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EDITORIAL

U.S. climate-smart agricultural and forestry incentives: from offsets to clean energy credits

Jeffrey K. O'Hara

Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC, USA
Email: jeffreyk.ohara@usda.gov

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Abstract

Climate-smart agricultural and forestry (CSAF) practices prevent greenhouse gas emissions from occurring or increase carbon sequestration. I examine how the development of U.S. CSAF incentives shifted from offset markets to biofuel regulations over time. My perspective is informed by two professional roles I had in developing these standards. First, as an economist at the Chicago Climate Exchange, I developed CSAF offset protocols between 2007 and 2010. Second, between 2022 and 2024, I was an economist at the U.S. Department of Agriculture (USDA) when USDA developed a climate-smart agriculture pilot protocol for the sustainable aviation fuel blender's tax credit. Twenty years ago, there were no U.S. biofuel mandates and CSAF incentives were conceptualized as occurring through offset markets. I explain how, in contrast to cap-and-trade programs, greenhouse gas emissions from agricultural and forestry practices are already included in the baseline of biofuel regulations. This implies that additionality issues, which have impeded the development of CSAF offset standards, are not as applicable to biofuel programs. Specifically, I examine the development of agricultural soil carbon, livestock digester, and forest carbon protocols as case studies. I conclude by discussing how CSAF crediting may evolve in the future.

Keywords: Agricultural soil carbon; forest carbon; livestock digester

JEL Codes: Q15; Q54; Q57

Introduction

Promoting U.S. climate-smart agricultural and forestry (CSAF) practices became a policy priority when the U.S. rejoined the Paris Agreement in 2021 (USDA 2021). I refer to CSAF practices as those that either prevent greenhouse gas (GHG) emissions that would have otherwise occurred or increase carbon sequestration. Interest in CSAF protocols exists because GHG emission reductions from the agricultural and forestry sectors have not occurred to the same extent as in other sectors. For instance, U.S. GHG energy sector emissions declined by 18% between 2005 and 2022. However, U.S. agricultural GHG emissions increased by 2%, and GHG mitigation from land-use, land-use change, and forestry declined by 6% (EPA 2024).

In this essay, I examine how U.S. CSAF incentives shifted from offset markets, which has proved challenging over a twenty-year period, to biofuel and energy regulations. While U.S. biofuel mandates did not exist twenty years ago, biofuels have subsequently become a major end-use for crops. This essay reflects my observations from two professional roles I had in developing CSAF protocols. First, I was an economist at the Chicago Climate Exchange (CCX) between 2007 and 2010, in which I was a staff lead in developing forest carbon protocols. Second, I was an economist at the U.S. Department of Agriculture's (USDA) Office of the Chief Economist between 2022 and 2024 when USDA developed a climate-smart agriculture pilot protocol for the sustainable aviation fuel blender's tax credit.

This evolution bookends the two most consequential U.S. legislative bills to address climate change. The first, the Waxman-Markey Bill to develop a U.S. cap-and-trade program, passed the House of Representatives in 2009. However, it never became law since it did not pass the Senate, and the lack of federal cap-and-trade legislation led to CCX's closure. The second bill, the Inflation Reduction Act (IRA), became law in 2022. The IRA contained provisions for clean energy tax credits for biofuels, hydrogen, and electricity production. These tax credits were unique because, instead of volumetric credits, the magnitude of the IRA credits was a function of the lifecycle greenhouse emissions from energy production. Since these emissions are influenced by farming practices, this structure provided an avenue for CSAF crediting.

A distinction between CSAF protocols in offsets and biofuels programs is that GHG emissions from agriculture and forestry are typically not included in the baseline in the former instance, while they are in the latter instance. This implies that the two main critiques of CSAF offset protocols are not as relevant for CSAF biofuel crediting. First, offsets are sometimes morally criticized because they allow polluters to avoid reducing their own emissions by paying another party for GHG mitigation. Second, there is concern that some CSAF offset protocols have low "additionality". Additionality exists when the payment leads to an activity that would not have otherwise occurred. The use of offsets without additionality can result in an emitter being credited for reducing emissions without any new mitigation activity occurring.

In the next section, I describe CSAF standards across three time periods. I begin with CCX, which developed the first prominent CSAF offset protocols during the latter half of the 2000s. I then review efforts by voluntary carbon standards and California during the subsequent decade. I conclude this section by examining the federal government's recent efforts to promote CSAF practices in biofuel and energy tax credits. In the following three sections, I respectively review the development of agricultural soil carbon, livestock anaerobic digester, and forest carbon GHG protocols as case studies. For the three practices, I describe both GHG offset standards and clean energy standards for these practices. In the conclusions section, I discuss how CSAF crediting may evolve in the future.

Evolution of CSAF protocols

Chicago climate exchange

Chicago became a major U.S. metropolis as the transportation and financial center for Midwest crop, livestock, and forestry commodities (Cronon 1991). From 1848 until 1975, futures contracts on the Chicago Board of Trade (CBOT) and Chicago Mercantile

Exchange were premised on agricultural and forestry commodities. Richard Sandor, CBOT's chief economist in the 1970s, led the development of financial futures contracts (e.g., stock indices, exchange rates, and interest rates). By the 1990s, Sandor saw commodifying air and water resources as the next frontier for Chicago's future industry (Sandor 2012). The success of the Acid Rain Program at reducing sulfur dioxide emissions was perceived as precedent-setting for how the potentially much larger market for GHG emissions could be regulated (Sandor and Skees 1999).

Sandor founded CCX in 2003. CCX was a cap-and-trade program for GHG emissions that companies could voluntarily join to attain legally binding emission reduction targets. CCX developed offset protocols as a low-cost compliance option for point sources seeking emission reduction credits. CCX closed in 2010 when efforts to pass federal cap-and-trade legislation collapsed.

CCX's offsets program focused on the collection and combustion of methane and increasing U.S. agricultural soil carbon sequestration (IncubEx 2021). During the late 2000s, CCX offsets compromised a considerable portion of the voluntary offset market (FTEM 2021). Approximately 9,300 U.S. farmers on 19 million acres enrolled in CCX's agricultural soil carbon protocols (Sandor 2012).

CCX's offset protocols were premised around the notion that standardization was essential for the scalable solutions that addressing climate change required. Standardization is important since high transaction costs are an impediment to the efficiency of environmental markets (Stavins 1995; USDA 2023). To address this, CCX's CSAF protocols were administered by offset "aggregators" like the Iowa Farm Bureau and North Dakota Farmers Union. Aggregators developed standard enrollment contracts, contracted a third-party verifier, and registered and transacted offset credits on CCX's trading platform. CCX issued offset contracts to aggregators in increments of 100 metric tons of carbon dioxide equivalent. Since CSAF offsets were issued for the entire project pool, an offset contract was not associated with specific land parcels.

CCX also reduced transaction costs by developing "look-up" tables for crediting agricultural practices. For each practice, the tables provided crediting rates by U.S. region in metric tons of carbon dioxide equivalent per acre per year. While an average parameter rate may not be accurate for a specific farm or ranch, CCX justified look-up rates based on the logic that average rates are accurate in the aggregate when applied to many farms or ranches. CCX developed the look-up tables since they deemed direct measurement and modeling for soil organic carbon practices as cost prohibitive (IncubEx 2021). This is because the annual effect of management practices on soil carbon levels is small and there is high variation of soil carbon levels across space and depth (Paustian et al. 2019a, 2019b). CCX convened soil science technical subcommittees to develop the tables, which were informed by state of the literature at the time and professional judgment.

Voluntary and California offset standards

The three main U.S. voluntary offset registries; ACR, Climate Action Reserve, and Verified Carbon Standard; were launched between 1996 and 2007 (Table 1). Between 2016 and 2022, an additional thirteen voluntary carbon market programs were established (USDA 2023). They are referred to as "voluntary" since companies that are not complying with a binding emission reduction target can voluntarily purchase offsets that are verified according to the registry's standard.

Reviewing the distinction between futures and forward contracts contextualizes the differences between CCX and voluntary carbon offset protocols. Forward contracts are customized for bilateral transactions, while futures contracts are designed to be fungible

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Table 1. Selected carbon market standards for U.S. agriculture and forestry projects

Program	Years	Coverage	U.S. Agriculture/Forestry Offset Protocols
Cap-and-Trade Programs with U.S. Offsets			
Chicago Climate Exchange	2003–2010	Over 100 emitting members (17% of Dow Jones Industrial Average; 20% of U.S. electric utility sector)	6 ag/forestry protocols. Issued 27 MMT CO_2e to U.S. agricultural soil carbon projects.
Regional Greenhouse Gas Initiative	2009 – present	Northeast U.S.	2 ag/forestry protocols, neither have never been used.
California Cap-and-Trade Program	2013 – present	California (linked with Quebec)	4 ag/forestry protocols, 2 have never been used. Issued 212 MMT CO_2e to forest carbon projects and 9 MMT CO_2e to livestock digester projects.
Washington Cap-and-Invest Program	2023 – present	Washington	Adopted 3 ag/forestry protocols from California's program, projects must provide direct benefit to state.
ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)	2024 – present	International aviation	Has approved ag/forestry protocols from 8 registries, including ACR, CAR, and VCS.
Main U.S. Voluntary Offset Registries			
ACR	1996 – present	Approved registry in California, CORSIA, and Washington	12 ag/forestry protocols, 6 of which have been deactivated
Climate Action Reserve (CAR)	2007 – present	Approved registry in California, CORSIA, and Washington	8 U.S. ag/forestry protocols, over 90% credits issued to forest projects
Verified Carbon Standard (VCS)	2003 – present	Approved registry in California and CORSIA	Over 40 ag/forestry protocols in total, 15 of which are applicable in U.S.

Sources: CARB 2024a; IncubEx 2021; RGGI 2024; Sandor 2012; USDA 2023.
Note: MMT CO_2e refers to million metric tons of carbon dioxide equivalent.

and traded anonymously at scale. The advantages of an exchange-traded futures contracts are price transparency, low transaction costs, and the removal of counterparty default risk. Futures contracts are unsuccessful if important features of the transaction cannot be standardized. Whereas CCX offsets were transacted anonymously on-screen with relatively little information conveyed to the purchaser (akin to futures contracts), voluntary offset credits are typically sold bilaterally to corporates seeking to publicly communicate or report these purchases (akin to forward contracts). I summarize the transactional differences between CCX and voluntary standards in Table 2.

The CCX market price reflected the cost of mitigating GHG emissions exclusively. However, non-GHG project co-benefits are typically embedded within the GHG price for voluntary offset credits (FTEM 2023). Buyers of voluntary credits may be publicly reporting the details of their transaction. So, they have an incentive to support "high-quality" projects with other social or environmental co-benefits (e.g., providing income to an indigenous community, improving water quality, or protecting endangered species). Since there are no markets for these other co-benefits, contractually these benefits are instead reflected in the GHG transaction price.

Unlike CCX, the voluntary standards' CSAF protocols were not conducive for aggregated pools of farmers or foresters. So, voluntary carbon standards established more precise protocols for measurement, monitoring, reporting, and verification (MMRV). More stringent MMRV requirements could include, for instance, (a) broader project boundaries for quantifying GHG emission reductions, (b) requirements to use direct measurement or modeling instead of look-up tables, (c) discounts applied for conservative crediting, (d) longer contract lengths for terrestrial soil carbon projects, (e) more scrutiny on additionality considerations, and (f) greater reporting standards. Ironically, while CCX's protocols were criticized for having low additionality due to low MMRV costs, high MMRV costs also reduce additionality. For instance, a landowner may only contractually commit to include their land in forest for 100 years if they had other (non-carbon payment) motives for doing so.

The large number of CSAF carbon protocols, along with high MMRV requirements, have contributed to market confusion and impeded the participation of U.S. farms and ranches in offset programs (USDA 2023). In a review of 55 protocols that could be used by U.S. farmers, ranchers, and foresters, USDA (2023) found that only 18 have been used. Negative media and academic research on international forestry projects, which I do not review in this paper, also contributed to successive declines in voluntary carbon market transactions in 2022 and 2023 (FTEM 2024).

Government regulators have also developed U.S. CSAF offset programs in cap-and-trade programs (Table 1). The California Air Resources Board's (CARB) program is the only active program that has registered offsets to-date. CSAF offsets in CARB's program have been registered under two protocols – forest carbon and anaerobic digesters – which I describe in later sections. I include CARB in the voluntary carbon section because CARB's forest carbon and anaerobic digester protocols were both derived from Climate Action Reserve protocols.

CARB has reduced the role of offsets in general, and out-of-state offsets specifically, within its cap-and-trade program. Beginning in 2021, CARB reduced the percentage of offsets that regulated entities could use for compliance from 8% to 4% and stipulated that at least half of offsets must provide environmental benefits to California. CARB's decision to curtail offset use was in response to complaints from environmental justice advocates that the program needed to prioritize reducing pollution in low-income areas within California.

Table 2. Comparison of Chicago Climate Exchange (CCX) and voluntary offsets transactions and protocols

	CCX offsets	Voluntary offsets
Marketplace Differences		
No. of transactions involving offset credit?	Potentially many. Hedge funds & proprietary traders were main buyers on CCX. Offsets retired by CCX members for compliance.	Typically only one transaction, after which the offset is retired.
How do transactions occur?	On-screen with anonymous counterparties. Ex ante, buyers unaware of what allowance type they are buying.	Bilaterally. Buyer typically identified prior to project registration.
Project information conveyed to purchaser?	Ex post, buyers learn limited info: country of origin, vintage, and basic offset type (e.g., forestry, soil carbon, rangeland). Offset contracts not associated with specific plots of land since contracts issued to aggregated pools of parcels.	Full information
Implications of higher transaction costs?	Offsets less cost-effective as a mitigation strategy	Signal of higher "quality" projects
Market prices incorporate project (non-GHG) co-benefits?	No	Yes
Compete with emission reductions from point sources?	Yes	No
Protocol Principles		
How do farmers, ranchers, and foresters participate?	Via CCX-approved aggregators with standard enrollment contracts	Not designed for aggregators
Longevity	Specified in aggregator-landowner contract of 5 years for farms/ranches, 15 years for forestry. Enforceability unclear beyond CCX market phase.	Typically for longer time horizons, which reduces likelihood of additionality.
Additionality	Did not exclude first adopters. Priority was for small-scale operators to adopt sustainable management plan.	Greater emphasis on difference between project and baseline scenario.
Quantification	Narrower project boundaries. Use of look-up tables (except for managed forests).	More expansive project boundaries. More emphasis on direct measurement/modeling.

CSAF incentives in energy policy

Clean transportation fuel programs are designed to reduce the GHG emissions from fuel use. The carbon intensity (CI) of a fuel represents its lifecycle GHG emissions per unit of fuel energy. Crop-based biofuel lifecycle GHG emissions typically include both the direct emissions associated with feedstock production, transportation, and biorefining; and the indirect emissions resulting from land-use change that may arise from biofuel mandates.

The direct emissions from crop-based biofuels include emissions from farming inputs and on-farm energy consumption, nitrous oxide (N_20) emissions from nitrogen application, and soil organic carbon sequestration (Liu, Kwon, and Wang 2021; Liu et al. 2020). Average farming practices are typically assumed in CI models (Liu et al. 2020). This implies, for instance, that the nitrous oxide emissions in a corn ethanol pathway are estimated assuming that farms are applying fertilizer at national average levels. Soil organic carbon emissions are not explicitly included typically, which implicitly assigns them a value of zero. Assumptions about farming practices, like tillage, are also embedded within indirect land-use change emission calculations. So, establishing a consistent baseline across the direct and indirect emission calculations is important for accurate CSAF crediting calculations.

Biofuels that use CSAF feedstocks have a lower CI than those that use conventionally produced feedstocks. However, there has not been precedent for CSAF crediting in U.S. biofuels programs. The two main U.S. biofuels policies are the federal Renewable Fuel Standard (RFS) and state-based transportation fuel policies, such as California's Low Carbon Fuel Standard (LCFS). The RFS establishes volumetric mandates for biofuels that attain specified CI thresholds. The state programs establish the CI of transportation fuel sold in their state instead of prescribing the volume of fuels. In these programs, producers of fuels below the required CI limit receive credits that they can sell to producers in deficit. In neither program type are biofuel CIs adjusted for CSAF practices. Similarly, federal biofuels tax credits have historically been premised on their per-gallon production volume and have not incentivized CSAF feedstocks.

The IRA established two biofuels tax credits in which the magnitude of the credit was a function of the pathway's CI: the "40B" sustainable aviation fuel blender's tax credit for 2023–24 and "45Z" clean fuel production tax credit for 2025–27.[1] The IRA designed these tax credits to incentivize CI reductions since the tax credit becomes greater as a fuel's CI declines. The IRA did not specify whether CSAF practices would be included in the CI methodology for the tax credit. Nonetheless, the first of these two tax credits, the 40B credit, established a pilot CSAF protocol for U.S. corn and soybean pathways.

The effects of energy policy on CSAF practices extend beyond crop farms. In recent years, the LCFS has had a more impactful role in incentivizing anaerobic digesters on livestock operations than offset programs (O'Hara, Xiarchos, and Weber 2023). Further, the establishment of GHG lifecycle accounting protocols for livestock anaerobic digesters is relevant to IRA tax credits for biofuel, hydrogen, and electricity production.

GHG accounting standards have likewise become relevant for sustainable forest management. This is because the eligibility of woody biomass in the IRA's clean electricity tax credit is premised on its carbon intensity estimate. I describe GHG accounting

[1]The 40B tax credit is \$1.25/gallon for SAF with a 50% lower CI than petroleum jet fuel. Each incremental percentage point CI reduction receives an additional \$0.01/gallon tax credit, so that the maximum credit is \$1.75/gallon. The 45Z credit will apply to any fuel with a CI less than 50 kg CO_2e per million British thermal units (47.4 gCO_2e/MJ). While the formula that determines the tax credit magnitude varies between 40B and 45Z, the 45Z tax credit is like the 40B credit in that the size of the credit increases as a pathway's CI declines.

standards for all three issues (crop-based biofuels, livestock anaerobic digesters, and woody biomass electricity generation) in subsequent sections.

Agricultural soil carbon protocols

Offset protocols

Soil carbon sequestration practices can prevent soil carbon losses that would otherwise occur (e.g., conservation tillage), increase atmospheric carbon removal (e.g., cover crops), or both (e.g., conversion of cropland to perennial grasses) (Paustian et al. 2019b). Developing agricultural soil carbon offset protocols was a strategic priority for CCX given a) the strong historical connection between the U.S. agricultural sector and Chicago's commodity exchanges, b) philanthropic support CCX received from the Great Lakes-focused Joyce Foundation, and c) research indicating that conservation tillage could significantly increase soil carbon levels in the Corn Belt (Sandor and Skees 1999; IncubEx 2021).

CCX developed U.S. soil carbon offset protocols for three practices: continuous conservation tillage, the conversion of cropland to grasslands, and sustainably managed rangelands. No-till is a type of conservation tillage in which farmers do not till the soil in the period between the harvesting of the previous crop and the current crop. This practice reduces soil erosion and, in many areas, increases soil organic carbon (Ogle et al. 2019; Paustian et al. 2019b).

CCX's conservation tillage and rangelands protocols required farmers and ranchers to contractually commit to undertaking the practice for five consecutive years. If an enrolled farmer reverted to conventional practices at any point, CCX's protocol required that the aggregator surrender an amount of credits equivalent to what that farm had accrued. Since less research about intermittent tillage was available at the time, CCX conservatively assumed that all credited soil carbon gains would be lost from one tillage event. Subsequent research found that occasional tillage (i.e., once every five or ten years) does not lead to soil carbon reversals (Blanco-Canqui and Wortmann 2020).

CCX's soil carbon protocols were critiqued for having low additionality. Some non-additionality from conservation payments is unavoidable given that payments are not the only consideration for farmers to undertake the practice. Concerns about CCX's protocol existed because conservation tillage adoption was increasing during 2002–2010 due to the cost savings it provided to farms from reduced field operations and input purchases (Claassen et al. 2018; Wallander et al. 2021). The on-farm benefits from conservation tillage imply that the practice has lower additionality relative to other farming practices, such as vegetative practices and cover crops (Wallander et al. 2019).

A specific reason CCX's protocol was criticized was because it did not exclude farmers who had previously employed the practice. CCX used a start-date criteria for additionality for protocols involving significant investments; including anaerobic digesters, afforestation, and the conversion of cropland to grassland. CCX's rationale for not excluding first adopters in the no-till and rangelands protocols was because farmers make these decisions annually, which implies that farmers that implement the practice in one year may discontinue the practice the following year. The percentage of farms undertaking continuous conservation tillage, as opposed to conservation tillage in one year, is relatively low (Claassen et al. 2018; IncubEx 2021; Wade and Claassen 2017). CCX also had concerns that excluding first adopters would be unfair to farmers already employing sustainable practices and could incentivize farmers to discontinue the practice to become eligible

(IncubEx 2021). Less research has focused on the additionality of continuous no-till because the USDA surveys only track tillage practices over a four-year time duration (Claassen et al. 2018; Wade and Claassen 2017). Research that examined no-till practices over longer time intervals would provide greater insight into the additionality of the practice.

Agricultural soil carbon offset crediting was dormant between 2010 and 2020. CARB did not adopt agricultural soil carbon offset protocols. Of the seven soil carbon voluntary carbon market protocols, five have never issued credits to U.S. projects and the other two were not adopted until 2020 (USDA 2023).

USDA conservation programs also supported soil carbon sequestration farming practices, although they were not considered "climate-smart" incentives historically. Instead, USDA conservation programs prioritized factors like increasing soil health and improving water quality instead of mitigating GHG emissions. Over time, USDA has shifted this support among practices, including reducing funding for conservation tillage while increasing funding for cover crops (Wallander et al. 2021).

USDA has recently begun prioritizing CSAF practices in its conservation programs. In 2022, the IRA provided $19.5 billion in funding over five years to USDA to support CSAF practices. USDA formally defined selected conservation practice standards as being "climate-smart" so that they be targeted for support.

Biofuels protocols

The U.S. established a goal of annually producing 35 billion gallons of sustainable aviation fuel (SAF) by 2050. The policy objectives of expanding SAF production include reducing GHG emissions from aviation fuel consumption and providing a large source of demand for domestic crop-based biofuels.

U.S. SAF production was only 14 million gallons in 2023, while renewable diesel and biodiesel production were 2.4 and 1.7 billion gallons, respectively (EPA 2024). Biodiesel and renewable diesel production have received a $1/gallon tax credit, which the IRA extended through 2024. Hydroprocessed esters and fatty acids (HEFA) pathways; which use fats, oils, and greases as feedstocks; have been the main commercial pathway for U.S. SAF production to-date. Even though SAF as currently produced competes for the same feedstocks as biodiesel and renewable diesel, SAF production received no comparable tax credit prior to the IRA.

HEFA pathways are projected to comprise the majority of U.S. SAF production through 2030. However, a significant expansion of alcohol-to-jet (ATJ) production, which can use corn as a feedstock, may be needed for the U.S. to meet its 2050 SAF objective. SAF could also provide a stable market for corn ethanol in the future because, unlike light-duty vehicles, the aviation sector is going to be challenging to electrify.

U.S. corn-based ATJ pathways with business-as-usual practices would not attain a CI reduction of 50% relative to petroleum jet fuel, and thus not be eligible for the 40B credit (Wang et al. 2024; Yoo, Lee, and Wang 2022). So, ATJ facilities would need to adopt some of the following strategies to reduce their CI: carbon, capture, and storage; sourcing CSAF feedstocks; substituting biogas or renewable natural gas instead of fossil natural gas to produce heat; and producing wind or solar on-site to displace electricity grid purchases. Thus, CSAF protocols would provide greater incentives for U.S. crops to be used as SAF feedstocks.

U.S. Treasury announced a USDA Climate Smart Agriculture Pilot Program to accompany their 40B tax credit guidance. This pilot program allows corn ethanol-to-jet blenders to deduct 10 grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ) from their CI if they source U.S. corn produced with no-till, cover crops, and enhanced

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efficiency fertilizers. The pilot also allows soybean oil HEFA pathways to deduct 5 gCO_2e/MJ if the blender sources U.S. soybeans produced with no-till and cover crops. The definitions for the practices are premised on USDA conservation practice standard definitions. The chain-of-custody verification protocols are premised on mass balance accounting. This implies that CSAF feedstocks can be co-mingled with conventional feedstocks but that the exact quantity of the feedstock is tracked throughout the supply chain.

It is unclear if the 40B Pilot Program will be used by blenders, as no U.S. corn is anticipated to be used as a SAF feedstock in 2024. Also, the program was announced only eight months before 40B expires and the requirement that farms undertake multiple CSAF practices will restrict the number of farms that could be eligible. Still, the significance of the 40B Pilot Program is that it establishes precedent for crediting CSAF practices in the CI of biofuels. CSAF crediting may also be possible in the 45Z tax credit, although as of this writing, this guidance has not been provided.

Livestock digester protocols

Offset protocols

Anaerobic digesters capture biogas with high methane levels at manure lagoons on dairy cattle and swine farms. CCX developed a protocol for methane collection and capture on livestock farms. There were few anaerobic digesters on U.S. livestock farms during the 2005–2010 timeframe (O'Hara, Xiarchos, and Weber 2023), so additionality was determined by a start-date criteria. The credited avoided methane was determined by either measuring the biogas's flow and methane concentration or the amount of electricity generated. In addition, the digester projects could generate renewable energy credits if they displaced fossil fuel use.

CARB's livestock digester protocol is like CCX's protocol since (a) additionality was premised on a start-date criteria and (b) developers were required to measure biogas flow and methane concentration. Between 2016 and 2019, CARB annually issued offsets of about one million metric tons (MMT) CO_2e to livestock anaerobic digesters. Digesters across the U.S. are eligible, and CARB issued more offsets to digesters in Wisconsin and Idaho than in California (O'Hara, Xiarchos, and Weber 2023). Still, the offset protocol in California's cap-and-trade was not used by all eligible digesters due to high transaction costs and lack of awareness of the protocol (Pierce and Strong 2023). Due to the limitations of offset incentives, the number of U.S. livestock digesters remain unchanged between 2013 and 2018 (O'Hara, Xiarchos, and Weber 2023).

Biofuels and energy protocols

While California is the largest U.S. milk-producing state, prior to 2018 it had few anaerobic digesters. California implemented a law to reduce its livestock methane emissions by 40% in 2030 relative to 2013 and began subsidizing digesters as part of this strategy. Also, LCFS credit prices exceeded \$200/MT CO_2e in 2020. These factors contributed to a 63% increase in U.S. livestock digesters between 2018 and 2023, with the increase predominately attributed to the construction of digesters in California for LCFS credits (O'Hara, Xiarchos, and Weber 2023). The LCFS livestock digester protocol is perhaps the only instance of a CSAF protocol that induced significant GHG mitigation from U.S. farms. LCFS prices subsequently declined to \$45/MT CO_2e by July 2024, which has reduced their financial incentive for digester construction.

Dairy cattle and swine farms can generate LCFS credits by upgrading their biogas into renewable natural gas (RNG) by removing non-methane gases, and then injecting the RNG into a pipeline. This RNG can be converted to compressed natural gas (CNG) for use at vehicle fueling stations for light trucks, buses, and other public vehicles.

Like CARB's offsets protocol, the LCFS baseline practice for livestock farms is venting methane. This implies that livestock farms receive credit for avoiding methane emissions, which has resulted in digester projects receiving large negative CIs. The LCFS baseline is flaring for landfills since flaring is required by law for larger landfills. So, landfill methane projects are less competitive within the LCFS than dairy methane projects. The credits CARB has issued in the LCFS to dairy and swine digesters for CNG have increased from 0.1 MMT CO_2e in 2018 to 4.8 MMT CO_2e in 2023 (CARB 2024b). Since livestock digesters cannot receive both offsets and LCFS credits from CARB, the shift towards CNG production has contributed to a reduction in offsets.

Book-and-claim crediting occurs when the supplier injects RNG into a natural gas pipeline and transfers the renewable attributes of the gas to an energy facility that is withdrawing natural gas from the pipeline. In the LCFS, book-and-claim can be used for RNG that is supplied for CNG as a transportation fuel and for biorefineries that procure RNG to produce hydrogen. So, digesters that connect to a common carrier pipeline are eligible for LCFS credits. However, book-and-claim is not permitted for biorefineries that procure RNG for heat (CARB, 2019), which implies that a direct connection between the RNG supplier and energy facility would be required. The decision to allow book-and-claim for biorefineries to produce hydrogen but not heat is based on a policy objective in California to promote hydrogen production.

Agricultural biogas also qualifies as a cellulosic biofuel in the RFS. RFS credits – Renewable Identification Numbers (RINs) – can be purchased by regulated parties for compliance. Livestock digesters receive "D3" RINs within the RFS, and livestock digesters may receive both LCFS credits and D3 RINs. So, the increase in RNG production digesters has coincided with an increase in D3 RINs issued to digesters (EPA 2024).

There are other energy uses for RNG besides conversion to CNG. RNG can substitute for fossil natural gas to produce hydrogen (e.g., steam methane reforming) and provide heat and hydrogen to bio-refiners. Biogas and RNG can also be combusted on-site to produce electricity. So, carbon intensity protocols are relevant to livestock digesters across the IRA tax credits for biofuels (40B and 45Z), hydrogen (45V), and electricity (45Y) production.

As of this writing, 40B is the only IRA tax credit relevant to RNG with a finalized methodology. SAF facilities sourcing RNG from landfills for heat can receive a reduction in their CI in 40B, but not when sourcing RNG from a livestock farm. Constraining the supply of RNG for SAF refiners will impede the ability of refiners to reduce their CI, and thus indirectly constrain crop-based biofuel production. It is unclear yet which RNG feedstocks will be eligible under the 45Z, 45V, and 45Y tax credits.

Whether an additionality requirement is imposed on RNG production (i.e., only sources placed into service after a cut-off date) for these tax credits has also yet to be determined. This requirement would require that eligible biogas come from its "first productive use." The restriction is relevant for the clean electricity credit since the credit is only applicable to sources of electricity production placed into service after December 31, 2024. The resolution of these methodological issues could have profound effects on manure methane mitigation in U.S. livestock farms for the next several decades.

Forest carbon protocols

Offset protocols

I was hired at CCX to work on water markets (O'Hara, Walsh, and Marchetti 2012), as well as to develop forest carbon protocols that were analogous to its agricultural soil carbon protocols. CCX had initially developed forest carbon standards so that commercial forest companies could opt-in their forest carbon fluxes along with their on-site combustion emissions. However, as vertically integrated companies began divesting their land in the 2000s, CCX saw the opportunity to develop offset protocols for smaller-scale foresters.

CCX developed offset protocols for both afforestation and sustainably managed forests, the latter of which included long-lived wood products crediting. The CCX sustainably managed forest protocol required that forest owners have sustainable certification, which was its additionality requirement. Once landowners established a baseline forest carbon level, CCX issued offset credits equal to the annual incremental forest carbon flux. CCX's protocol required landowners to establish a baseline inventory through direct measurement, with annual crediting determined with approved growth-and-yield models. CCX's contractual commitment for foresters for 15 years exceeded the 5-year contractual commitment for the agricultural soil protocols.

CARB's forest offset protocol was implemented at a considerably larger scale than CCX's. Through May 13, 2024, CARB had issued 212 million metric tons of carbon dioxide equivalent (MMT CO_2e) in forest carbon offset projects (CARB 2024). This represents 81% of total offsets that they have issued. CARB's forest carbon offsets are predominately issued for "improved forest management" activities (USDA 2023). These activities include increasing rotation ages, improved or sustained high stocking densities, and removing competing brush or diseased trees.

While CARB's digester protocol was conceptually like CCX's digester protocol, the CCX and CARB forest carbon protocols were dissimilar. CARB's forest carbon protocol issues most of its credits up-front. The intention of doing so is to provide financial assistance to developers and to incentivize projects with high carbon stocks to enroll (Badgley et al. 2022). This issuance represents the difference between the initial carbon stock and the average 100-year baseline carbon stocks that would have occurred in the absence of the project. Project developers propose their own baseline, although it cannot be lower than CARB's common practice standard. Badgley et al. (2022) found that developers almost always choose the common practice standard for their baseline, which maximizes the credits they can generate. Studies have found that CARB's forestry protocol has low additionality because enrolled projects are not reducing harvesting rates and low-value forests with high carbon stocks are self-selecting into the program (Coffield et al. 2022; Haya et al. 2023; Stapp et al. 2023).

Clean electricity protocols

Woody biomass facilities qualified for the pre-IRA renewable electricity production tax credit. However, in the IRA's new electricity production tax credit, woody biomass feedstocks are only eligible if their lifecycle GHG rate equals zero.

Woody biomass can be supplied either from waste byproducts or feedstocks grown primarily for electricity generation. Byproducts include forest management residuals from noncommercial thinning, harvest waste, and biomass removal; and sawmill wood residuals from processing logs into lumber. If forest residues are not used as an electricity feedstock, then typical business-as-usual practices are to either pile burn the material (which releases CO_2) or leave it to decompose (which can increase wildfire risk). These avoided emissions can be incorporated into the lifecycle GHG methodologies of using forestry residues for electricity production. Woody biomass principally grown for electricity generation, such as perennial crops or faster-growing trees, increase GHG sequestration since they incentivize afforestation and more intensive management (Daigneault, Sohngen, and Sedjo 2012; Favero, Daigneault, and Sohngen 2020; Favero and Mendelsohn 2014).

Whereas there has been regulatory precedent established for lifecycle GHG protocols through the RFS for crop-based biofuels, there has not been an analogous federal protocol for woody biomass. So, it is unclear yet what types of woody biomass production will be eligible for the 45Y tax credit. Nonetheless, developing effective GHG woody biomass protocols will remain an important issue since woody biomass incentives can be complementary with forest carbon incentives (Baker et al. 2019; Favero, Mendelsohn, and Sohngen 2017).

Conclusion

In this essay, I trace how incentives for U.S. CSAF practices shifted from offsets in a cap-and-trade program to credits in clean energy regulations. I revisit my experience at CCX since there were few *ex post* evaluations of CCX's offset program. Also, since the voluntary carbon market has not incentivized U.S. CSAF practices to-date, an acknowledgment of the importance of standardized CSAF protocols has come full circle in the fourteen years since CCX has closed. As evidence, USDA (2024) announced an intention to establish a Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program to rectify the barriers impeding U.S. farmers, ranchers, and foresters from participating in offset markets.

While CCX's protocols were designed for offset programs, there are legacy effects evident in biofuel standards. First, CCX pioneered the use of standardized regional-level crediting rates for agricultural soil carbon practices. For instance, the main model used in clean transportation fuel programs – the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation model – has a module that provides county-specific carbon intensity estimates for feedstocks produced with CSAF practices, like no-till and cover crops (Liu, Kwon, and Wang 2021; Liu et al. 2020). Also, as I described earlier, the principles underlying CCX's livestock digester protocol have remained intact over time.

CSAF incentives for agricultural soil carbon, livestock digesters, and forest carbon remain a topic of ongoing discourse. For biofuels, additionality thresholds for CSAF practices are less of a concern since cropping practices are already included in the transportation fuel baseline. However, if CSAF crops produced for biofuels led to the diversion of CSAF crops from other markets (like animal feed), then more comprehensive cross-sector CSAF standards may be needed. CSAF biofuels standards may establish precedent for the development of CSAF standards in non-biofuel markets. These include standards for upstream "Scope 3" emissions reporting by corporations that source agricultural or forestry commodities as inputs.

Whether CSAF incentives become standardized financial contracts in the future is uncertain. Conceptually, tradeable certificates for CSAF practices in biofuel program could be employed if book-and-claim accounting standards were adopted instead of mass balance standards. However, allowing CSAF certificates to be separated from an agricultural commodity and separately traded would require market infrastructure, like a registry for certificates, that currently do not exist. Given that the interest in reducing GHG emissions from the agricultural and forestry sectors will remain a high-priority topic for the foreseeable future, it is conceivable that improved market infrastructure will be required.

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