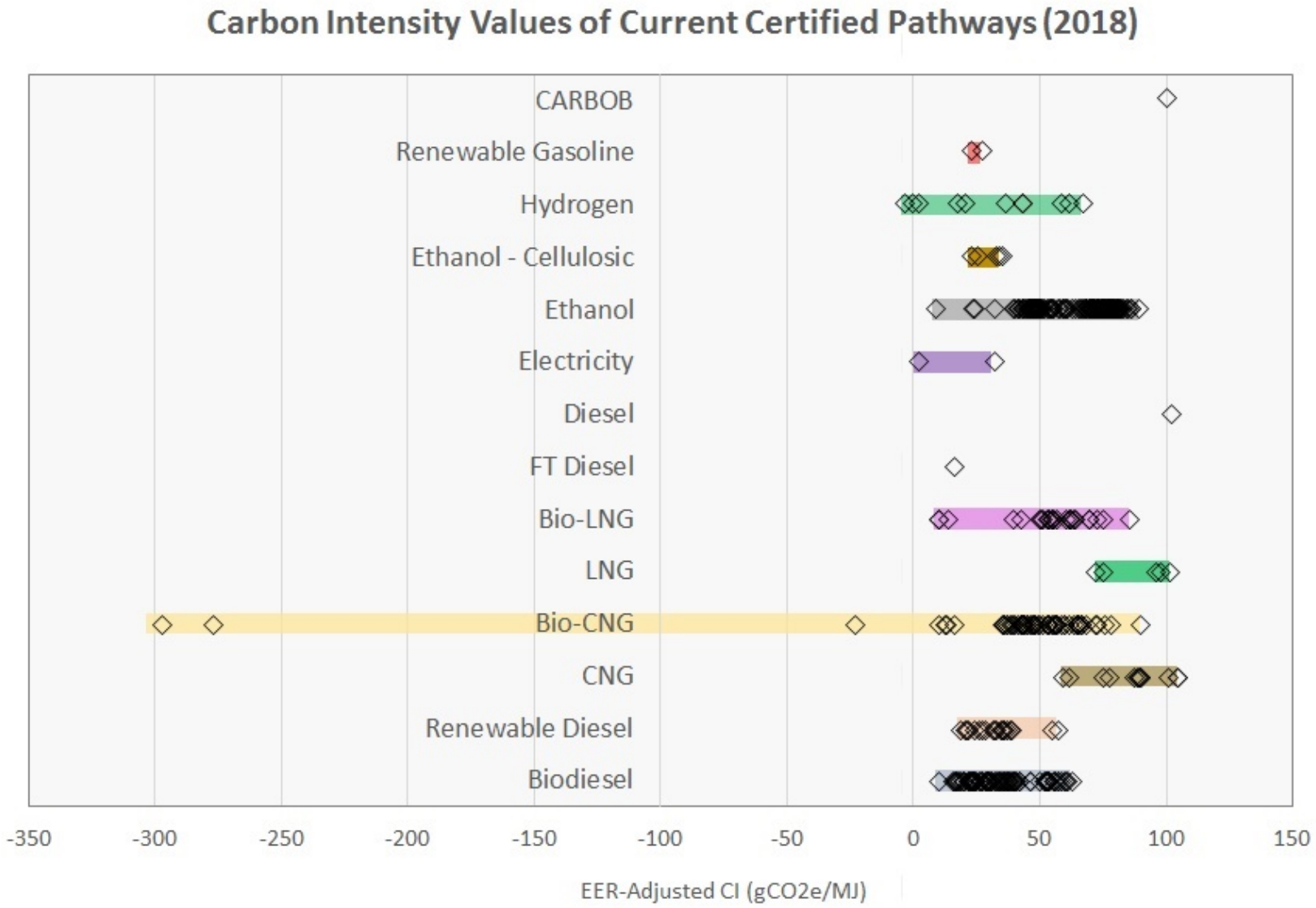
Cellulosic biofuels (D3) – 60% GHG reduction

- Cellulosic diesel or ethanol from switchgrass, miscanthus, energy cane, giant reed and napier grass
- Fuels from crop residue, forest material, secondary cover crops on existing crop land, cellulose from food and yard waste
- Thermochemical pyrolysis, thermochemical gasification, biochemical direct fermentation, biochemical fermentation w/ catalytic upgrading w/ biomass process energy

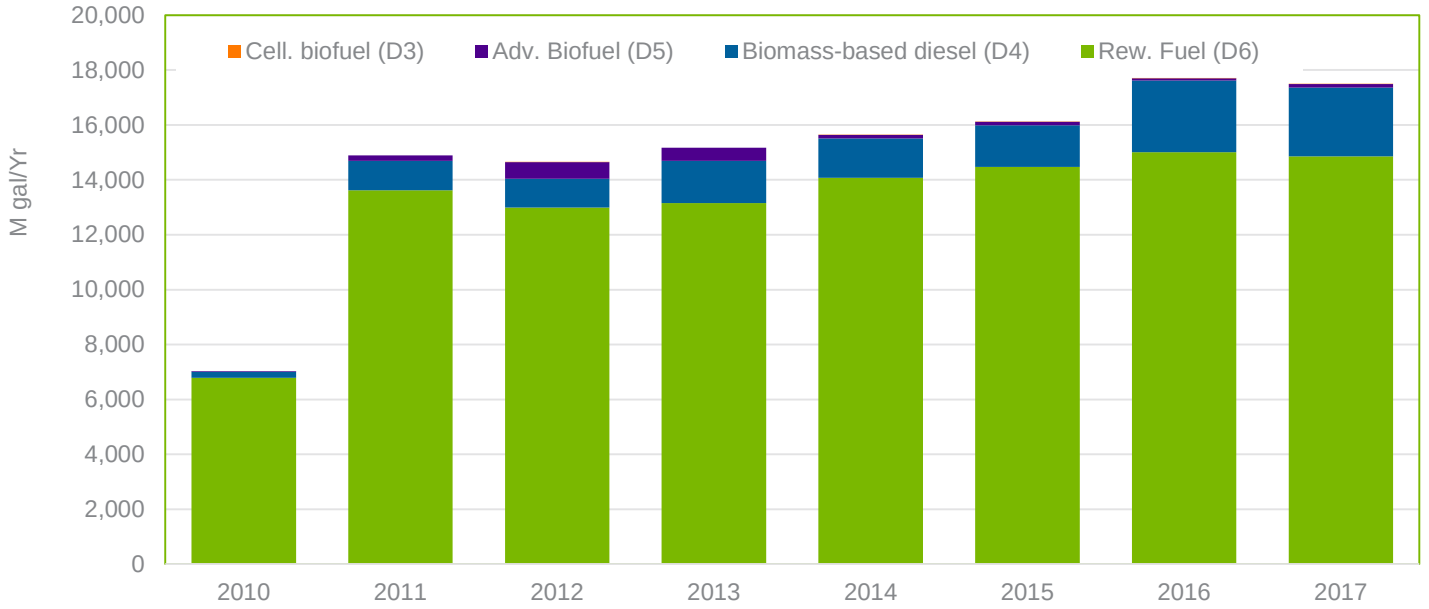
California Low-Carbon Fuel Standard (LCFS) promotes low-carbon, liquid fuels

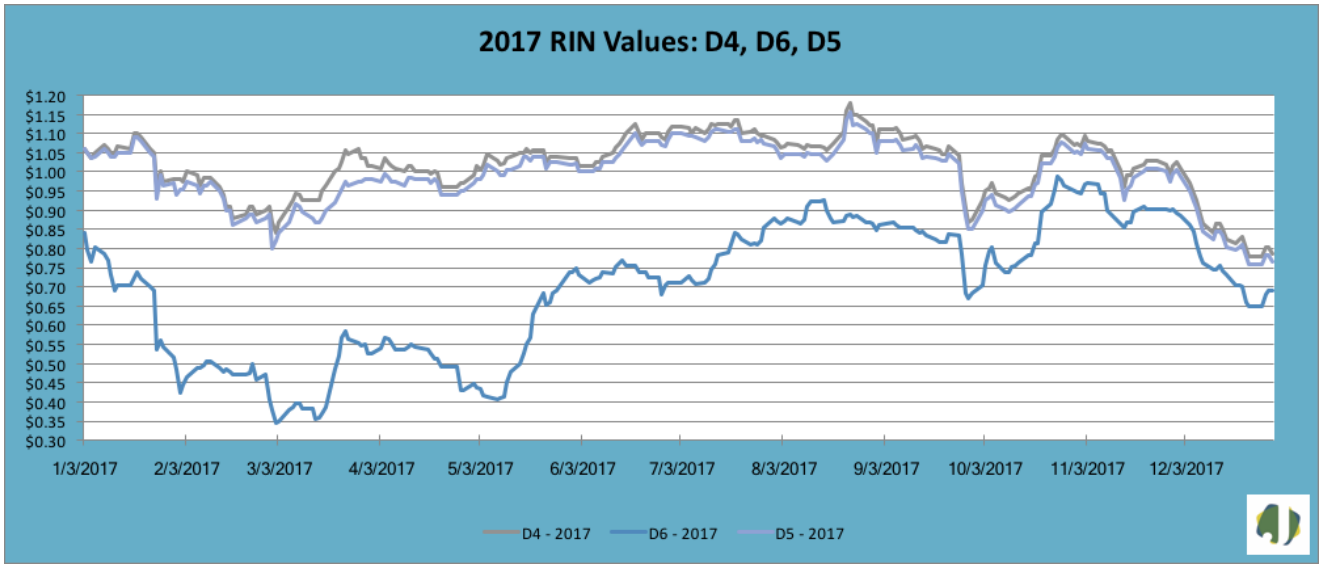
- Adopted in 2009 by the State of California
- To reduce California's transportation fuel carbon intensity (CI) by 10% in 2020 relative to 2010
  - Gasoline
  - Diesel
  - Alternative fuels
  - Electricity and hydrogen
- GHG emissions for various fuels are determined on LCA basis
  - Carbon intensity (CI), in grams of GHGs (CO_2, CH_4, and N_2O), is the measure of GHG emissions associated with producing and consuming a fuel
  - GREET was adapted to CA-GREET to decide fuel's LCA GHG intensity (or well-to-wheels CI)
- LCFS has been the most successful program so far; CARB is now deciding LCFS requirement for after 2020

LCFS certified carbon intensities of fuel pathways



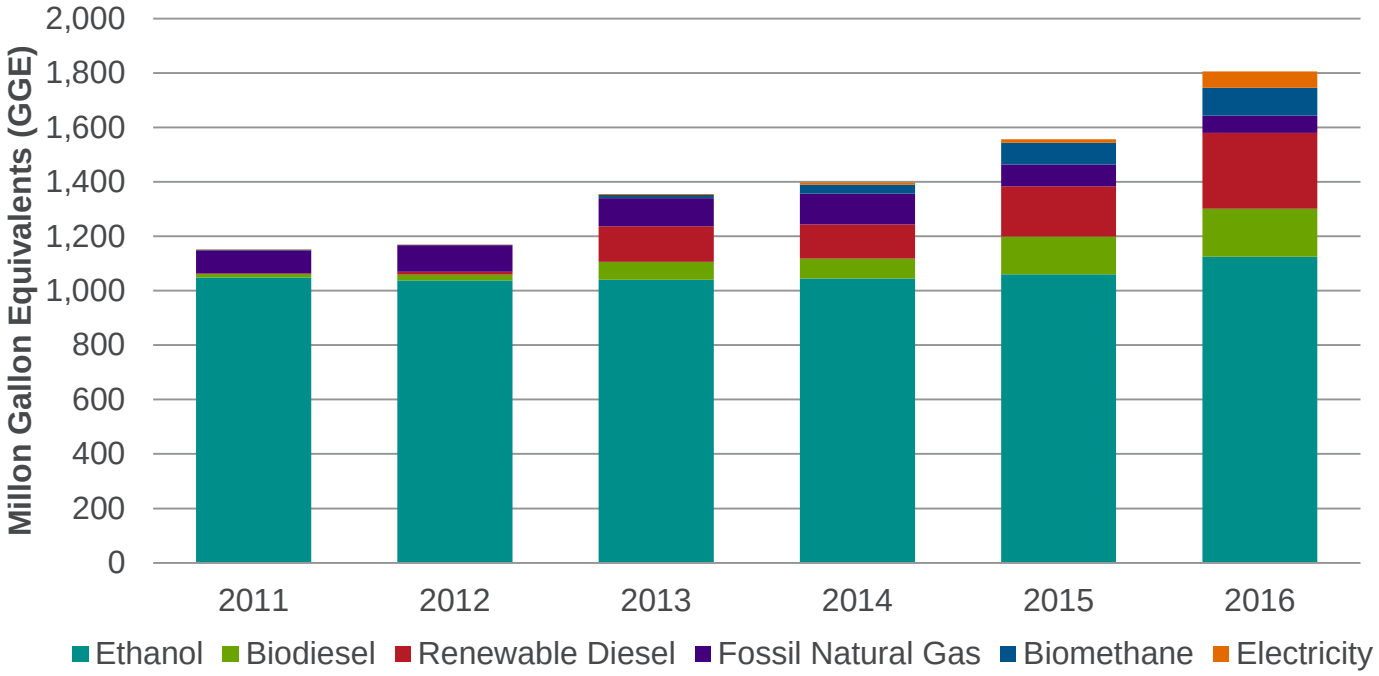
US biofuel volumes under the RFS program





From Bob Lane of Jacobsen

California LCFS has increased alternative fuels significantly



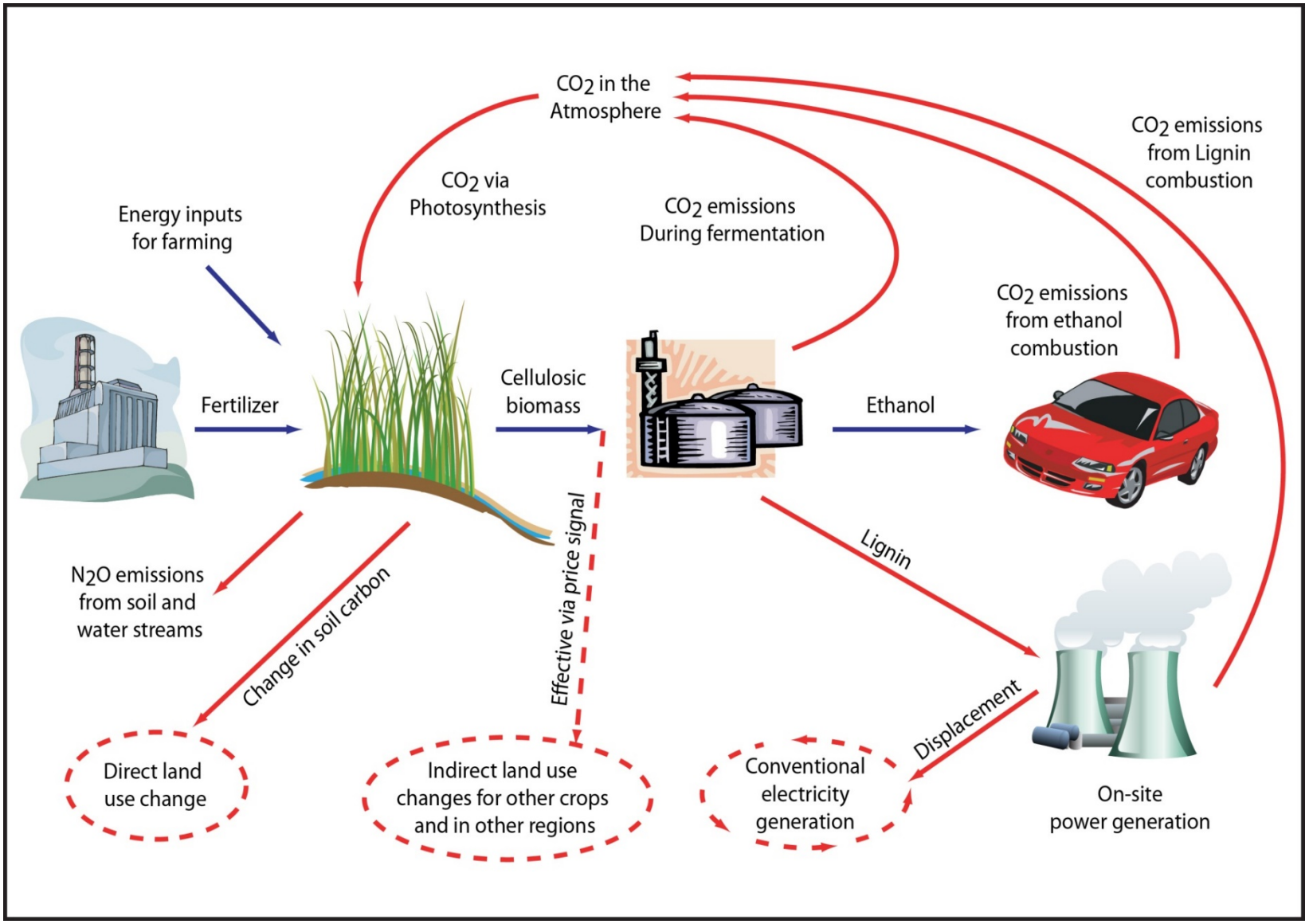
Ethanol LCFS credits

- LCFS: $90-100/ton CO2 (imputed from LCFS trading)
- CA economy-wide carbon market: $13-15/ton CO2
- With $100/ton LCFS CO2 price; a gallon of ethanol has LCFS credit:

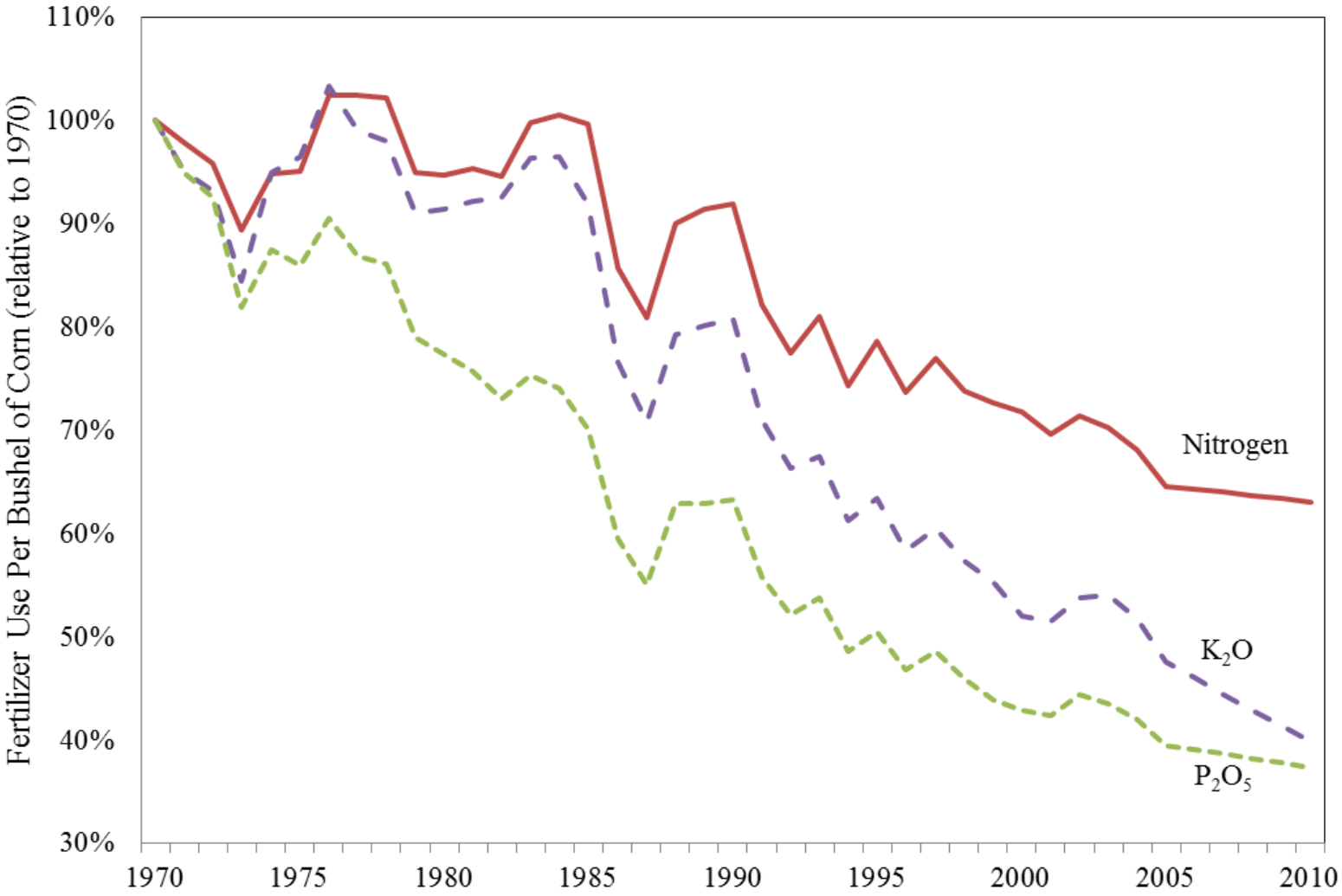
EtOH CI: gCO2e/MJ	LCFS value: $/gal EtOH
70 (corn EtOH)	$0.45
50 (corn EtOH)	$0.81
30 (sugarcane EtOH)	$1.17
10 (Cell EtOH)	$1.53

Argonne NATIONAL LABORATORY

GREET system boundary for biofuel LCA: direct activities and indirect effects are included



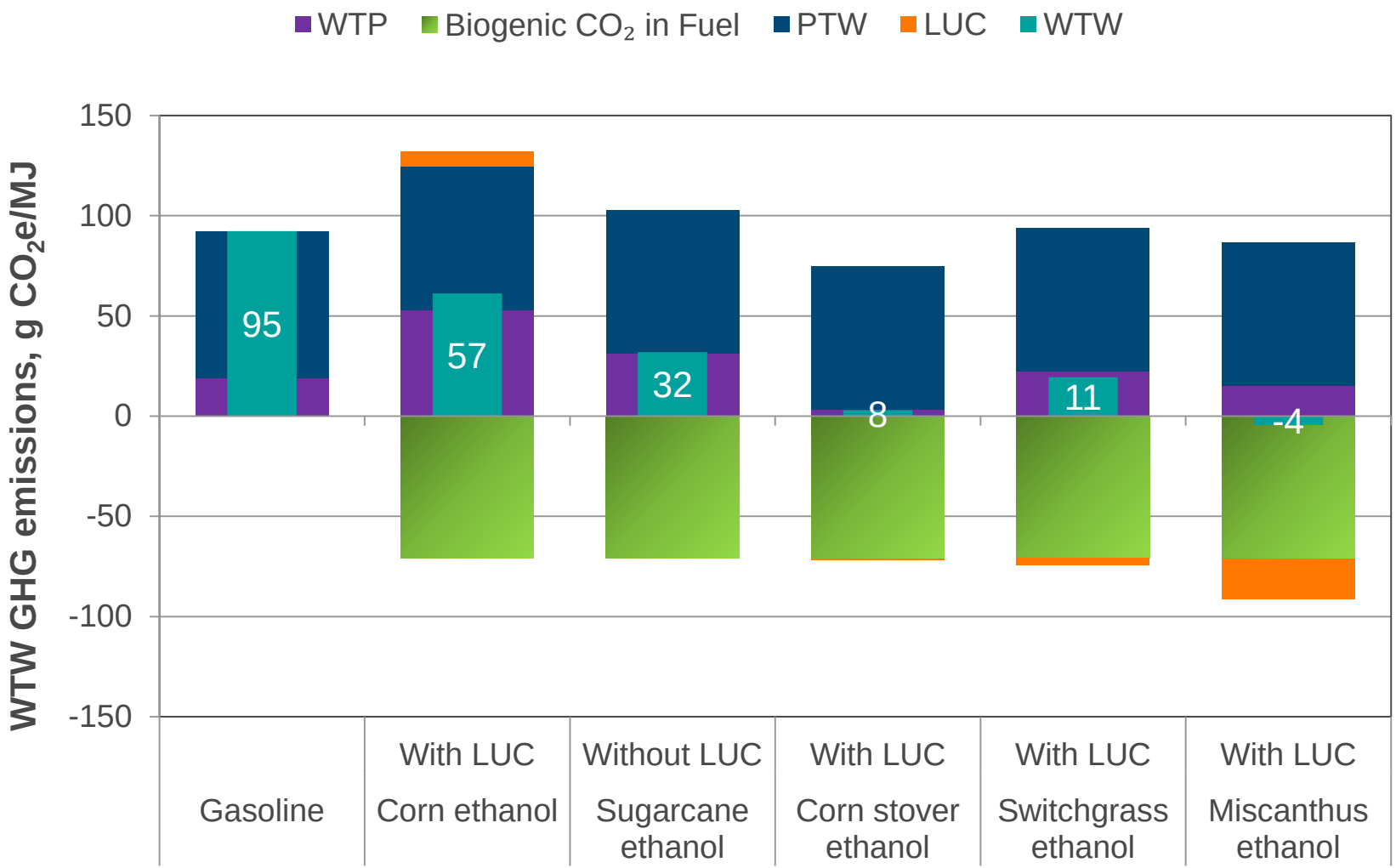
Fertilizer use in U.S. corn farming has reduced significantly in the past 40 years



This is US annual statistics. Measured data at farm level will help biofuel LCA move to finer resolution.

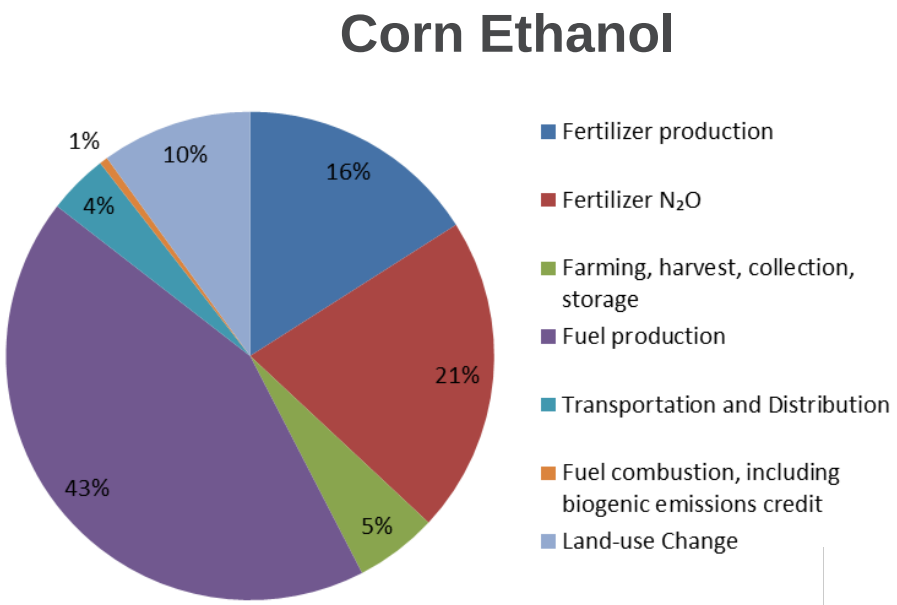
Argonne NATIONAL LABORATORY

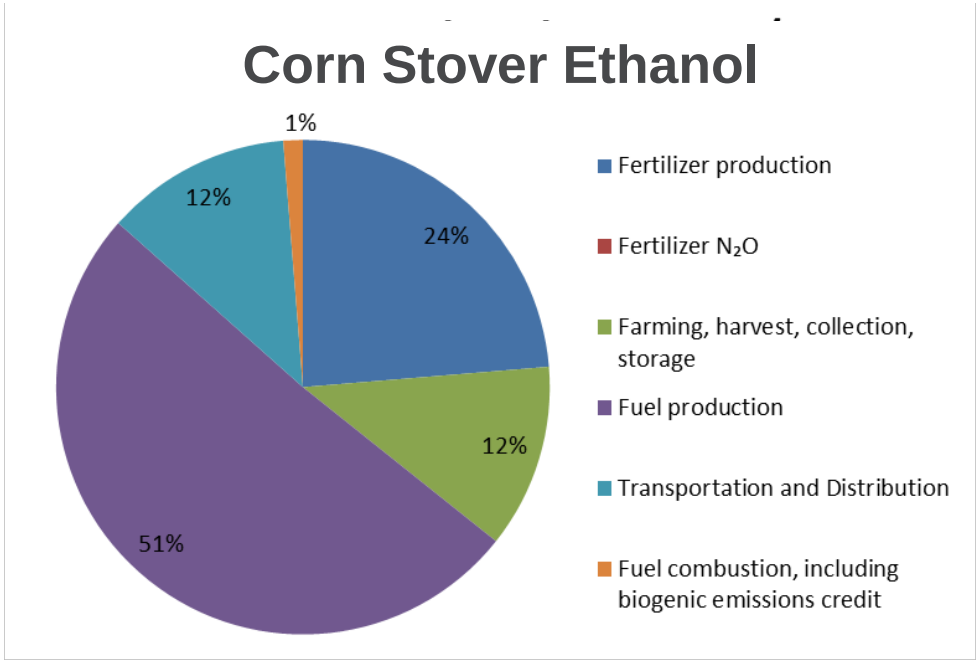
GREET life-cycle GHG emissions of selected biofuels: feedstock is the main driver



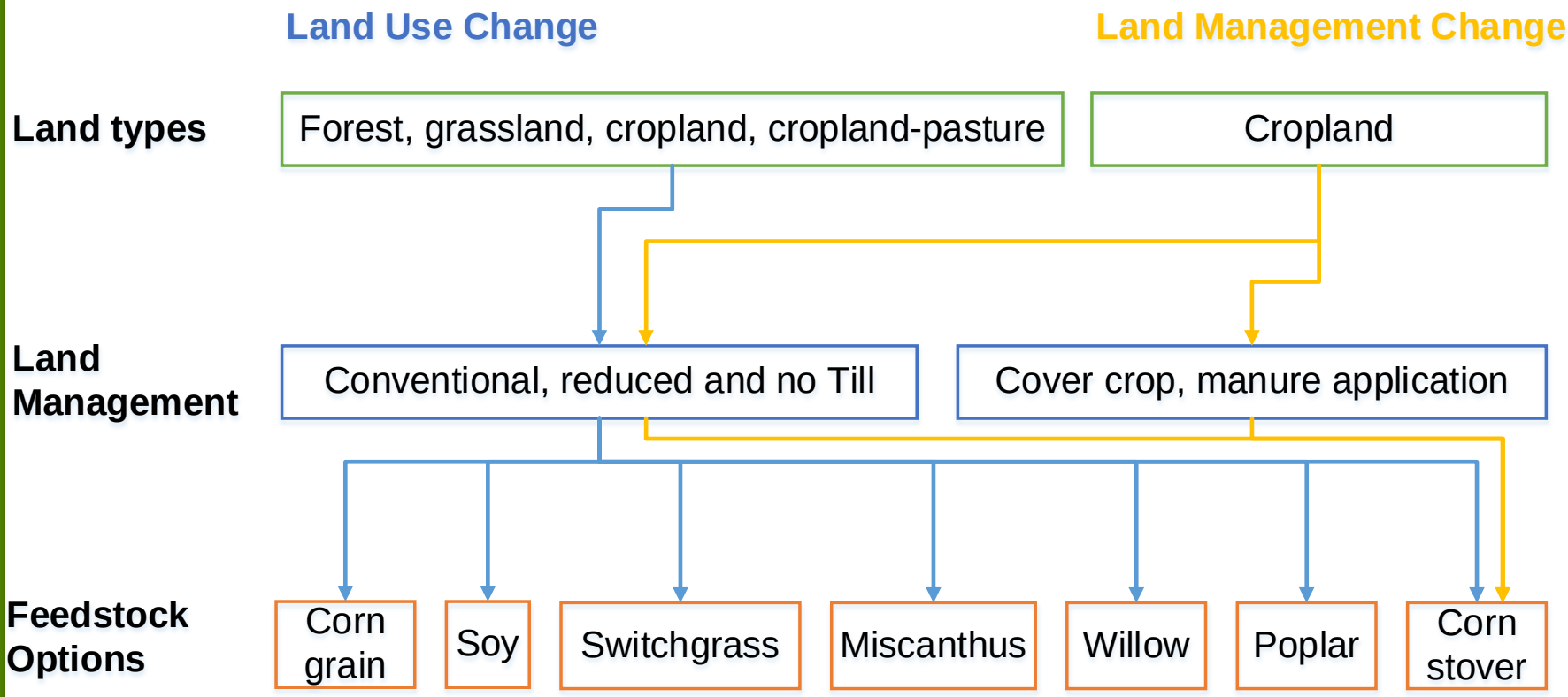
LUC: Land use change

Emission breakout for two ethanol types





Production of bioenergy feedstocks can cause land-use change and/or land management change



Argonne NATIONAL LABORATORY

Summary

- GREET has become a standard LCA tool to examine energy and environmental footprints of energy systems
- GREET has been used by EPA and CARB to develop RFS and LCFS regulations; it is now a compliance tool for LCFS
- GREET biofuel LCA includes all activities for biomass growth:
  - Farming energy input
  - Fertilizer production and use
  - Farming management practices
- Next generation GREET could benefit from real-time data
  - In field sensors: account for productivity and management practices with higher resolution than survey data
  - Local resolution of soil carbon storage and albedo: enhance and verify results from predictive models
  - In-field monitoring allows demonstration of continuous improvements
  - Identity opportunities to connect stakeholders along biofuel supply chain allowing to incentivize sustainable practices

Please visit http://greet.es.anl.gov for:

- *GREET models*
- *GREET documents*
- *LCA publications*
- *GREET-based tools and calculators*