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Grain-Washing: The Issue with Corn Ethanol as a Sustainable Aviation Fuel

Emily J. Rinn

GRAIN-WASHING: THE ISSUE WITH CORN ETHANOL AS A SUSTAINABLE AVIATION FUEL

EMILY RINN

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READERS:

PROFFESOR COLIN ROBINS

PROFFESOR MARC LOS HUERTOS

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Abstract

Decarbonizing the aviation sector remains one of the most prevalent obstacles in reducing the United States' significant contribution to global greenhouse gas emissions. Launched in 2021, the Sustainable Aviation Fuel (SAF) Grand Challenge aims to supply enough fuel to meet 100% of demand by 2050 through reducing its production costs and enhancing its sustainable practices. Corn ethanol feedstock has been proposed to make up as much as half of all SAF production in the 2030 benchmark. This thesis explores the assemblage of corn ethanol – from its true environmental impacts, role in the future SAF market, to research claiming corn ethanol's environmental benefits that is perforated with conflict of interest. The paper culminates in a call to discontinue the subsidization of corn ethanol under the guise of environmental benefits and a warning against its infiltration into the SAF market.

Preface

Oftentimes, I have taken a product's sustainability at face value – with buzz words such as "carbon neutral" or "plant-based" advertised, this has been enough to convince me that I am making an informed choice. I am not alone. The majority of the world does not have the time nor resources to scrutinize each product they buy, or every action embedded in a bill they vote "yes" on. Being raised in the U.S. in the early 2000's, I remember seeing "ethanol blend" signs on gas stations. To this day I associate "American ethanol", "clean air", and the color green, together. This thesis is a eulogy to the blind trust I once had in corporate and governmental sustainability.

This journey started when I went to Strasbourg in the Fall of 2022, a city located on the eastern edge of France. I interned at the University of Strasbourg with a professor who was doing research on waste-to-energy biomethane plants in rural France. Although our task was to research the benefits of biomethane production, some of the articles I sifted through mentioned growing discords between small farms and corporate, biomethane-producing farms. At the time, I was attending a class at the University called "*La France urbaine et rurale"* and had inquired if there were economic benefits that biomethane could provide to small farmers. A response from a classmate who had recently attended a conference on biomethane caught my attention. He sent me an article he had written on the environmental harm the biomethane industry was causing to rural communities. This harm included raising land prices, disrupting historic landscapes, decreasing in air quality, and polluting water with excessive amounts of nutrients such as nitrate. In 2022, there were around 1400 biomethane sites in France, but less than half were owned by farmers (Chambres d'agriculture France, 2022). The establishment of biomethane plants would have not been possible without the economic support of the French government, who covered 40% of the costs associated with connecting biomethane to the grid (Ministères écologie énergie territoires, 2017). This multi-million-dollar backing was justified by biomethane's sustainably benefits on behalf of the Government. However, in the wake of polluted water, sky-high rent prices, particulate matter in the air, and water pollution – how could biomethane possibly qualify as sustainable? This question, with a few tweaks, carried over to my thesis.

My topic was further developed at Washington State University as part of the Food, Energy, Water Nexus REU this past summer. I was introduced to the budding Sustainable Aviation Fuel (SAF, for short) industry. I met my mentor Lina, who had built a model that examined the effect of government incentives on the success of SAF facilities in their first years of operation. She concluded that these incentives are critical to establishment of SAF facilities due to high start-up costs and long-pay off periods. My summer research concluded in the expansion of this model, where I factored in the cost of renewable energy to power SAF plants and the degree to which price fluctuations would impact their success. When I returned to Scripps, I realized how little I understood about **how** aviation fuels were qualified as sustainable. As I learned more about SAF production, I noticed some parallels between biomethane production in France and what I was reading about regarding renewable fuels such as U.S. corn ethanol. Thus, this thesis is an expansion of my time in Strasbourg, my research with Lina at Washington State University, and the culmination of my knowledge as an Environmental Analysis student of Scripps, Pomona, and Pitzer college.

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Introduction

On January 1, 1914, the first passenger flight crossed Tampa Bay, carrying a single passenger. The seaplane was a Benoist Model XIV, and the flight, 11 hours by rail, took 23 minutes. The later invention of the Boeing 247 changed the aviation industry forever. It was the first modern airplane and could cross the U.S. in less than 20 hours while flying 50% faster than existing models. Air travel would come to revolutionize the transportation sector.

Flight is powered by “fossil fuels” which are formed from marine plankton that have been heated, pressurized, and buried deep in the Earth’s crust over millions of years. Crude oil or liquid petroleum is the principal source of aviation fuel. Liquid petroleum contains exceptional amounts of carbon and is highly combustible, meeting the necessities of an airplane engine. In the early 1900’s, gasoline, derived from petroleum but less potent, was widely commercially produced and was used for the automobile. The availability and easy transportation of petroleum fuels rendered possible the ability to build an aircraft engine with seemingly limitless potential.

The airplane would go on to lose its novelty and become part of everyday life for some. But aviation is environmentally costly - the Boeing 747, one of the most widely used commercial aircrafts uses one gallon of fuel every second. (Homer, 22). This type of travel offers unapparelled speed but has high fuel requirements that put tremendous stress on the environment. Aviation’s impact in terms of emissions is particularly visible when comparing it with alternative forms of transportation such as cars, buses, and trains.

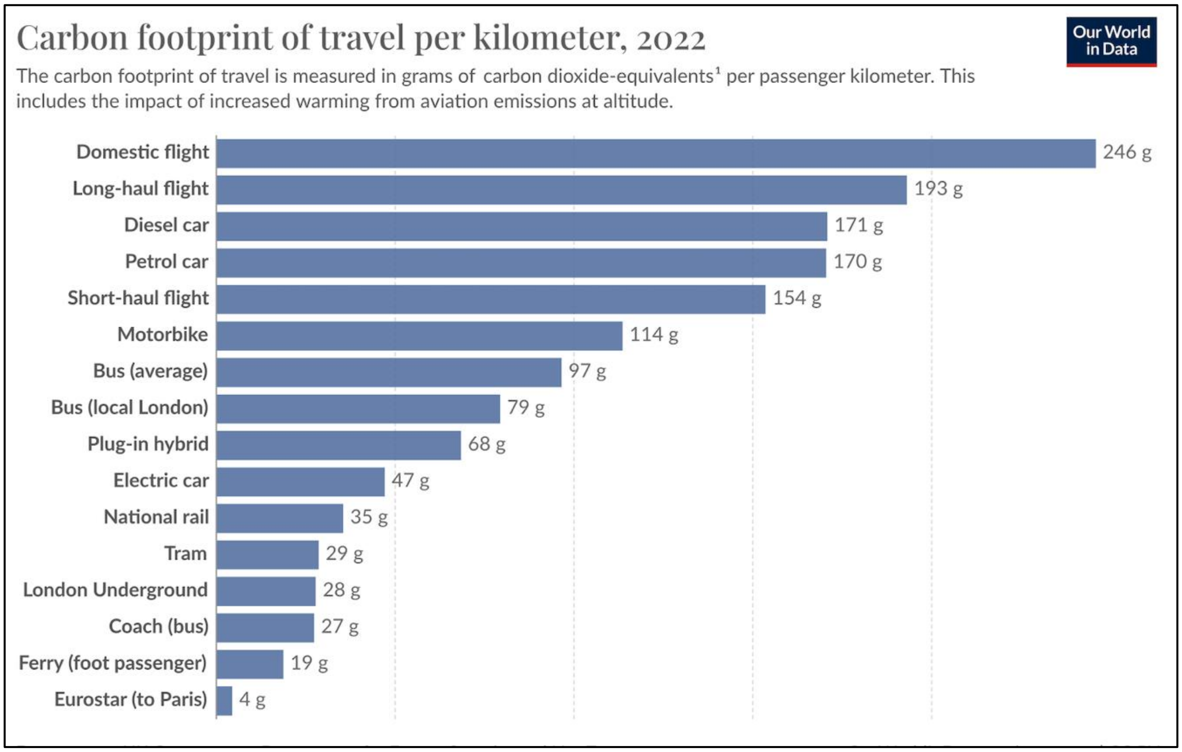

Figure 1: Chart displaying grams of CO_2 emitted per passenger per kilometer. Data collected by Global Change Data Lab in 2022.

Domestic and long-haul flights rank first and second, respectively, in terms of individual traveler impact in carbon emissions. Domestic flights rank higher than long-term flights due to intensive fuel use associated with takeoff and landing- all in order to travel a shorter distance. In examining carbon dioxide emissions alone, aviation constitutes **10%** of all emissions within the U.S. transportation sector, as well as **3%** of total domestic emissions. The U.S. is also the largest single contributor to global aviation emissions, accounting for one quarter of all carbon produced from flying annually (Hopkinson, 2021). In addition to the carbon intensity of conventional aviation fuels, they emit high levels of nitrous oxides, water vapor, sulfates, soot, and particulate matter.

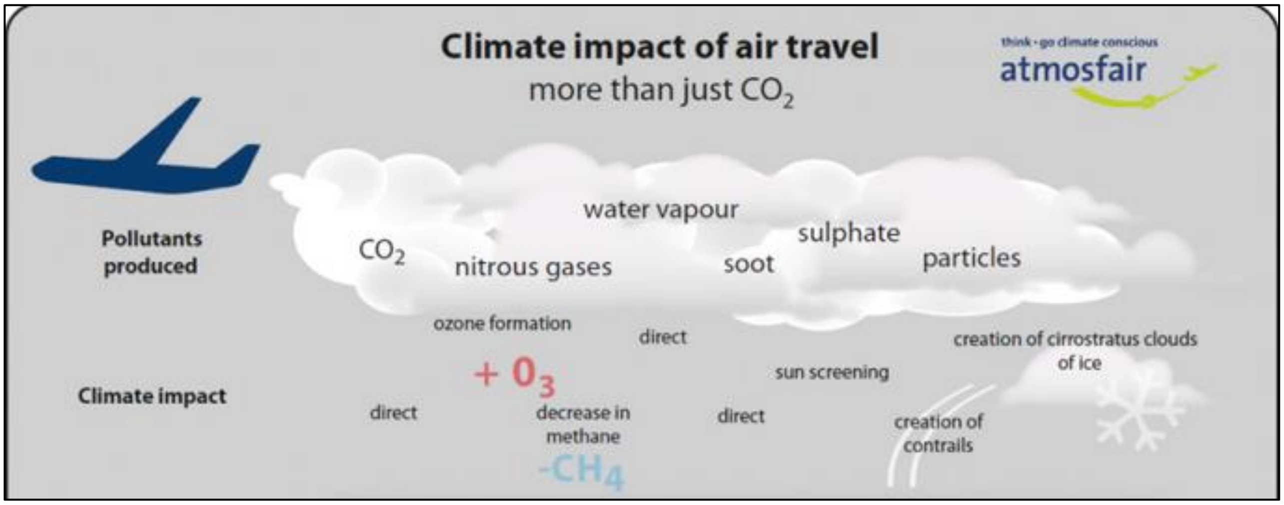

Figure 2: The range of pollutants produced from aviation travel. Atmosfair, 2022.

In conjunction with the greenhouse effect caused by carbon dioxide and nitrous oxide, pollutants such as water vapor lead to the formation of contrails and cirrus cloud formation, which trap the sun's infrared rays and may create a warming effect three times as potent as carbon dioxide. Moreover, due to an influx of emissions during takeoff and landing, localized air pollution in communities that surround airports is prevalent. Environmental injustice based on race, class, and other factors that are pervasive in examining the communities that live in areas of increased air pollution surrounding airports.

The decarbonization of aviation has proved arduous and has historically been excluded from large-scale climate policies such as the 1992 Kyoto Protocol or the 2015 Paris Accords (International Council on Clean Transportation, 2023). Unlike terrestrial vehicles, aircrafts pose complicated technical challenges due to their weight, size, energy requirements, and strict safety controls. In the face of growing market demand for air travel, setting clear decarbonization benchmarks for the aviation sector has been eagerly anticipated. Lowering aviation's footprint is possible through the use of sustainable aviation fuel, or SAF for short. SAF is any non-petroleum based “drop in” fuel, meaning that is readily compatible with existing aircraft engines. Although SAF emits carbon levels similar to petroleum fuel when combusted, it decreases lifecycle emissions through its choice of feedstock. While does emit carbon dioxide, it emits far less extraneous pollutants such as particulate matter, soot, sulphate (Energy.gov, 2023). SAF can be produced through a variety of different processes and with a diversity of feedstocks. Some of the most common processes include 1) hydrogenation which refines fats or vegetable and waste oils into SAF, 2) Alcohol/Ethanol-to-Jet that makes SAF primarily using plant derived ethanol, and 3) Fischer-Tropsch, which converts material with high carbon content to SAF, using feedstocks such energy crops, agricultural residues, and landfill.

However, these SAF production processes have proven costly. With a lack of policy support, little SAF development has occurred in the last few decades. This is changing with the announcement of the SAF Grand Challenge, launched in 2021 by the U.S. government, which intends to produce 100% of aviation fuel demand through SAF by 2050. This level of fuel production will be made possible through multi-stakeholder collaboration of state and federal governmental bodies, fuel producers, airlines, farmers, and others along the SAF supply chain. The SAF Grand Challenge is ambitious in its rapid production goals. To produce three billion gallons of SAF by 2030, production must increase by nineteen-fold. Afterwards, SAF production must increase an additional ten-fold to reach 100% of demand, which is around thirty billion gallons, by 2050 (Office, U.S. Government Accountability, 2023).

With the 2030 benchmark swiftly approaching, the SAF Grand Challenge is seeking fast solutions. Corn ethanol, a widely used biofuel in the U.S., has been identified to constitute as much as 50% of all SAF production by 2030 (Mansur, 2023). Corn has been employed as a biofuel feedstock for decades, growing particularly popular under the 2007 Renewable Fuel

Standard, which mandates that U.S. gasoline contains a 10% blend of corn ethanol. However, the environmental outcomes of corn ethanol production are dubious and have raised notable scientific controversy. A mounting body of research claims that corn ethanol is as, if not more, environmentally harmful than petroleum fuel. This is due primarily to the externalities of unsustainable corn cultivation, which include effects on water, air, soil, and land use changes. Influential organizations such as the Renewable Fuels Association have contradicted this research, claiming its findings ungrounded. However, there is reason to believe that some of these organizations have conflict of interest and therefore their bias must be accounted for when addressing this scientific debate.

This thesis will examine all of the above, including why corn ethanol has been accepted as a SAF as well as the greenwashing entangled within the success of the corn ethanol industry. Given modern agricultural practices and environmental outcomes, a strong advisory will be made against the utilization of corn ethanol as SAF.

Methodology

"*Take the example of the coconut - the conjunction of sunshine, soil nutrients, water, human relationships, harvesting efforts, taste aspirations, market prices, deities, mythologies, ideas about health and so forth*" (Daele, 2022)

This thesis employs an "assemblage" methodology to examine a large breadth of human, non-human, animate, and non-animate actors to construct the current reality of corn ethanol production and usage. Assemblage methodology recognizes that everything (from soil microbes to biofuel lobby groups), must be regarded as an actor (Wilshire, 2018). When these components are understood as agents of change who are responsive and adaptive to their circumstance, the interactions between them can be analyzed. To understand the state of corn ethanol is to recognize the relationship between the loss of soil carbon, the rise of corporate farming, U.S. nationalism and desire for energy independence, algal blooms in the Mississippi, the role that conflict of interest plays in scientific research, and federal environmental and energy policy genesis.

Literature Review

1) The SAF Grand Challenge

In 2021, the U.S. government launched the SAF Grand Challenge, an initiative that aims to decarbonize the ever-growing aviation sector by 2050. This principal departments involved with this project include the Department of Agriculture (DOA), the Department of Transportation (DOT), Department of Energy (DOE), and the Environmental Protection Agency (EPA). The objective of the Challenge is to supply entirely renewable aviation fuel in two timestamps: 1) to supply 3 billion gallons of domestically produced SAF by 2030 with a 50% reduction in lifecycle carbon emissions 2) to supply around thirty billion gallons per year, meeting 100% of the aviation sectors fuel demand, achieving an 100% reduction in lifecycle emissions (Energy.gov, 2023).

These lofty goals aim to position the U.S. as the top producer, user, and exporter of SAF within the global market. This poses political and economic advantages in the face of growing interest and need for renewable energy and fuel. These goals take a "all hands-on deck" approach, requiring high-level collaboration for airlines, fuel producers, farmers, universities, politicians, and engineers. With this in mind, the three important focus areas of the Challenge are 1) expanding and commercializing supply chains, 2) reducing the cost of SAF, and 3) rendering production pathways as sustainable as possible. There are six ways in which participants will accomplish these goals: (* what this thesis aims to do)

- Feedstock Innovation
- Conversion Technology Innovation
- Building Supply Chains
- Policy Analysis *
- Enabling End SAF Usage

- Communicating Progress

The goal of production and usage of 100% SAF by 2050 requires strong financial backing and political goal monitoring as its foundation. SAF production technologies have high start-up costs, requiring special equipment and workers, as well as careful analysis to ensure the process is meeting the mandated lifecycle carbon reductions. A body of policy already exists incentivizing SAF infrastructure, such as certain provisions in the Inflation Reduction Act, the California Low-Carbon Fuel Standard, and the Renewable Fuel Standard (RFS). These policies incentivize the production and usage of SAF via tax subsidies and sellable/tradeable credits. Policies such as the SAF blender's credit can be simultaneously used with the RFS and Low Carbon Fuel Standard, which reduces probability of financial loss due to high start-up costs (Martinez-Valencia, 2023)

2) SAF Blender's Credit

Signed into law by President Biden in 2022, the Inflation Reduction Act gives SAF blenders a two-year tax credit and SAF producers a three-year tax credit, and a 290-million-dollar grant over four years to establish projects that produce, transport, store, or develop SAF technologies. It is important to note that SAF eligible for credits by the IRA must achieve a 50% lifecycle GHG improvement in comparison with petroleum fuel. The tax credit gives $1.25 to SAF that achieves this goal and increases one cent every percentage point that GHG's are reduced (Energy.gov, 2022).

50% GHG reduction = $1.25 credit
75% GHG reduction = $1.50 credit
100% GHG reduction = $1.75 credit

This credit is poised to generate billions of dollars in subsidies, having considerable financial benefits to producers and users.

The Biden Administration remain split over whether corn ethanol should be included in the SAF Blender's Credit; the decision has been postponed until December 2023. Corn ethanol lobbyists have cited the credit's ability to considerably expand the ethanol market, inquiring that the administration formulate a model in which corn ethanol may qualify, even though it does not meet the 50% GHG reduction threshold (Renshaw et. al., 2023). Lobbyists, including commercial airlines and state lawmakers have argued that the SAF Grand Challenge will not achieve its fuel production goals if it excludes the corn ethanol market from the subsidy. This statement holds considerable weight on policymakers as corn ethanol is one of the only SAF-transferable mass-produced biofuels in the U.S.

3) Renewable Fuel Standard

Initially created under the Energy Policy Act of 2005, the Renewable Fuel Standard (RFS) has gone through many changes and has scaled-up considerably since its genesis. Created in 2007, the second version of the RFS became a national policy enforcing the blend of renewable fuels with conventional petroleum fuel across all terrestrial transportation sectors. The majority of renewable fuel produced under the guidance of the RFS is corn-derived ethanol, blended at a mandated 10% rate with gasoline. The RFS is regulated primarily by the Environmental Protection Agency which, in consultation with the Department of Agriculture and the Department of Energy, creates the guidelines. The RFS recognizes four types of renewable fuel as eligible for accreditation:

Fuel Type	Feedstock	Mandated GHG reduction to receive credits
Biomass-based diesel	In the U.S, biodiesel production is typically produced from soybean oil	50% emission reduction
Cellulosic biofuel	Non-food based and could be crop residues, wood residues, dedicated energy crops, and other wastes	60% emission reduction
Advanced biofuel	Includes agricultural and forestry residues, aquatic biomass, or dedicated energy crops	50% emission reduction
***Conventional* Renewable fuel**	**Ethanol derived from corn crop**	**20% emission reduction**

The RFS puts forth these credits as Renewable Identification Numbers (RINs). One RIN is earned for each gallon of renewable fuel that is produced. These credits are able to be bought and sold, and parties that do not meet the annual EPA mandate must purchase them. Parties can either buy RINs on the market, or by purchasing a gallon of renewable fuel (EPA, 2023). The RFS has been instrumental to the success of the corn ethanol industry, having provided billions of dollars in subsidies.

4) Modeling Environmental Impact

Many models used to calculate the environmental impact of a certain product (ex. a specific fuel production pathway) employ a lifecycle analysis approach. These models are used to determine if a certain type of fuel aligns with policies such as the SAF Blender's Credit, RFS and other subsidy programs. Some examples of what these models may consider in their analysis are as follows:

Production Stage	GHG emissions considered by LCA
Feedstock preparation and transportation	Increases and decreases in crop production Changes in land use due to feedstock demand, cultivating new farmland
Fuel production and distribution	Energy and material inputs associated with fuel production processes All scope 2 emissions
Use of the finished fuel	Emissions associated with the combustion of fuels

There are many models that have been employed to measure the lifecycle of renewable fuels. For example, the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model was created by Argonne Laboratories who is operated by the Department of Energy. The GREET model can estimate the total energy consumption, emissions of air pollutants, emissions of greenhouse gases, and water consumption of a product throughout its lifetime (Energy.gov, 2019). Another example is the MOVES (Motor Vehicle Emission Simulator) model, created by the Environmental Protection Agency, that targets lifecycle emissions of pollutants and greenhouse gasses (EPA, 2023). Given the nature of modeling, a range of assumptions must be made to predict a result. However, modeling assumptions can drastically differ depending on who is creating the model and what the desired results are. In the case of corn ethanol, it is worth reconsidering models that assure a >20% emissions reductions levels and if there may be conflict of interest at play.

5) Ethanol-to-Jet Pathway

The Ethanol-to-Jet pathway is projected by the SAF Market outlook to be one of the most common SAF production pathways in the coming years after the HEFA (oil-based) pathway

(Mansur, 2023). Ethanol is turned into SAF by removing its oxygen and linking the remaining molecules together to attain desired carbon chain length. Assuming this fuel is produced domestically, the vast majority of ethanol feedstock will be corn. Corn ethanol provides a low-cost and widely available feedstock for SAF producers due its existing production for vehicle fuel under the RFS. Companies such as Gevo and DG Fuels have already announced their construction of Ethanol-to-Jet SAF plants via corn ethanol feedstock (Energy.gov, 2023).

6) Corn Production in the United States

The cultivation of corn is deeply entrenched in the agroeconomic history of the United States. As of 2023, the United States it the top consumer, producer, and exporter of corn in the world. The top corn-producing states are Iowa, Illinois, and Ohio, which all fall within a region known as the Corn Belt. It is estimated that around 90 million acres of corn crop are planted each year, with increasing amount of bushels per acre. Out of the yearly corn produced, around half goes to ethanol production for renewable fuels (USDA, 2023).

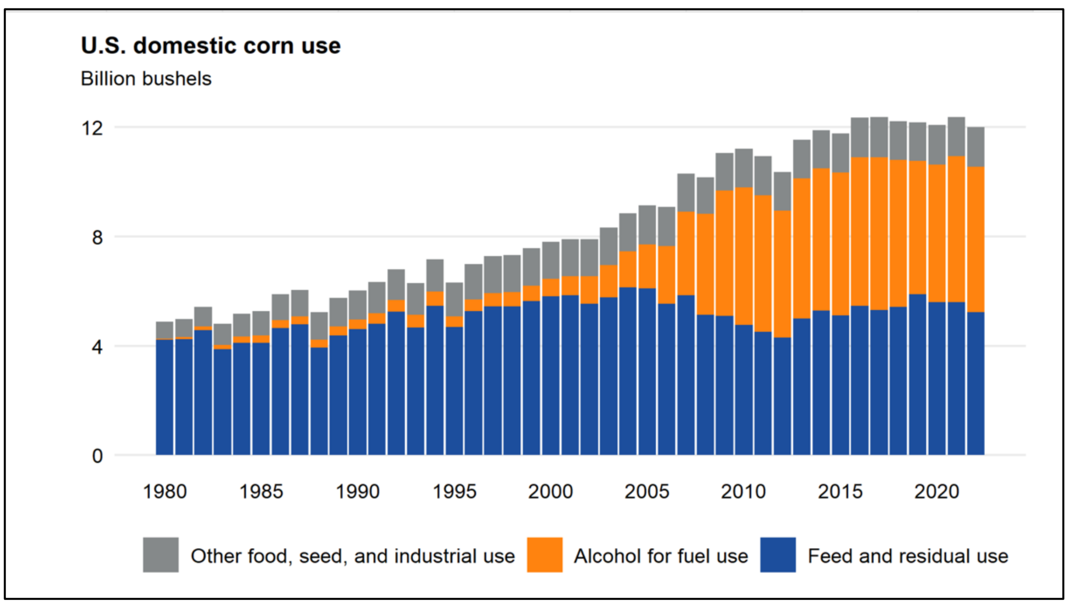

Figure 3: “U.S Domestic Corn Use”, U.S. Department of Agriculture, 2021

This graph puts into perspective the amount of corn that is being grown and used for ethanol. It is interesting to note the dramatic increase in corn for fuel use following 2007, when the modern version of the RFS was enacted.

7) Greenhouse Gas Emissions from Corn Ethanol Production

It is important to understand where greenhouse gas emissions could come from when considering corn ethanol production processes. Firstly, land conversion or agricultural expansion can be seen as one of the largest sources of potential emissions of carbon. Agricultural land conversion is carbon intensive regardless of what crop is grown – however, informed by the RFS, there was an estimated 26% expansion of land to support corn demand for ethanol (Lark, 2022). Within this process, the majority of carbon emissions come from soil exposure and tillage. Over decades to centuries, soil accumulates and stores massive amounts of carbon, and when these soils are tilled, a significant amount of that carbon is released into the atmosphere as carbon dioxide. According to Cynthia Giles, author of Next *Generation Compliance Environmental Regulation for the modern era*, “the carbon from land use changes alone can wipe out any benefit from biofuels” (Giles, 2022).

Other carbon emissions from the corn ethanol production process could derive from fuel combustion in mechanized farming practices, transportation in all stages, and non-renewable energy inputs required to create ethanol from corn (emissions would be even greater if corn ethanol were to be transformed into a SAF). An additional greenhouse gas that must be accounted for is nitrous oxide – the atmospheric form of nitrogen. U.S. corn agriculture mandates large amounts of nitrogen fertilizer to continue to produce high yields. It is estimated that nitrogen fertilizers may contribute as much as 2.1% of **global** greenhouse gas emissions. This comes from both the carbon-intensive process to create nitrogen fertilizer, and the release of nitrous oxide in fertilizer use. Nitrous oxide is a greenhouse gas that is drastically more potent than carbon dioxide, and an estimated 75% of all nitrous oxide emissions in the U.S. in 2021 came from agricultural soil management (EPA, 2022). Highlighting the ways in which corn ethanol production can emit greenhouse gasses is essential to understand the role it will play in future climate solutions.

I

Why Use Corn Ethanol for SAF?

According to the SAF Grand Challenge, corn ethanol is considered to be a promising feedstock for Sustainable Aviation Fuel production (Energy.gov, 2022). According to some estimates, corn ethanol could comprise half of all SAF production by 2030, remaining a static and reliable fuel source through 2050 (Mansur, 2023). Due to policies like the RFS that mandate ethanol blending in conventional gasoline, corn ethanol is already being produced at a mass commercial scale. The jump between corn ethanol and jet fuel is relatively minimal in terms of additional processing. Due to shortfalls in other SAF production routes, corn ethanol is being heavily considered to remedy production shortfalls. However, it is necessary to carefully examine both the motivations behind corn ethanol usage and the ramifications it may cause. As of 2023, the RFS is decreasing its projected corn ethanol mandates which is causing anxiety within the industry. The SAF market is a beacon of light, promising high profits and the continuous scaling up of the corn ethanol industry. It is vital to note the possibility that the utilization of corn ethanol as a principal SAF feedstock could financially outcompete other, more sustainable SAF pathways. This is because corn ethanol already widely available as a feedstock as opposed to more obscure options with less supply chain infrastructure.

1.1) Shortfalls in SAF Production

According to the 2023 Sustainable Aviation Fuel Outlook by SkyNRG, a global leader in SAF production, the United States could realistically only produce around 2 billion gallons of SAF in 2030 which is two-thirds of the SAF Grand Challenge goal. This figure is based on the summation of up-to-date publicly announced capacity estimations from SAF producers (Mansur, 2023). This 1-billion-gallon shortfall can be attributed to four principal challenges faced by SAF producers: (1) start-up costs, (2) technology design, (3) SAF transportation and (4) feedstock availability (Energy.gov, 2022).

(1) SAF production facilities are new and oftentimes, standalone initiatives due to the unique requirements of SAF compared to other renewable fuels. Depending on the pathway, facilities can cost anywhere from millions to even a billion dollars. Without proper financial aid and incentives, these projects can easily run out of funding before even starting production.

(2) Unforeseen complications with the construction or supply chain are common due to SAF projects still being in infancy. Oftentimes, there is no reference point for producers to anticipate challenges or results. This means that SAF capacity estimations could be marginally incorrect, having significant implications for the success of the SAF Grand Challenge.

(3) Petroleum fuel is transported to airports via pipelines, ensuring an efficient and low-cost operation. Because SAF does not have this benefit, it must be transported via truck to airports; this has much higher costs and can increase lifecycle emissions for SAF production. Since policy incentivizes SAFs with the lowest possible lifecycle emissions, transportation can pose financial barriers for producers who rely on low-carbon incentives.

(4) Depending on the feedstock, producers may face a wide range of issues procuring adequate amounts of feedstock to reach their intended capacity. This is especially true for producers who use more advanced pathways that require feedstocks such as landfill and woody biomass and no way to efficiently collect, sort, and transport feedstock.

To exemplify this last point, we can take the case of Fulcrum Bioenergy and Red Rock Biofuels, two U.S. SAF producers who in 2014 announced to have SAF available by 2018. They predicted to generate about 11 and 15 million gallons respectively but, as of 2022, have not started commercialized production. These companies intend on utilizing advanced SAF pathways such as Gasification Fisher-Tropsch from feedstocks like landfill (Fulcrum Bioenergy) and woody biomass (Red Rock Biofuels) (Office, U.S. Government Accountability, 2023). Due these companies' use of advanced production pathways, they become more vulnerable to the aforementioned issues. Indeed, their delays in production are attributed to lack of construction finances, delays in engineering, and difficulties in supply chain due to a lack of existing market. In trying to promote the use of more sustainable feedstocks such as landfill or woody biomass rather than corn ethanol, these financial barriers must be incorporated to create effective incentives for advanced fuel producers.

1.2) Corn Ethanol to Fil in the Gaps of SAF Production

As the top producer of corn globally with over half of it going to ethanol production, the United States has a built a booming industry. Under the RFS, corn ethanol use is both mandated in vehicle fuel and is credited via the RIN system. This causes an increase in market demand which leads to increased corn cultivation. In 2018, 95% of the RINs generated by the RFS were to corn ethanol and biodiesel users (EPA, 2023). In the short amount of time left to increase 15.8 million gallons (as of 2022) to 3 billion gallons of SAF in 2030, stakeholders in the SAF industry would like to take the most feasible short-term route to meet this goal. The SAF Grand Challenge emphasizes that "the existing corn ethanol industry has tremendous near-term potential to increase SAF production volumes through the ATJ pathway" (Energy.gov, 2022). This potential is jointly due to the fact that domestic corn ethanol will generate significant amounts of revenue within the corn industry. This is due to the high demand for non-petroleum aviation fuels and that corn ethanol based SAF promises short-term low prices as opposed to advanced fuels. Currently, the announced SAF capacity of corn ethanol is around 500 million gallons by 2030. However, according to the SAF Market Outlook 2023 due to the high market competitivity of SAF within the industry, this output could be higher.

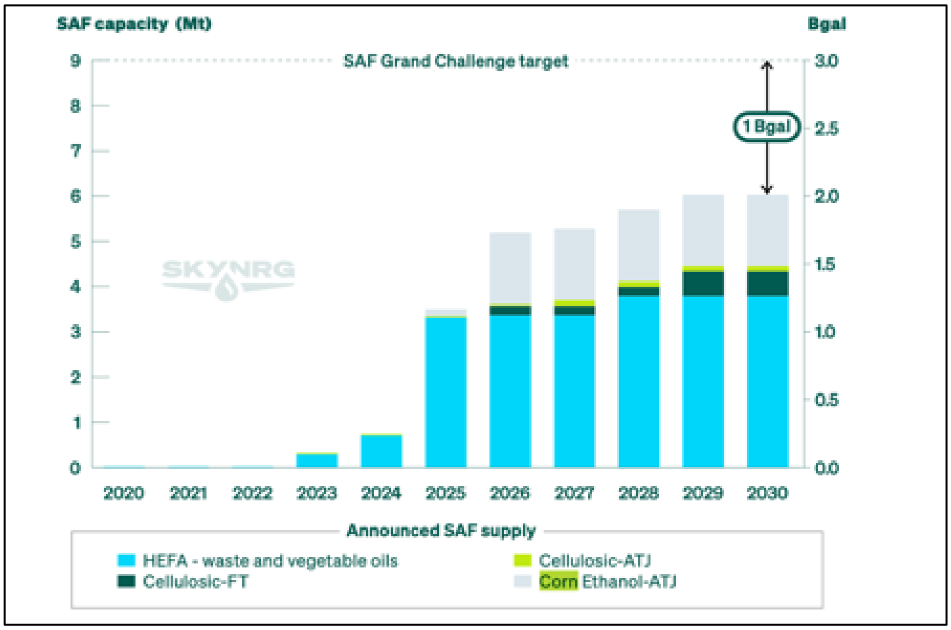

Figure 4: "SAF Grand Challenge aspirational goal for 2030", SkyNRG Sustainable Aviation Fuel Market Outlook 2023

The report approximates that 1.5 billion gallons of SAF could be produced from corn ethanol in 2030. That would be half of all domestically produced SAF use relying on the domestic production of corn. In this scenario, the other half would comprise of primarily HEFA pathways from vegetable and waste oils with small amounts of cellulosic (agricultural residues) pathways.

1.3) From Terrestrial to Jet Fuels

In 2023, the Environmental Protection Agency finalized the RFS targets of corn ethanol production, setting a 250 million reduction as compared to the original production goal in the next couple of years. This greatly dismays biofuel lobby groups and farmers, who rely on the RFS to increase market demand for corn ethanol. These reductions by the RFS are accompanied by the expanding electrification of vehicles that drastically reduces fuel demand. The threat of extinguishing the corn ethanol market cause corporate farmers and biofuel lobby groups anxiety. However, the budding SAF market is optimistic and even poses higher selling prices as well as long-term business partnerships (Neeley, 2023).

The corn ethanol to SAF market transition only can operate under the assumption that the RFS will continue to subsidize corn ethanol. Additionally, the decision of whether the IRA's SAF blender's credit will include corn ethanol is also pivotal to the transition of terrestrial to jet fuel. If 1) the RFS discontinues corn ethanol subsidies and/or 2) the blender's credit decides to exclude corn ethanol, this could block corn ethanol to SAF market infiltration.

One of the reasons this blockage may be beneficial is that corn will likely outcompete the production of advanced SAFs that have tangible environmental benefits. This can be seen historically in that unlike advanced SAF, corn ethanol has had no problem meeting its projected production goals. The RFS aimed for 15 billion gallons of corn ethanol to be consumed in 2022, and within that goal, 14 billion gallons were consumed. This comes in direct contrast to advanced biofuel production with feedstocks such as agricultural waste and woody biomass. Within the same timeline, the RFS created a production goal of 16 billion gallons, while less than 1 billion gallons of fuel from these feedstocks was actually produced (Lashof, 2023). The reasons behind this failure correlate to the four principal challenges detailed in the first section of this chapter: high start-up costs, supply chain issues, fuel transportation, and sufficient feedstock sourcing. There is a correlation between the ample production of corn ethanol and the scarcity of more advanced fuels. The relative low-cost and high availability of corn ethanol disincentivizes the production of other types of fuel with solid environmental benefits. As long as advanced biofuel makers are facing these start-up challenges, corn ethanol will always be relatively cheaper and will have the upper edge in the market. This could have serious environmental consequences and could be contradictory to the stated environmental goals of the SAF Grand Challenge.

1.4) A Critical Analysis of Key Stakeholders in the Corn Ethanol Industry

A key stakeholder group in the corn ethanol to SAF market transition is the Renewable Fuels Association, which is a Trade Association made up of companies that produce fuels such as corn ethanol. In 2022, Proceedings of the National Academy of Sciences of the United States (PNAS) published an article titled "The Environmental Outcomes of the Renewable Fuel Standard" (Lark et. al). The article pools from authors ranging from professors at the University of Madison-Wisconsin, Kansas State, and the University of Kentucky. This article garnered significant media attention due to its bold claim concerning the environmental repercussions of corn ethanol production under the guidance of the RFS. In the article, Lark et. al states that corn ethanol production under the guidance of the RFS is equivalent and potentially more carbon intensive than petroleum gasoline. This is seemingly due to notable changes in land use with an increased corn production that accompanied the mandate for a 10% ethanol blend in U.S. gasoline. Lark et. al draws a connection between the mandate, a raise in demand, a rise in corn prices, and thus an expansion of corn acreage. This agricultural expansion led to increases in domestic fertilizer use, decreases in water quality, and "caused enough domestic land use change emissions such that the carbon intensity of corn ethanol produced under the RFS is no less than gasoline and likely at least 24% higher" (Lark et. al, 2022). The article touches on excessive nutrient application, water quality impacts, land use changes, and soil health to support this point.

This articled generated both supporters condemning the corn ethanol industry and critiques denouncing the article's claims. One critique, written by Taheripour et al., argues that the article assumes that the RFS is directly responsible for all corn ethanol demand and that marking it as a causality is unjustified. Another critique is that Lark et. al double counted their N_2O emissions in corn cultivation for ethanol usage (Taheripour et al, 2022). While gaps in their methodology may or may not exist, the fundamental arguments made by Lark et. al concerning the environmental externalities of corn ethanol production must be addressed by renewable fuel stakeholders and the U.S. government. Besides Taheripour et al, the loudest of critics is the Renewable Fuels Association, whose public image is directly jeopardized by the claims made by Lark et. al. A statement released by CEO Geoff Cooper from the Association remarks that "the claims in this report simply don't align with reality and the facts on the ground, and the paper reads more like a fantasy novel than a genuine piece of academic literature. It should not be taken seriously" (Renewable Fuels Association, 2022). The inflammatory language used by Cooper may allude to the presence of a genuine threat to the corn ethanol industry: what happens to an industry built on the advertisement of renewability is not actually renewable?

The paper cited by Cooper, created by the Renewable Fuels Association, uses cherry-picked facts to back their argument. For example, the paper asserts that nitrogen fertilizer per bushel of corn has decreased (Renewable Fuels Association, 2022). While this true, due to the expansion of corn acreage, nitrogen fertilizer application as a whole has increased. By associating nitrogen use with a downward trend, the paper attempts to assert a lack of evidence in questioning corn ethanol's sustainability.

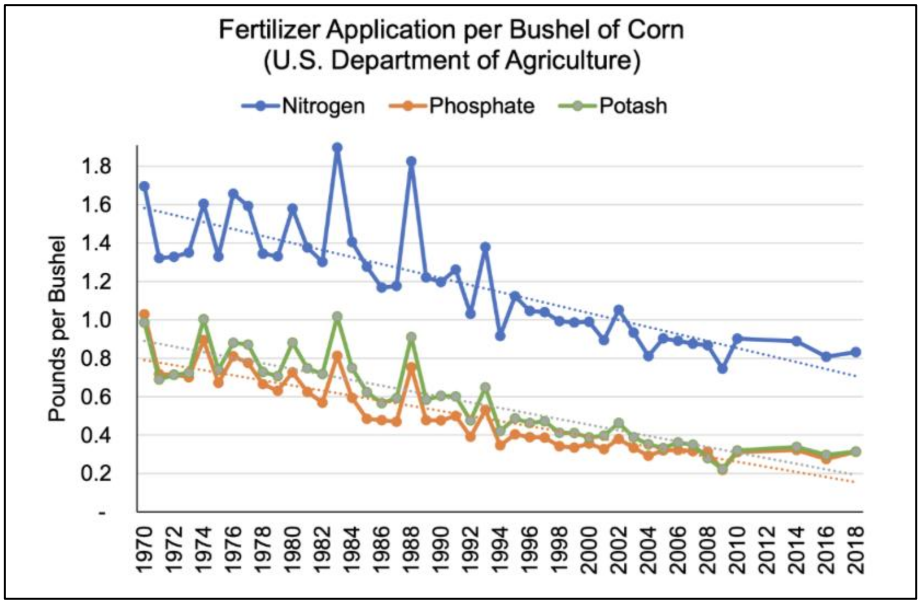

Figure 5: "Fertilizer Application per Bushel of Corn", USDA, 2019

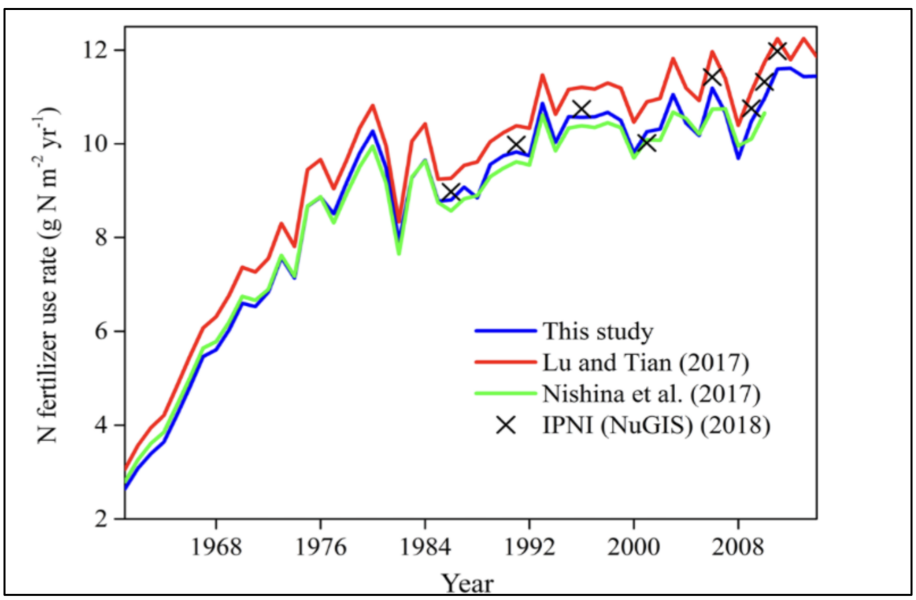

Figure 6: Nitrogen fertilizer use over time in the United States, Lao et. al, 2018.

Corn is the most produced crop in the U.S. and requires higher amounts of fertilizer than soybean or wheat (EPA, 2019), which are 2nd and 3rd respectively in U.S. crop production.

Therefore, an increase of national nitrogen fertilizer use is, to a significant degree, attributable to an uptick in corn production for ethanol fuel. As posited by the USDA, "in many cases, farmers have increased corn planted area by shifting acres away from less-profitable crops. Corn production has also expanded to nontraditional growing areas, especially in the north, as short-season hybrids have been developed." As other less-profitable crops in the United States have indeed reduced acreage, corn became the anomaly. The USDA cites that "much of this growth in area and production is a result of expanding ethanol production, which now accounts for nearly 45 percent of total corn use." It also essential to note the increase in monocrop farms, in which the percentage of corn farms with more than 500 acres has skyrocketed, while farms under 500 acres have all but gone away (USDA, 2023).

II

The Reality of Corn Ethanol

"*Resolving the scientific question of whether corn starch ethanol reduces emissions or not, relative to gasoline and diesel, is absolutely central to determining whether the EPA is implementing and enforcing an RFS that has net climate benefits, or one that has neutral climate impacts, or even has net climate damages*." – **Scientific Advisory Board for the Environmental Protection Agency, 2023**

In determining corn ethanol's role in the SAF industry, an interrogation of its "renewable" qualities is required. The U.S. Energy Information Administration defines renewable resources as "virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time". Renewable resources are naturally replenishing but are dependent on time and a controlled amount of extraction to sustain themselves. Renewability and sustainability are harmonious, if a resource is renewable, it is in most cases also sustainable. For example, petroleum fuels are non-renewable because they require the extraction of million-year-old fossilized organisms. Likewise, these fuels are not sustainable because the store of these fossils will eventually deplete and vanish.

A secondary tactic of qualifying fuel renewability is the flow of carbon throughout the lifecycle of the fuel. In the case of petroleum, carbon compounds are extracted from the lithosphere, combusted, and emitted as carbon dioxide, staying in the atmosphere indefinitely (relative to the Anthropocene). In the case of corn ethanol, carbon dioxide is sequestered (fixed via photosynthesis) from its atmospheric form by corn crop, is combusted in an engine, and is re-emitted into the atmosphere, theoretically creating a more balanced carbon flow. Corn ethanol would be a renewable fuel if it did not strain critical natural resources nor rely on petroleum fuels for planting, harvesting, transporting, and refining – and it used to be. In the pre-settler era, corn was a staple crop in many Indigenous tribes. Corn production was robust and able to be supported over long periods due to the techniques employed to maintain soil health (Ngapo et al, 2021). Following the industrial revolution, the introduction of chemical fertilizers promised higher short-term yields without requiring additional land, quickly becoming a widespread agricultural practice. The use of corn in a growing variety of foods and as livestock feed increased its demand, making chemical fertilizers all the more necessary. With ever-increasing demand for corn and rapid advancements in chemical fertilizer efficiency, it is easy to ignore the environmental externalities of production. However, considering modern agricultural practices in corn production, it is impossible to label corn ethanol as a renewable fuel. The negative effects on soils, water quality, and atmospheric carbon balance are too great to sustain corn ethanol's continued mass-production. This chapter will go more in depth with a few of these environmental externalities and will culminate with a reflection on the corn ethanol industry.

2.1) Soil Erosion

Agricultural practices in corn production in the United States have had dubious effects in regard to renewability. In 2021, corn farmers in Minnesota applied nitrogen to 98 percent of planted acres; phosphate (phosphorus) and potash (calcium) were additionally used for the majority of corn crop (Minnesota AG News, 2022). In the face of a constant and substantial demand for corn, farmers continue to renew soil nutrients artificially rather than using slower, more sustainable and slow techniques such as cover-cropping, multi-cropping, and crop rotation. For example, the implementation of a cover crop such as cereal rye can act as a way to reduce sediment losses from corn soils (USDA Climate Hubs, 2017). In cover cropping, the farmer does not harvest the crop but rather lets it degrade back into the soil, thus replenishing it. However, the transition to sustainable agricultural practices such as cover cropping can be slow and produce lower annual yields in the short-term. In the face of high biofuel demand, the current market pressure for high corn yields may be too great for farms to make this transition.

Chemical fertilizers add essential nutrients such as nitrogen, phosphorous, potassium and sulfur. The continued application of these fertilizers has led to both reliance and resistance from agricultural soils, leaving them to unable to replenish themselves on their own. Fertilizers have this effect on soils for a few reasons. Firstly, the excess of nitrogen and other nutrients within chemical fertilizers evoke high amounts of microbial activity which decompose carbon. In other words, the more microbes there is, the more soil organic carbon will be decomposed. When soil organic carbon is decomposed, it is released into the atmosphere as carbon dioxide. This poses serious environmental setbacks for any carbon-reduction benefits claimed by corn ethanol producers.

Additionally, carbon decomposition leads to the dispersal of soil aggregates - the "glue" that holds healthy soils together. Without stability, the soil profile will erode, leaving the land barren of agricultural promise. In fact, a 2020 study conducted by Thaler et. al estimates that roughly one-third of topsoil within the Corn Belt has been completely eroded. As topsoil is the medium for plant-growth, its erosion signifies lowered yields and potentially between $0.9 - 2.8 billion in annual losses (Thaler et. al, 2021). How can these economic losses be justified? Here, a paradox created – the continued production of corn ethanol poses the same problem as petroleum fuel – its production means the depletion of a natural resource as well a net flux of carbon dioxide emissions. This continues to reveal itself when examining corn cultivation's impacts on water quality, from the upper Mississippi basin to the Gulf of Mexico.

2.2) From Farm to Sea

Iowa – the top corn-producing state in the U.S., receives anywhere (on average) from 32-40 inches of precipitation per year. Historically, the wettest months of the year have been May-August, aligning well with the sowing of corn crop in May and its growth throughout the summer. Despite this, states in the Corn Belt like Iowa have been facing increasing droughts and extreme summertime heat, elevating the need for irrigation. Iowa has gone from irrigating 142,109 acres of cropland in 2002 to 222,000 in 2017, this is a 56% increase. In 2021, Iowa used 16,221 million gallons of groundwater to irrigate corn and soy crop, making up the vast majority of its cropland (Miller, 2023). Iowa and many neighboring states have historically had little trouble with rainfall, and the last two years have been unusually wet summers. An Iowa raindrop has a 63% chance of falling onto a corn or soy farm, where it will face one of two scenarios (Bittman, 2019). The water will either get absorbed into the soil, evaporate, or will run straight off into a nearby stream. This runoff depends on soil permeability conditions - for example, a soil would be less permeable if there is fallow or waterlogged due to heavy rainfall or irrigation. The Corn Belt is connected within a network of waterways and water that is not absorbed by soils or is evaporated will flow into the Mississippi. Due to heavy fertilizer use, the water will accumulate nitrogen, phosphorus, and potassium, and cause significant environmental damage.

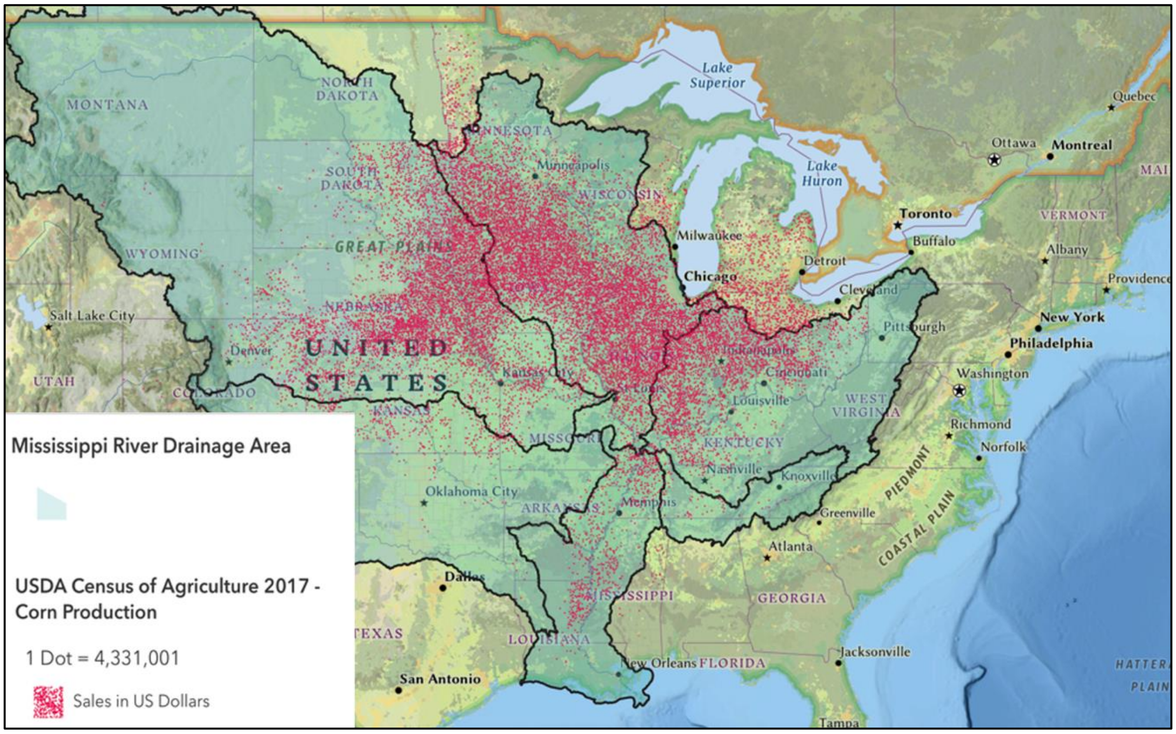

Figure 7: Map of the Mississippi River drainage area, Mississippi sub-basins, and U.S. corn production in 2017. Map created by Emily Rinn in ArGIS Online.

This map acts as a visual aid in understanding the connection between corn agricultural production in the Corn Belt, the and the extensive water systems that lead to the Mississippi. The next two maps illustrate the distribution of nitrogen fertilizer application in the U.S., emphasizing just how much nitrogen is present in the region and is attributable to corn production.

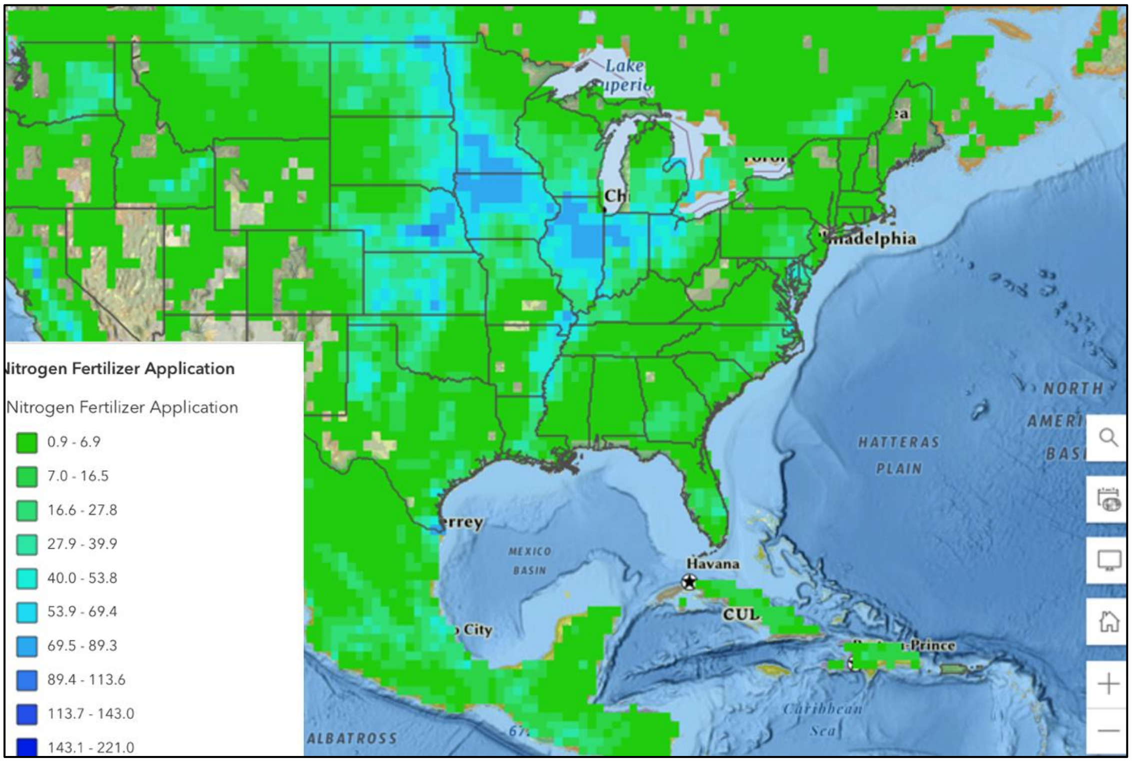

Figure 8: Map of nitrogen fertilizer application distribution in the U.S. Map created by Emily Rinn in ArGIS Online.

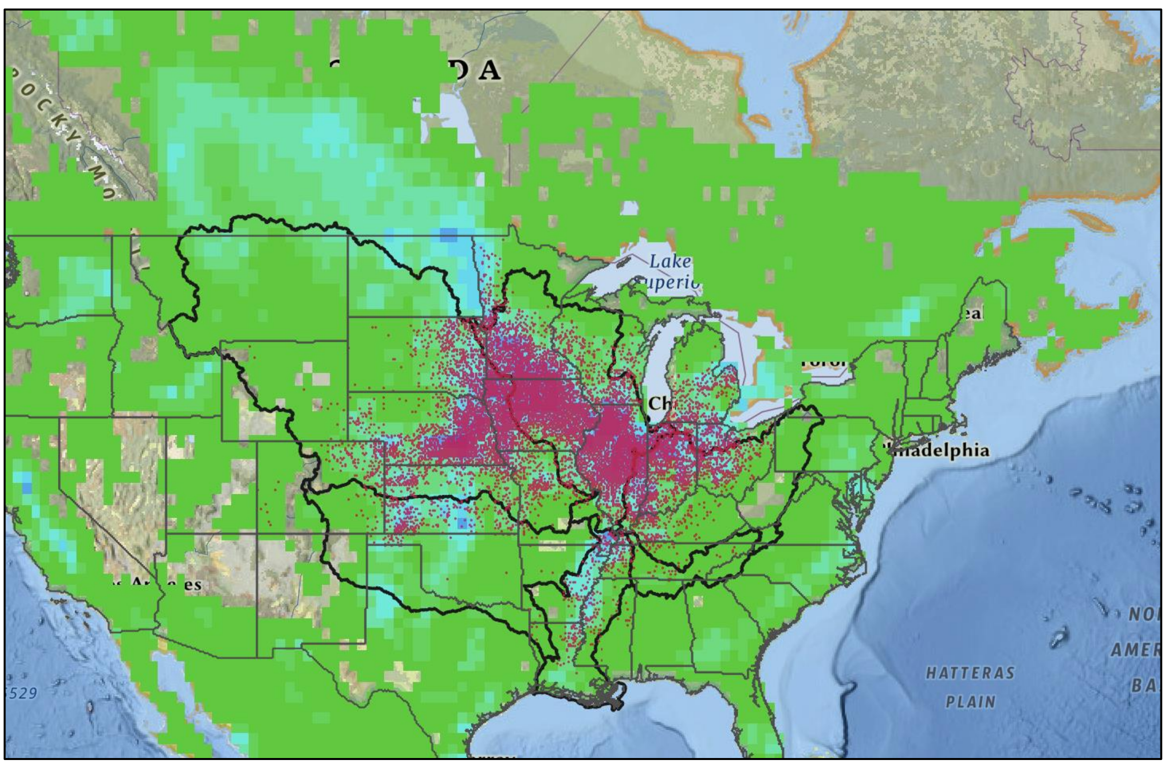

Figure 9: Map of nitrogen fertilizer application, corn production, and Mississippi sub-basins in the United States. Map created by Emily Rinn in ArGIS Online.

As excessive flows of nitrate and other compounds enter tributaries, the Mississippi, and out to the Gulf of Mexico, a stream of disaster is left in its wake. First, farmers who rely on local water sources face serious consequences of its consumption such as methemoglobinemia, which can affect how people's blood cells carry oxygen. Excess of these compounds also cause harmful algal blooms within a process called eutrophication. Fresh or saltwater bodies of water receive mass quantities of nutrients which cause rapid algal growth. When the algae degrade, they require oxygen to decompose, thus reducing dissolved oxygen content in the water. This lack of oxygen leads other aquatic life forms to suffocate and die, leaving waters barren of life. EPA estimates that 71% of lakes, and 84% of bays and estuaries in the U.S. have impaired water quality with agricultural runoff being the main source. This effectively means that bodies of water cannot support human welfare, such as drinking water, fishing, or recreation (Smith et. al., 2019). Eutrophication is a major issue in the Gulf of Mexico and has created an oceanic "dead zone"; a multi-thousand square mile hypoxic vacuum of marine life. This has caused massive economic damages to fishing and shrimping industries along Texas, Louisiana, and Mississippi. The dead zone has been extensively researched and there have been efforts to reduce the milage of this hypoxia. However, it has nowhere near gone away and will continue to worsen with growing nutrient flows from the Mississippi.

2.3) Discussion on the Corn Ethanol Industry (Interview with Lark)

An interview was conducted with Tyler Lark from the University of Wisconsin-Madison, who is the first author of the "Environmental Outcomes of the Renewable Fuel Standard". As previously mentioned, this article ruffled feathers across the renewable fuels industry as it made strong claims against the environmental benefits of corn ethanol production under the RFS. The conversation spanned many subjects, from the motivations of organizations such as the Renewable Fuels Association to differences in models that measure corn ethanol's lifecycle emissions. The following is a combination of subjects covered in the conversation and research to supplement any informational gaps.

One of the primary goals of this interview was to pinpoint where there was and was not conflict of interest within this scientific debate. For every article that denounced the existence of corn ethanol's emission reduction benefits, there was another rebutting it, saying these articles were based on overly pessimistic assumptions. However, it was clear that most of these rebuttals were repeatedly citing studies from the same few organizations such as Argonne Laboratories, a federal organization. Although it is easy to assume federal organizations as neutral, there was still doubt over how scientists could label corn ethanol as "renewable" given the existing knowledge of corn agriculture practices.

For many years, Lark had been tracking the expansion of agricultural land in the U.S., particularly in the midwestern region. He had noticed the conversion of many grasslands and wetlands into agricultural areas. Among others, he was determined to understand the driving factors driving these land use changes. It was known that agricultural expansion due to biofuel crops, specifically corn, were part of this land use change equation, but there was little knowledge to what extent. Thus, Lark and his team of economists, geographers, and agroecosystem modelers set out to discern the effects of corn agricultural expansion driven by increased biofuel production. Their results did not surprise them. In fact, since the creation of the second RFS in 2007, many environmental advocacy organizations had opposed the advertisement of corn ethanol being a carbon-reduction initiative, given the drastic changes in land use that would accompany the mandate.

Its must be noted that besides carbon reductions, there were notable economic and geopolitical factors that informed the genesis of the RFS mandate. In 2007 under the Bush Administration, the U.S. was facing severe economic turmoil in regard to petroleum prices (Hamilton, 2009).

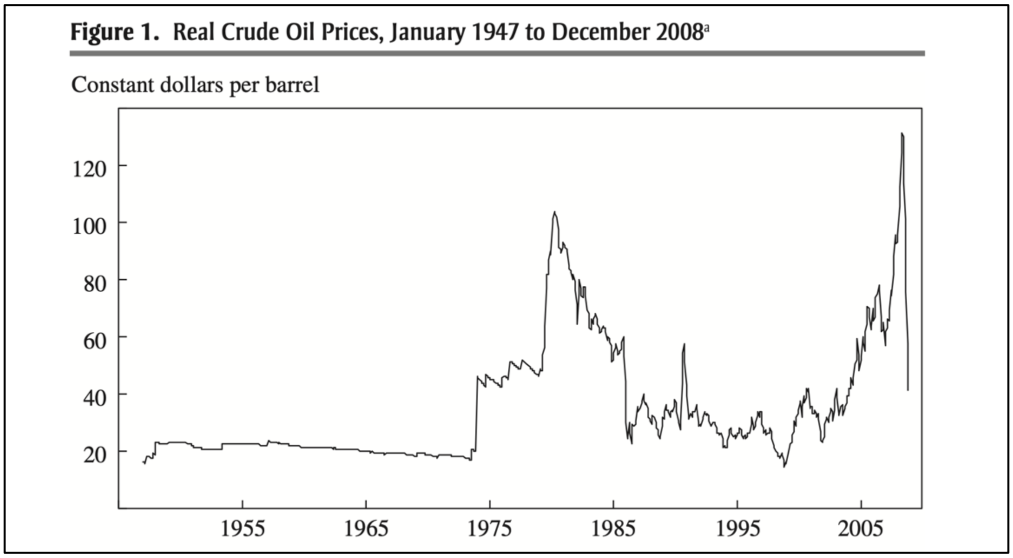

Figure 10: Energy Information Administration (EIA) data; Bureau of Labor Statistics data. Monthly average price of West Texas Intermediate crude in dollars of November 2008.

Important factors regarding these energy security issues were 1) increased petroleum demand and 2) militarized conflict in Iraq. As the U.S. economy had grown, so had the demand for petroleum resources. In 2007, the U.S. was facing a petroleum scarcity problem due to continued reliance on Iraq for petroleum. Simultaneously, the U.S-Iraq war was at its peak, with the highest number of U.S. troops being in Iraq in November of 2007 (Anastacio et. al, 2023). Given the energy crisis, quick policy action ensuring the sourcing of alternative energy had to be made. This is where the RFS and corn ethanol production came into the equation. Given the small but consequential amount of existing ethanol production and notable pro-biofuel sentiment at the birth of the RFS, increased corn ethanol production was an optimal solution for increasing domestic fuel production. According to Dr. Hana Breetz, a biofuels researcher at Arizona State, the U.S. Government was much more interested in replacing petroleum than looking a renewable energy source (Hock, 2021). Given the task of creating policy that would incentivize alternative energy production, policymakers framed the RFS as a multifaceted solution to address domestic energy production, rural economic prosperity, and carbon emissions reductions. With the exception of the carbon reduction aspect, the RFS succeeded in achieving these goals.

In 2023, where carbon reduction is integral to future energy policy, the marketing of corn ethanol as a "renewable fuel" does not hold up. Nevertheless, since the industry was built in 2007 partially on the premise of carbon reduction, the corn ethanol industry has become deeply entangled with U.S. environmental and energy policy. In exposing the environmental harms caused by its production, many reputations are put on the line. Nowhere does this reveal itself more than in the Renewable Fuel Association's response to Lark's paper, which was published on the same day. The Association was clearly facing a substantial amount of pressure when they released their response, as seen in their provocative language and scientifically underdeveloped argument. This pressure evidence is stacked against corn ethanol's renewability, there would be no reason to provide the 2.2 billion dollars in subsidies that it receives annually (Miller, 2022). If it were to stop being so heavily subsidized, it is likely that corn ethanol production would substantially decrease, resulting in market collapse.

2.4) Differences in Modeling Conditions

If corn ethanol is not a renewable fuel, how is it still being marketed and subsidized as such? This boils down to the way that production emissions are modeled and whether favorable conditions are selected or not. In the case of corn ethanol, modeling is a political tool that drives its continued market success. Due to high amounts of economic stake on behalf of companies, government, and affiliated organizations, there has been a wide array of ways in which corn ethanol is modeled to show environmental benefits or lack thereof. For example, an article by Scully et. al (2021) states that "market conditions that favor greater adoption of precision agriculture systems, retention of soil organic carbon, and demand for co-products from ethanol production may lower the CI of corn ethanol" (CI= carbon intensity) (Scully, et. al, 2022). Scully et. al propose that current model estimations of the CI of corn ethanol are likely too high since they do not adequately incorporate advances in production efficiency. This article's findings have been used as evidence to advertise corn ethanol's carbon reductions. However, this study was commissioned by POET LLC., a U.S. biofuel company that specializes in corn ethanol production. This directly contrasts the responses to the article, such as Spawn-Lee et al., who argues that Scully "disproportionately favors small values and optimistic assumptions without rigorous justification nor empirical support" (Spawn-Lee et. al, 2021) Unlike Scully, Spawn-Lee notes their lack of conflict of interest involved in the researching and writing of this article.

It is vital to consider the role that conflicts of interest may play in the curating of emissions models. The underlying assumptions that inform these models can range from optimistic to pessimistic- and this is, in many ways, dependent on the intended outcomes of the study (or rather, dependent on who is funding the research). For example, the GREET Model is one of the most popular models that shows corn ethanol as having sufficiently low carbon lifecycle emissions. This model considered highly reputable due to the fact that it was created by the Department of Energy (DOE), which operates Argonne Laboratories. Still, it must be asked whether the DOE, a governmental branch who has invested billions of dollars into the corn ethanol industry, has zero conflict of interest. The DOE and biofuel companies have the same common goal: to continue and grow the corn ethanol industry. As conveyed in previous analysis, with the help of subsidies, corn ethanol is an economical alternative to petroleum fuels. It is a lucrative opportunity for biofuel companies and bolsters domestic fuel production. The DOE, whose mission is to “ensure America's security and prosperity” (Energy.gov, 2023), encourages biofuel production because it decreases U.S. reliance on petroleum imports.

Despite the GREET Model’s popularity, continued corn ethanol production remains controversial in governmental organizations such as the EPA Scientific Advisory Board, who recently published “Commentary on the Volume Requirements for 2023 and Beyond under the Renewable Fuel Standard Program”. This commentary was in response to the RFS’s release of 2023 volume requirements of corn ethanol, which as previously mentioned, reduced but certainly did not significantly lessen the benchmarks of corn ethanol production. The Board urges the EPA to commission further analysis on corn ethanol’s sustainability benefits before continuing to incentivize its production. The Board cites the MOVES model that projects “seven of the 20 estimates from the models used for corn starch ethanol’s lifecycle GHG emissions are above the upper bound of that threshold” (EPA, 2023). In this case, the “threshold” mentioned is the maximum amount of emissions permissible by the RFS, making corn ethanol outside the legal limit in 35% of cases. This commentary goes on to cite the articles by Lark and Scully in recognizing “that science is divided on this issue”. EPA must be urged to consider the presence of stakeholder conflict of interest and funding within this division of scientific opinion. Noting the discrepancy between Scully, who received funding from a biofuel company, and Lark, who has no conflict of interest or reason to tarnish the name of the corn ethanol industry.

Conclusion

This is a call to stop the subsidizing corn ethanol production under the guise of environmental benefits. Corn cannot be used as a major feedstock source in the SAF Grand Challenge, as modern agricultural practices and land use changes do not render corn production sustainable in the slightest. Additionally, the utilization of corn ethanol as SAF may economically disincentivize the development of advanced fuels with proven environmental benefits. Corn ethanol has never, nor is, a truly renewable fuel and must stop being marketed and subsidized as such. Corn ethanol lobbyists and policymakers need to make any conflict of interest more apparent when attempting to promote its environmental benefits or contradicting alternative research.

While electrification poses a promising alternative for decarbonizing terrestrial vehicles, it is likely that aviation will continue to rely on liquid fuels. Therefore, producing SAF with tangible environmental benefits is essential to decarbonizing the aviation sector. The incentivizing of advanced SAF production with feedstocks such as landfill, sludge, and agricultural and forest residues via Fisher-Tropsch and other pathways is an essential next step. These technologies have been extensively researched and have been proven viable but require increased economic backing to overcome start-up costs. Additionally, a re-examination of the U.S.'s agricultural practices is necessary. Although there has been remarkable progress in limiting the amounts of chemical that are applied to crops, it does not mean much for the corn industry if sustainable practice is not universally enforced. A transition to sustainable corn cultivation would mean less ethanol yield but would produce a genuinely renewable fuel. Governmental organizations such as the EPA, DOE, and USDA must reflect on what is truly important in these unprecedented times – prioritizing sustainability often means making difficult short-term financial decisions. In due time, these decisions **will** pay off, creating a more equitable, biodiverse, and self-sustaining world.

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