

Biofuels and Climate Change

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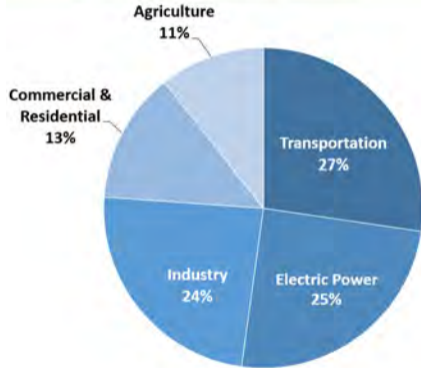
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Transportation contributes 27% of US GHG Emissions

Total U.S. Greenhouse Gas Emissions
by Economic Sector in 2020



- About 95% of transportation energy comes from **petroleum** (gasoline, diesel, jet fuel)
- Potential **alternatives**: ethanol, biomass-based diesel, sustainable jet fuel, batteries, hydrogen
- Alternatives may not reduce GHG emissions depending on **how they produce energy**

Source: EPA

We are Stuck with Liquid Fuels for the Foreseeable Future

- New gasoline-powered **cars** will not be sold in CA after 2035
 - but there will still be a lot of gasoline-powered cars on the road
 - other states will transition slower
 - the rest of the world will transition slower still
- **Trucks and buses** will move away from petroleum slower than cars
- **Airplanes** will move even slower
 - batteries are really heavy
- Implication: **lots of biofuels**

- ① Conventional ethanol
- ② Cellulosic ethanol
- ③ Biomass-based diesel
- ④ Sustainable aviation fuel

- Ethanol = alcohol
- Ethanol uses a third of US corn
- Can be **blended** with gasoline up to 10% concentration
- Higher-blend ethanol fuels require engine, regulatory, and infrastructure changes



- ① Conventional ethanol
 - ② Cellulosic ethanol
 - ③ Biomass-based diesel
 - ④ Sustainable aviation fuel
- Ethanol made from inedible parts of plants
 - Examples include wood, grasses, and corn stalks
 - Much **lower emissions** than conventional ethanol
 - Not yet commercially viable



① Conventional ethanol

② Cellulosic ethanol

③ Biomass-based diesel

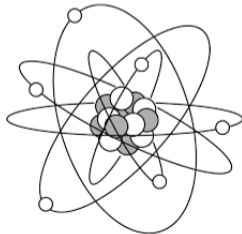
④ Sustainable aviation fuel

- Made from vegetable oils or animal fats
- Soybeans the most-used feedstock
- Can be blended with petroleum diesel
- **Lower emissions** than conventional ethanol



- 1 Conventional ethanol
- 2 Cellulosic ethanol
- 3 Biomass-based diesel
- 4 Sustainable aviation fuel

- Can be produced from vegetable oils, animal fats, or cellulosic material such as crop residue and woody biomass
- **Chemically similar** to petroleum product, so can be blended at any concentration
- Expensive

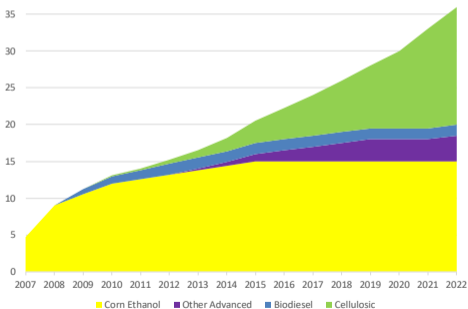




“There is fuel in corn; oil and fuel alcohol are obtainable from corn, and it is high time that someone was opening up this new use so that the stored-up corn crops can be moved.” —**Henry Ford**, *My Life and Work* (1922).

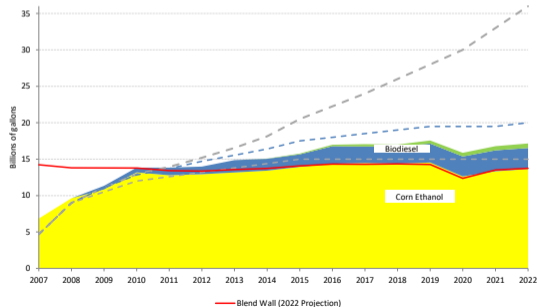
2007 Federal Renewable Fuel Standard Mandates Biofuel Volumes

- **conventional** is corn ethanol
- **advanced** mostly sugarcane ethanol
- **biodiesel** mostly from vegetable oils and animal fats



How It Started

- Corn ethanol use is **stuck** at 10% of gasoline (the “blend wall”)
- Essentially **no cellulosic**
- **Biodiesel** growing

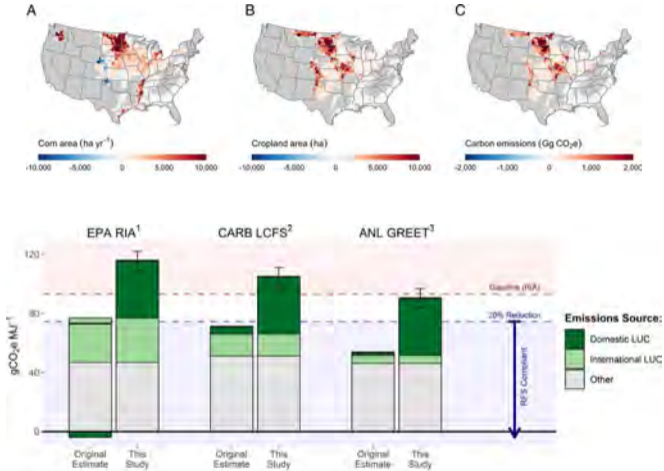


How It's Going

Federal Biofuel Policy at Crossroads

- EPA will soon set federal biofuel mandates for future years
 - Ethanol has hit the 10% “blend wall” (costly to use more ethanol)
 - GHG benefits of ethanol doubtful
- Inflation Reduction Act includes incentives for **renewable diesel** and **sustainable aviation fuel**
- Various state policies are also driving biofuels (e.g., CA’s LCFS)
- There is a coming boom in **renewable diesel** and **sustainable aviation fuel**

Land Use Change Makes Ethanol GHG Emissions Higher Than Gasoline



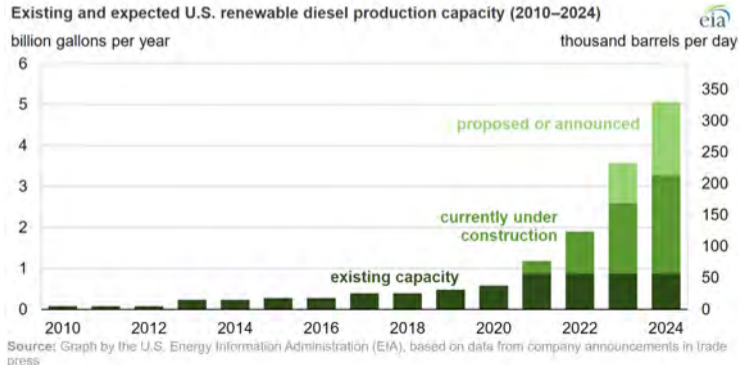
¹U.S. Environmental Protection Agency (EPA) Regulatory Impact Assessment (RIA), Projection for 2022.

²California Air Resources Board (CARB) Low Carbon Fuel Standard (LCFS); Estimated from approved values for 2019, see SI Appendix.

³Argonne National Laboratory (ANL) Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model, Default values from 2020.

Renewable Diesel and Sustainable Aviation Fuel About to Boom

- Renewable diesel now more than a third of CA diesel
- Large numbers of oil refineries are re-purposing to produce RD and SAF from vegetable oils and animal fats
 - This would require a huge proportion of global vegetable oil production
 - Resulting land use change may offset carbon benefits



- Liquid biofuels remain in our future, pushed by decarbonization policies
- Ethanol is not going away, but renewable diesel and sustainable aviation fuel are the new front
- Converting land to crops may offset the GHG benefits of biofuels