Chapter 30
Agriculture

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Summary

This chapter examines the agricultural strategies, practices, and technologies available to increase soil carbon sequestration and reduce GHG emissions. It summarizes the research documenting the many agricultural practices that have been demonstrated to reduce GHG emissions and increase carbon sequestration in soil, including cover cropping, more varied crop rotations, agroforestry and silvopasture (adding trees into cropping or grazing systems), perennial crops, prescribed rotational grazing, dry manure management, and others. It details pathways for amending existing federal and state legal regimes and enacting new ones, and recommends improving public agricultural research, development, and extension efforts; reforming federal subsidy and conservation programs; and revising trade policy, tax policy, regulatory strategies, financing for carbon farming, grazing practices on government land, and GHG pricing. It also describes how the private and philanthropic sectors can stimulate carbon farming; strategies for reducing emissions that stem from farm inputs and that result from food processing, distribution, consumption, and waste; and the potential to encourage consumption of climate-friendly foods through national dietary guidelines, procurement at all levels of government, and private-sector initiatives such as certification schemes and healthier menu options. The chapter notes that many of the practices recommended to reduce agriculture's contribution to climate change also will make farms and ranches more resilient to extreme weather and often increase soil health, productivity, and profitability. There can thus be a confluence of interests supporting incentives for broader adoption of these practices.

I. Introduction

Agriculture is both a source and a sink for greenhouse gases. To convey agriculture's contribution to climate change accurately, this chapter focuses on net emissions—that is, the quantity of greenhouse gases released into the atmosphere less the quantity sequestered in soil and plants. Decisionmakers can take full advantage of agriculture's potential to slow climate change only by acknowledging the sector's dual role in decarbonizing the economy, and seeking both to minimize agricultural greenhouse gas emissions and to maximize carbon storage.

Two terms are used throughout this chapter to describe agricultural methods that reduce net agricultural emissions. The first, "climate-friendly," refers to practices or strategies that reduce greenhouse gas emissions or increase soil carbon sequestration when compared to conventional methods. While superior to standard practices, climate-friendly practices are not necessarily optimal, both in terms of their climate benefits or their overall benefit to society. In contrast, "carbon farming" describes a suite of climate-friendly practices and strategies designed to result in optimal environmental, societal, and climate outcomes.[1] For example, anaerobic digesters, which reduce greenhouse gas emissions from concentrated animal feeding operations (CAFOs), may be climate friendly, but they do not fall under the chapter's definition of carbon farming because they are integrated into a system of agricultural production with significant greenhouse gas emis-

1. "Carbon farming" includes grazing and animal husbandry. As Eric Toensmeier notes in *The Carbon Farming Solution*, there are "several, sometimes conflicting, definitions of carbon farming." However, it is generally described as a system of agricultural economics and practices organized around carbon sequestration. Eric Toensmeier, The Carbon Farming Solution 6 (Brianne Goodspeed & Laura Jorstad eds., 2016). "Regenerative agriculture" is another term for largely overlapping agricultural practices. *See generally* Rodale Institute, Regenerative Organic Agriculture and Climate Change.

sions (especially from feed production) and other negative environmental externalities.

While not applicable in the absence of an economy-wide price on carbon, there is a further difference between climate-friendly practices and carbon farming: the former focuses on the production of agricultural goods while reducing greenhouse gas emissions; the latter views increased carbon soil sequestration as a goal. As discussed below, the United States now uses hundreds of millions of acres of land to grow crops that are largely wasted or used inefficiently to produce corn ethanol, sweeteners, or highly processed animal products. With a price on carbon, soil carbon sequestration could become one of the primary uses of this land, while farmers would be compensated for sequestering practices. The result could be a significant increase in the carbon sink.

Decisionmakers should prioritize climate-friendly practices that reinforce carbon farming systems. Although many Republican leaders, as well as rural voters, tend to ignore or doubt climate science, the many benefits of climate-friendly practices provide independent reasons for their adoption. Although not the norm currently—and not widely supported by agrochemical companies and other traditional sources of information—climate-friendly practices almost always improve soil health and thus can increase farm yield, enhance resilience to climate change, and often increase profitability (especially over the longer term). Thus, decisionmakers, regardless of their position on climate change, should strongly support broader adoption of these practices to assist farmers, ranchers, and rural communities, and to protect basic environmental needs such as clean air and water.

This chapter focuses on agricultural emissions because agriculture presents a unique and complex set of challenges and opportunities. Nonetheless, to aid readers in developing a comprehensive understanding of possible and necessary emissions reductions, the chapter also briefly addresses avenues to reduce emissions from other components of the food system, discussed in detail elsewhere.

Section II discusses agriculture's role in deep decarbonization. It also examines the on-field strategies, practices, and technologies available to increase soil carbon sequestration and reduce agricultural emissions. (Fisheries and aquaculture are also important parts of the food system but, as they present very different greenhouse gas and legal issues, they are not addressed in this chapter.)

Section III details public law pathways—amending existing federal and state legal regimes and enacting new ones—for reducing net agricultural emissions. It begins by identifying pathways for improving public agricultural research, development, and extension efforts, and then considers opportunities to reform federal subsidy and conservation programs. The section also evaluates trade policy, tax policy, regulatory strategies, financing for carbon farming, grazing practices on government land, and greenhouse gas pricing.

Section IV describes non-public law approaches, focusing on how the private and philanthropic sectors can stimulate carbon farming. The topics covered include agricultural research, financing for carbon farming, measuring carbon content, conservation tools, and offset markets.

Section V looks at overall food system emissions. It provides an overview of strategies for reducing upstream emissions—those that stem from farm inputs—and downstream emissions—those that result from food processing, distribution, consumption, and waste.

Finally, Section VI examines the potential to encourage the consumption of climate-friendly foods through national dietary guidelines, procurement at all levels of government, as well as through private-sector initiatives, such as certification schemes and healthier menu options. Section VII concludes.

II. Agriculture's Role in Deep Decarbonization

A. *Greenhouse Gas Emissions in the Food System*

The food system encompasses the full life cycle of food. In addition to agriculture, this includes activities that take place off the farm—from the pre-planting conversion of native grasslands and production of agricultural chemicals, for example, to the post-harvest distribution, consumption, and disposal of food.[2] The food system is responsible for an estimated 19%-29% of both national and global greenhouse gas emissions.[3] Decisionmakers must approach the food system as a whole to craft laws and policies that address the system's full complement of social, nutritional, and environmental impacts.

2. Sonja Vermeulen et al., *Climate Change and Food Systems*, 37 Ann. Rev. Env't & Resources 195, 198-202 (2012).
3. *Id*. at 195. GRAIN, an international research and advocacy organization, estimates that emissions from the food system are as high as 44%-57% of global emissions. GRAIN, *Commentary IV: Food, Climate Change, and Healthy Soils: The Forgotten Link*, *in* Trade and Environment Review 2013, at 19-20 (United Nations Conference on Trade and Development 2013).

B. Reducing Net Emissions From Agriculture

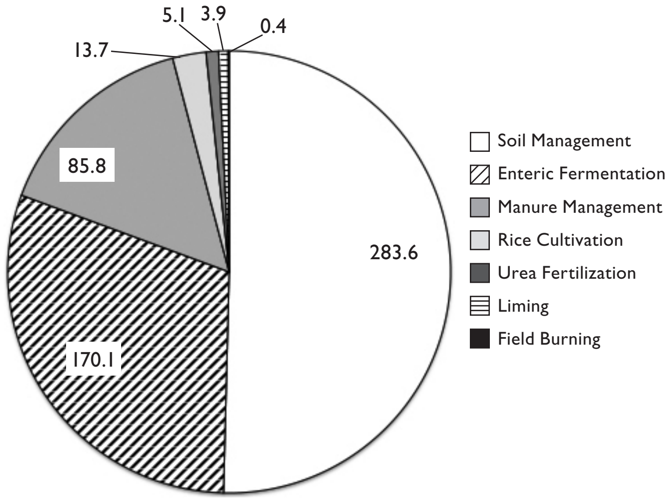
Agriculture refers to the cultivation of crops and the raising of animals for the "4Fs": food, feed, fuel, and fiber. It accounts for 51% of the country's total landmass and 61% of the landmass of the contiguous 48 states, making it the single largest type of land use in the United States.[4] Of the country's total 2.3 billion acres, approximately 408 million acres are in use as cropland, 614 million acres as grassland pasture and range, and 127 million acres as grazed forestland.[5] As a result of agriculture's large footprint, relatively small changes in agricultural practices, which may have a modest impact per acre, can significantly affect this sector's contribution to climate change if they are widely implemented. Small changes can also improve farmers' and ranchers' ability to adapt to the changing climate.

A core concept of this chapter is that carbon sequestration should be added to this list of the fundamental aims of agriculture, as well as to the federal programs and policies that support it. Achieving climate stability is as critical a human need as the other functions of agriculture. By reducing greenhouse gas emissions while also increasing soil carbon stores, agricultural operations can make a substantial contribution to decarbonization in the United States.

1. Greenhouse Gas Emissions From Agriculture

The U.S. Environmental Protection Agency (EPA) estimates that emissions from agriculture account for approximately 9% of total U.S. greenhouse gas emissions each year.[6] Unlike the energy and transportation sectors, which emit primarily carbon dioxide as fossil fuels are burned, crop and livestock greenhouse gas emissions consist largely of nitrous oxide and methane. Nitrous oxide is a particularly potent greenhouse gas—the average radiative forcing of nitrous oxide is 265-298 times that of carbon dioxide over 100 years.[7] Nitrous oxide emissions will also be the primary cause of stratospheric ozone destruction this century.[8] Like nitrous oxide, methane is a powerful greenhouse gas: the average radiative forcing of methane is about 28-34 times that of carbon dioxide over 100 years.

Figure 1
Major Sources of Agricultural Emissions in the United States



In 2016, total agricultural emissions of nitrous oxide and methane amounted to about 560 million metric tons of carbon dioxide equivalent.[9] In other words, agriculture released an amount of greenhouse gases roughly equivalent to that produced by 120 million automobiles in a typical year.[10] Agriculture is responsible for more than 80% of U.S. nitrous oxide emissions and almost 40% of U.S. methane emissions.[11]

As Figure 1 shows, the largest source of U.S. agricultural greenhouse gas emissions is agricultural soil management—a series of practices intended to improve crop yields, including fertilization, tillage, drainage, irrigation, and fallowing of land.[12] Soil management generates half of all U.S. agricultural emissions and 94% of all U.S. nitrous oxide emissions from agriculture.[13] Seventy-three percent of nitrous oxide emissions from agricultural soil management come from cropland and 27% come from grazed grasslands.[14]

The next largest source of agricultural emissions is enteric fermentation, which results from the digestive pro-

4. Cynthia Nickerson et al., U.S. Department of Agriculture, Major Uses of Land in the United States, 2007, at 4 (2011) (EIB-89).
5. *Id.*
6. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks (last updated Apr. 12, 2018).
7. Intergovernmental Panel on Climate Change, Climate Change 2013: The Physical Science Basis 714 (2014). Table 8-7 presents these and other "global warming potential" values.
8. A.R. Ravishankara et al., *Nitrous Oxide (N_2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century*, 326 Science 123, 123-25 (2009).
9. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016, at 5-1 (2018) (EPA 430-R18-003).
10. *Compare id. with* EPA, Greenhouse Gas Emissions From a Typical Passenger Vehicle (2014) (a typical passenger vehicle emits 4.7 metric tons of carbon dioxide annually).
11. *See* EPA, *Overview of Greenhouse Gases: Nitrous Oxide Emissions*, https://www.epa.gov/ghgemissions/overview-greenhouse-gases#nitrous-oxide (last updated Apr. 11, 2018); EPA, *Overview of Greenhouse Gases: Methane Emissions*, https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane (last updated Apr. 11, 2018).
12. EPA, *supra* note 9, at 5-21, 5-22. Soil emits nitrous oxide in a dynamic process involving a number of factors, including humidity and precipitation, in addition to soil management practices. *See* Klaus Butterbach-Bahl et al., *Nitrous Oxide Emissions From Soils: How Well Do We Understand the Processes and Their Controls?*, 368 Phil. Transactions Royal Soc'y B (2013). Tillage and unrestricted grazing also disturb existing soil carbon content stores, resulting in carbon loss.
13. *See* EPA, *supra* note 9, at 5-2 tbl. 5-1.
14. *See id.* at 5-26 tbl. 5-17.

cess of ruminants (largely cows and sheep in the United States). Enteric fermentation creates methane, which animals subsequently release into the atmosphere through belching and exhalation.[15] Enteric fermentation is responsible for 30% of all agricultural emissions and 26% of methane emissions in the United States.[16]

Manure management activities are the third major category of U.S. agricultural emissions, releasing nitrous oxide and methane in quantities that total 15% of total U.S. agricultural emissions.[17] Intensive livestock facilities, colloquially known as factory farms and called CAFOs by federal law, generate the substantial majority of these emissions.

Methane emissions released from soils flooded for rice cultivation and the field burning of crop residues make up almost 3% of total U.S. greenhouse gas emissions from agriculture.[18] In 2015, EPA included carbon dioxide emissions from urea fertilization and liming in its estimate of agricultural emissions for the first time.[19] Together these two sources are responsible for less than 2% of agricultural emissions.[20]

The vast majority of agricultural emissions are related to animal production. This is due, in part, to the large amount of land used to grow animal feed: approximately half of all harvested cropland is devoted to feed crop production.[21] This cropland is often cultivated more intensely than cropland growing human food, with the result that feed crop production can emit more nitrous oxide per acre than the production of crops for human consumption.[22] (Although not addressed here, fertilizer production is energy intensive and is responsible for additional emissions equivalent to about 25% of the greenhouse gas emissions resulting from the application of that fertilizer.[23]) Moreover, feed crop cultivation produces more calories per acre than human food crops with the result that non-human animals eat two-thirds of the calories derived from crops grown in the United States. However, only a fraction of those crop calories are delivered to humans because, for example, the production of one pound of beef from feedlot cattle requires 15 pounds of grain.[24] Thus, despite the greater use of resources devoted to animal production,[25] humans receive only 30% of their calories from animal products.[26] Because grazing and feed crop production contribute almost two-thirds of nitrous oxide emissions from agricultural soils,[27] and because animals are the major source of agricultural methane emissions, meat and dairy production account for almost 80% of agriculture's greenhouse gas emissions in the United States.[28]

2. Soil Carbon Sequestration by Agriculture

Agricultural activities not only emit greenhouse gases but can change the amount of carbon stored in soils, thus effectively releasing or absorbing carbon dioxide. Carbon storage is increased by plant growth, which removes carbon dioxide from the atmosphere during *photosynthesis*, the process by which plants convert energy from the sun into energy stored in the chemical bonds of carbohydrates, complex carbon-based molecules. Carbon storage is decreased when these bonds are broken by organisms to access the stored energy and the carbon contained in carbohydrates is returned to the atmosphere as carbon dioxide. Thus, *net* carbon storage can be increased by increasing the amount

15. Andy Thorpe, *Enteric Fermentation and Ruminant Eructation: The Role (and Control?) of Methane in the Climate Change Debate*, 93 Climate Change 407, 411 (2009).
16. *See* EPA, *supra* note 9, at ES-7 tbl. ES-2, 5-2 tbl. 5-1.
17. *See id*. at 5-2 tbl. 5-1.
18. See *id.*
19. See *id.*
20. See *id.*
21. There were approximately 310 million acres of harvested cropland in 2007 according to the Census of Agriculture. National Agricultural Statistics Service, U.S. Department of Agriculture, 2007 Census of Agriculture: U.S. National Level Data 16 tbl. 8 (2009). The U.S. Department of Agriculture (USDA) estimates that approximately 165 million of those acres were devoted to feed crops; however, up to 10% of the feed was diverted to biofuels. Nickerson et al., *supra* note 4, at 20. This total does not include soybeans, which USDA considers a "food crop," despite the fact that soybean meal is typically used as animal feed. Tani Lee et al., USDA Major Factors Affecting Global Soybean and Products Trade Projections (2016).
22. Conventionally grown feed crops, such as corn, soybean, and hay, generally result in high nitrous oxide emissions. *See* EPA, *supra* note 9, at 5-23.
23. Evan M. Griffing et al., *Life Cycle Assessment of Fertilization of Corn and Corn-Soybean Rotations With Swine Manure and Synthetic Fertilizer in Iowa*, 43 J. Envtl. Quality 709 (2014).
24. The feed conversion ratio expresses the number of pounds of grain necessary to increase the "live weight" of a head of cattle by one pound. At industrial feedlots, a feed conversion ratio of 6:1 is common. Dan W. Shike, Beef Cattle Feed Efficiency 3 (2013). About 40% of the live weight of a head of cattle is sold as beef, which means that 15 pounds of grain is necessary to yield one pound of beef. *See* Rob Holland et al., University of Tennessee Institute of Agriculture, How Much Meat to Expect From a Beef Carcass 9 (PB-1822).
25. *See* Emily Cassidy et al., *Redefining Agricultural Yields: From Tonnes to People Nourished Per Hectare*, 8 Envtl. Res. Letters 1, 4 (2013). This figure is based on data from 1997-2003. Biofuel production has increased rapidly since then, likely resulting in a lower proportion of crops devoted to either feed or food.
26. USDA, Economic Research Service, *Seventy Percent of U.S. Calories Consumed in 2010 Were From Plant-Based Foods*, https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=81864 (last updated Jan. 6, 2017).
27. This includes grassland emissions, which account for 78 million metric tons of carbon dioxide equivalent (MMT CO_2 eq.), as well as 48% of cropland emissions—the approximate percentage of harvested cropland devoted to feed crop production in 2007—which adds an additional 98.8 MMT CO_2 eq. *Compare* EPA, *supra* note 9, at 5-2 tbl. 5-1, 5-26 tbl. 5-16 (showing annual emissions from agriculture by source), *with supra* note 21 (explaining how the percentage of harvested cropland devoted to feed crop production was calculated). Together, they were responsible for 176.8 MMT CO_2 eq. or 62% of all emissions from agricultural soils in 2016. This total does not include the approximately 16.5 million acres devoted to the production of biofuel feedstock. *See supra* note 21.
28. This includes emissions from enteric fermentation and manure management and nitrous oxide emissions from agricultural soils devoted to feed crop production or grazing. Together, they were responsible for 434.7 MMT CO_2 eq. or 77% of agricultural emissions in 2016. *Compare* EPA, *supra* note 9, at 5-2 tbl. 5-1 (showing annual emissions from agriculture by source), *with supra* note 27 (calculating emissions from agricultural soils devoted to feed crop production or grazing).

of photosynthesis, such as by adding cover crops over bare ground or incorporating trees, or by slowing the decomposition of soil organic matter, such as through use of perennial crops or no-till practices.

Scientific studies have identified a number of agricultural practices that could help to slow climate change by capturing carbon. For example, in 2016, researchers concluded that the expansion of existing U.S. Department of Agriculture (USDA) conservation practices could lead to the sequestration of 277 million metric tons of carbon dioxide equivalent annually by 2050.[29] Capturing this volume of carbon in the soil would cut net agricultural greenhouse gas emissions in half. Similarly, agroforestry (incorporating trees and shrubs into cropland and pastureland) and perennial agriculture (plants that live year-round and do not need annual replanting, thus disturbing the soil less) offer significant climate benefits by locking carbon in the perennial biomass of the plant roots and shoots and stimulating a more biodiverse ecosystem that stores more carbon. According to a 2012 study, the widespread adoption of agroforestry practices in the United States could sequester 530 million metric tons of carbon dioxide equivalent each year, thereby transforming agricultural land into a carbon sink.[30]

Like cropland, rangeland used for livestock grazing can also sequester carbon. Overgrazing has damaged vegetation and degraded soil quality across the western United States, resulting in the release of carbon that would otherwise remain locked in organic matter.[31] However, reducing the intensity of use and adjusting the timing of grazing to facilitate plant growth can repair these landscapes,[32] and restore their function as carbon sinks.[33]

As these examples demonstrate, methods to mitigate agriculture's net contribution to climate change already exist. However, policies must recognize that biological sequestration is reversible and limited. Climatic events, such as droughts or wildfires, or human actions, such as resumed tillage, increased grazing, or deforestation, can quickly destroy biomass and disrupt soils, thereby releasing stored carbon.[34] In addition, gains in soil carbon slow as soils approach a new equilibrium under improved management practices.[35] (Additional research is needed to clarify how quickly this occurs, but location, prior soil quality, and land management practices all appear to be important factors.[36])

While sequestration alone cannot offset ever-increasing greenhouse gas emissions, it remains a necessary strategy for avoiding catastrophic climate change. Current levels of atmospheric carbon are so dangerously high that we cannot choose between reducing emissions and sequestering carbon.[37] We must do both.

C. *Agricultural Practices for Reducing Greenhouse Gas Emissions*

1. Introduction

To implement sound policy and pursue effective legal strategies, decisionmakers and advocates must become familiar with the climate-friendly agricultural practices that, together, comprise carbon farming.[38] Accordingly, this section briefly reviews the tools and technology available to reduce agricultural greenhouse gas emissions and sequester carbon.[39] The section begins by summarizing the practices and technologies applicable to cropland, before considering those available for grazing lands and animal feeding operations (AFOs), in turn.[40] It concludes by dis-

29. Adam Chambers et al., *Soil Carbon Sequestration Potential of U.S. Croplands and Grasslands: Implementing the 4 Per Thousand Initiative*, 71 J. Soil & Water Conservation 68A, 70A (2016). This total represents four times the carbon sequestration of forest soils. *See* Rattan Lal et al., *Achieving Soil Carbon Sequestration in the United States: A Challenge to the Policy Makers*, 168 Soil Sci. 827, 838 (2003) (finding that forest soils could sequester 63 MMT CO_2 eq. annually).
30. Ranjith P. Udawatta & Shibu Jose, *Agroforestry Strategies to Sequester Carbon in Temperate North America*, 86 Agroforestry Systems 225, 239 (2012).
31. *See* John Carter et al., *Moderating Livestock Grazing Effects on Plant Productivity, Nitrogen, and Carbon Storage*, 17 Nat. Resources & Envtl. Issues 191, 191-92 (2011).
32. Sherman Swanson et al., *Practical Grazing Management to Maintain or Restore Riparian Functions and Values on Rangelands*, 2 J. Rangeland Applications 1, 10-14 (2015).
33. David Lewis et al., University of California Cooperative Extension, Creek Carbon: Mitigating Greenhouse Gas Emissions Through Riparian Revegetation 22 (2015).
34. Uta Stockmann et al., *The Knowns, Known Unknown, and Unknowns of Sequestration of Soil Organic Carbon*, 146 Agric. Ecosystems & Env't 80, 82 (2012).
35. Catherine Stewart et al., *Soil Carbon Saturation: Concept, Evidence, and Evaluation*, 86 Biogeochemistry 19, 25-28 (2007); Stockmann et al., *supra* note 34, at 94-95.
36. Stockmann et al., *supra* note 34, at 82.
37. *See* Marcia DeLonge's Union of Concerned Scientists blog for an informal discussion of carbon sequestration's potential to help address climate. Marcia DeLonge, *Soil Carbon Can't Fix Climate Change by Itself—But It Needs to Be Part of the Solution*, Union Concerned Scientists, Sept. 26, 2016, http://blog.ucsusa.org/marcia-delonge/soil-carbon-cant-fix-climate-change-by-itself-but-it-needs-to-be-part-of-the-solution.
38. Many climate-friendly agricultural practices are "regenerative," meaning that they regenerate healthy soil carbon levels as part of a holistic management system. *See* Regeneration Agriculture Initiative & The Carbon Underground, What Is Regenerative Agriculture? (2017).
39. This section does not provide an exhaustive literature review. However, because the Deep Decarbonization Pathways Project did not examine agriculture, we have briefly summarized the most commonly discussed and promising methods available to reduce agricultural emissions and increase carbon sequestration, and provided a rough estimate of their potential in the United States. Although further research and development is necessary—and, indeed, is one of this chapter's main recommendations for advancing carbon farming—most of the methods described in this section are currently in use and suitable for widespread adoption.
40. Estimated carbon sequestration rates and emissions reductions for each practice are included in Table 1 when possible. Most of the data are derived from COMET-Planner, an online tool developed by USDA and Colorado State University that provides approximate net emissions reductions for a number of practices recognized by the USDA Natural Resources Conservation Service (NRCS). *See* Amy Swan et al., COMET-Planner: Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning. Projections of the total amount of farmland where each practice is applicable are also included when possible. This is designed to allow read-

cussing several factors that complicate agriculture's ability to achieve maximum decarbonization, including scientific uncertainties, the need to balance climate benefits against other environmental concerns, and the practical challenges of implementing carbon farming on a national scale. Subsequent sections of the chapter will describe legal pathways for incentivizing or promulgating adoption of these climate-friendly practices.

2. Cropland

Responsible management of croplands should aim to increase carbon sequestration, while simultaneously reducing greenhouse gas emissions. The main sources of greenhouse gas emissions from cropland are synthetic and organic fertilizers, which release nitrous oxide, and soils, which release carbon dioxide.[41] The analysis begins by describing farming methods to reduce nitrous oxide emissions. The analysis then moves to three methods to reduce net carbon dioxide emissions by increasing the organic matter content of soil—reducing tillage, increasing carbon inputs from crops, and adding soil amendments, respectively. Soil organic matter, which consists primarily of decomposing plants and animals, is rich in carbon. Thus, practices that increase the organic matter content of soil generally also increase soil carbon sequestration and, thereby, reduce net emissions. Increasing soil organic matter is a particularly important method of sequestering carbon in temperate parts of the world, such as the United States, where soils contain vastly more carbon than plants (both above and below ground).[42] Such healthier soils can also require less fertilizer, decreasing nitrous oxide emissions.

Next, the analysis describes three agricultural systems that offer a range of climate benefits—organic farming, agroforestry, and perennial agriculture, respectively. Although organic farming is increasing in popularity, it remains uncommon—less than 0.5% of agricultural land in the United States is devoted to organic production.[43] U.S. farmers have been slow to adopt agroforestry and perennial agriculture, and these practices are unlikely to expand without significant changes in public law and policy. Nonetheless, they are included in this chapter because they are reliable methods to achieve significant, long-term carbon sequestration.

The analysis then explains the importance of prioritizing the production of crops that provide people with healthy food, instead of those that primarily become processed food, animal feed, and biofuels. The latter set of crops—namely corn, wheat, and soy—consume lavish amounts of energy and land as they are commonly produced in the United States,[44] but, as noted below, offer relatively little nutritional benefit in return. If humans consumed these crops or other whole foods directly, which would require significantly less land and energy, the resulting food system would use land much more efficiently in terms of human nutrition.

Finally, the analysis examines practices rice producers can adopt to reduce methane emissions.

a. Improve Management Practices for Synthetic Fertilizers

Because plants utilize nitrogen from the soil and crops carry it away from the field after harvest, fields must eventually be replenished. This is typically accomplished through the application of synthetic or organic (such as manure) nitrogen fertilizer. However, farmers routinely apply fertilizer at higher rates than crops require for a variety of reasons—as a form of insurance or risk avoidance, hope for a great year, over-focus on yield over return, habit, and misinformation.[45] On average, only 50% of the nitrogen applied as fertilizer to annual grains is removed at harvest.[46] Similarly, a 2011 study found that farmers applied at least 40% more nitrogen than the prior harvest removed on nearly one-third of acres planted with key commodity crops.[47] Because excess fertilizer is now routinely applied, farmers can apply fertilizer less frequently—and, when necessary, apply less fertilizer per acre—without reducing yield. When they do this, they will also reduce the amount by which the supply of nitrogen in the soil exceeds the demand for nitrogen by crops, thus limiting the avail-

ers to gauge not only how effective a practice might be on any given parcel of land, but also what its cumulative potential might be for the country as a whole.

41. *See id.* at 3. Organic fertilizers are produced using human waste, animal matter, or plant matter, while synthetic fertilizers are industrially manufactured or extracted from minerals.

42. In tropical forests, however, soil and vegetation sequester approximately the same amount of carbon. This has important land use implications. For example, conventional agriculture in tropical regions is generally worse for the climate than conventional agriculture in temperate ones. For more information, see Intergovernmental Panel on Climate Change, Land Use, Land-Use Change, and Forestry.

43. *Compare* National Agricultural Statistics Service, USDA, 2014 Organic Survey 1 tbl.1, *and* National Agricultural Statistics Service, USDA, 2015 Certified Organic Survey 1 tbl.1, *with* National Agricultural Statistics Service, USDA, 2012 Census of Agriculture, U.S. National Level Data 16 tbl.8 [hereinafter 2012 Census of Agriculture, U.S. National Level Data] (finding more than 914 million acres of farmland).

44. Cassidy et al., *supra* note 25, at 3-4.

45. Farmers often apply excess fertilizer "in the hopes that 'this year will be the one in ten' when extra N will pay off." G. Philip Robertson & Peter M. Vitousek, *Nitrogen in Agriculture: Balancing the Cost of an Essential Resource*, 34 Ann. Rev. Env't & Resources 97, 117 (2009). As discussed *infra* Sections III.B.7 and III.D, both incentives, such as a payment-for-ecosystem-services program that rewarded farmers using best management practices, and disincentives, such as a tax on fertilizer, could be used to reduce overfertilization.

46. G. Philip Robertson, *Nitrogen Use Efficiency in Row-Crop Agriculture: Crop Nitrogen Use and Soil Nitrogen Loss*, *in* Ecology in Agriculture 351 (Louise E. Jackson ed., Academic Press 1997).

47. Marc Ribaudo et al., USDA, Nitrogen in Agricultural Systems: Implications for Conservation Policy 11 (2011) (ERR-127).

ability of excess nitrogen that is lost to the environment, including as nitrous oxide.[48]

In general, best practices for fertilization include reducing the rate of application so that nitrogen supply is closer to the level demanded by crops, improving the timing of application so that nitrogen is available when crops can best utilize it, and varying the placement of nitrogen within fields to account for spatial variability in utilization by crops. These practices are routinely grouped by fertilizer companies, industrial farmers, and many extension programs as the "4Rs": apply the right fertilizer product, at the right rate, using the right method, and at the right time.[49] These practices are not mutually exclusive, and their combination in broader nutrient management plans will likely be most effective.[50]

Even if the rate of fertilizer application matches crop needs, improper timing and placement can increase greenhouse gas emissions. One of the most important practices would be to apply fertilizer no earlier than the planting season.[51] Nonetheless, due to ease of application, soil and water conditions, the lower cost of fertilizer in the fall, availability of machinery, and other reasons, farmers now fertilize a significant portion of the nation's cropland each fall, even though those fertilized fields will not be seeded until the following spring.[52] Fertilizer left unutilized in the soil over winter is vulnerable to environmental loss, including as nitrous oxide.[53]

Some experts argue that farmers can increase efficiency by practicing "split application"—that is, applying small amounts of fertilizer early in the planting season and, again, when nitrogen demand is highest, typically after plants emerge from the ground.[54] Studies have found that split application may reduce emissions by a significant amount. In one study on potatoes, an especially nitrogen-intensive crop, split application resulted in a 30% reduction in cumulative emissions compared to a single application.[55] Slow-release fertilizer formulations can also improve efficiency. For instance, polymer-coated urea fertilizes crops continuously as soil temperature, moisture, and other factors break down its coating over the course of the growing season.[56]

Nitrogen availability can vary within fields, as factors like prior yields (and thus nitrogen removal at harvest) affect its distribution. Precision agriculture, also called satellite or soil-specific farming, allows farmers to optimize placement via the Global Positioning System (GPS) and other forms of technology that use spatial and temporal data about fields.[57] Precise harvesting machines can track the yield in each small section of each row; improved satellite imagery can accurately estimate plant nitrogen and soil moisture levels in each area; and soil and plant samples can determine soil type and needs and plant needs. These data then inform how and when fields are fertilized as well as irrigated, sprayed with pesticides, and harvested, leading to productivity gains and reduced pollution. Unfortunately, because precision agriculture requires a significant investment in technology, this management system is likely prohibitively expensive for most farms smaller than 500 acres.[58]

Farmers can also improve nitrogen placement by applying fertilizer in irrigation water via subsurface drip irrigation (SDI) systems, which deliver nitrogen more precisely and in proximity to plant roots, increasing plant uptake and limiting excess nitrogen in the soil.[59] SDI is also less likely to fill soil pore space with water, avoiding the anaerobic conditions that are especially conducive to the generation of nitrous oxide.[60] At present, SDI systems have been studied only on fruit and vegetable crops.[61] However, some evidence indicates that the adoption and use of SDI systems would be cost effective for corn in the Great Plains.[62] Because the cultivation of corn accounts for almost half of the nitrogen fertilizer applied in the United States,[63] this expansion could substantially reduce nitrous oxide emissions.

Some studies have suggested that nitrification inhibitors, chemicals that delay the conversion of ammo-

48. Robertson & Vitousek, *supra* note 45, at 104.
49. *See* Terry L. Roberts, *Right Product, Right Rate, Right Time, and Right Place . . . the Foundation of Best Management Practices for Fertilizer*, *in* Fertilizer Best Management Practices 29-32 (2007).
50. G. Philip Robertson et al., *Nitrogen-Climate Interactions in U.S. Agriculture*, 114 Biogeochemistry 41, 55-56 (2013).
51. Ribaudo et al., *supra* note 47, at 6.
52. According to a USDA study, farmers applied fertilizer unnecessarily early on nearly one-quarter of acres planted with key commodity crops. Ribaudo et al., *supra* note 47.
53. Ribaudo et al., *supra* note 47, at 75; X. Hao et al., *Nitrous Oxide Emissions From an Irrigated Soil as Affected by Fertilizer and Straw Management*, 60 Nutrient Cycling Agroecosystems 1, 5 (2001); C. Wagner-Riddle & G.W. Thurtell, *Nitrous Oxide Emissions From Agricultural Fields During Winter and Spring Thaw as Affected by Management Practices*, 52 Nutrient Cycling Agroecosystems 151, 162 (1998).
54. Bijesh Maharjan et al., *Fertilizer and Irrigation Management Effects on Nitrous Oxide Emissions and Nitrate Leaching*, 106 Agronomy J. 703, 712 (2014).
55. David L. Burton et al., *Effect of Split Application of Fertilizer Nitrogen on N_2O Emissions From Potatoes*, 88 Canadian J. Soil Sci. 229, 233 tbl. 3 (2008).
56. Maharjan et al., *supra* note 54, at 711.
57. Rattan Lal, *Preface* to Soil-Specific Farming: Precision Agriculture vii (Rattan Lal & B.A. Stewart eds., CRC Press 2015).
58. Michael McLeod et al., Cost-Effectiveness of Greenhouse Gas Mitigation Measures for Agriculture: A Literature Review 26 (OECD Food, Agriculture, and Fisheries Papers No. 89, 2015).
59. Diego Abalos et al., *Management of Irrigation Frequency and Nitrogen Fertilization Mitigate GHG and NO Emissions From Drip-Fertigated Crops*, 490 Sci. Total Env't 880, 880 (2014).
60. *Id*.
61. *See generally* Taryn L. Kennedy et al., *Reduced Nitrous Oxide Emissions and Increased Yields in California Tomato Cropping Systems Under Drip Irrigation and Fertigation*, 170 Agric. Ecosystems & Env't 16-27 (2013) (discussing studies within single cropping systems).
62. Freddie R. Lamm & Todd P. Trooien, *Subsurface Drip Irrigation for Corn Production: A Review of 10 Years of Research in Kansas*, 22 Irrigation Sci. 195, 198 (2003).
63. Economic Research Service, USDA, Fertilizer Use and Price (last updated Oct. 12, 2016).

nium to nitrate, may reduce nitrous oxide emissions by allowing plants to absorb a larger share of nitrogen.[64] However, reductions may be modest compared to split application.[65] Moreover, nitrification inhibitors are antimicrobial pesticides that kill or inhibit the soil microbes involved in nitrification. The broader impact of these inhibitors on soil microbial communities, and ultimately soil health and fertility, requires further study.[66] Growers can also reduce net emissions by replacing synthetic nutrients with manure or other organic soil amendments, discussed further below.

In addition to the climate benefits, reducing the amount of excess fertilizer applied to fields and improved fertilizer management may reduce surface and subsurface runoff of nitrogen, which is now a major source of contamination of rivers, lakes, and drinking water supplies.[67] It can also save farmers money, as fertilizer purchase and application is often a significant expense.

b. Reduce or Eliminate Tillage

To prepare for planting, farmers routinely till their land by plowing or otherwise breaking up the soil and eliminating unwanted material. This process accelerates the breakdown of organic matter in the soil, increasing emissions of carbon dioxide. Thus, farmers and others are examining ways to prepare soil for planting with no, or reduced, tillage. No-till agriculture, which completely eliminates tillage, uses herbicides or other methods to control weeds instead of tillage, and leaves the soil physically undisturbed, protecting organic matter from soil microbes that could otherwise accelerate the carbon cycle by returning soil carbon to the atmosphere as carbon dioxide.[68] Reduced tillage practices that integrate some amount of plant residue into soils may also reduce nitrous oxide emissions and further increase carbon sequestration.[69]

No-till agriculture began to grow steadily in the United States after inexpensive herbicides and specialized equipment became widely available in the 1970s.[70] A 1972 survey of USDA officials found that there were an estimated 3.3 million acres of no-till cropland in the United States.[71] By 2012, farmers reported practicing no-till on 96 million acres and reduced tillage on another 77 million acres.[72] In contrast, conventional tillage was practiced on 106 million acres—only 38% of the 279 million acres suitable for tilling according to the 2012 Census of Agriculture.[73] While no-till's impact on crop yields varies according to a number of factors, including soil conditions, management techniques, weather, and crop type, a 2016 meta-analysis found that no-till generally results in similar yields to conventional tillage after a transition period of five or more years.[74] Even with yield reductions during the transition phase, however, no-till may remain more profitable for farmers than conventional tillage due to its potential to reduce expenditures on labor, fuel, and in some cases, fertilizer.[75] Although initially adopted in the United States to reduce the heavy burden on tractors and thus reduce costs and to limit soil erosion by reducing the amount of bare soil, USDA,[76] industry groups,[77] and some scientists now promote no-till as a way to sequester carbon. Indeed, conservation tillage, which includes no-till farming and some methods of reduced tillage, is among the most widely studied agricultural practices with respect to climate change.

Despite all the attention, however, there are questions about the potential of no-till practices to mitigate greenhouse gas emissions.[78] A 2007 review noted flaws in how soil organic carbon has been measured in some of the more favorable studies,[79] while a 2015 study found that

64. Maharjan et al., *supra* note 54, at 712.
65. *Id*.
66. A single gram of soil contains between 10,000 and 50,000 species of bacteria. Amber Dance, *Soil Ecology: What Lies Beneath*, Nature, Oct. 8, 2008. *Nitrosomonas* bacteria are primarily responsible for the conversion of ammonium to nitrite, which is subsequently converted to nitrate. Darrell W. Nelson & Don Huber, *Nitrification Inhibitors for Corn Production*, Iowa St. U. Extension, at 1 (1992) (NCH-55). While *Nitrosomonas* are the targets of nitrification inhibitors, the impact of nitrification inhibitors on other soil microorganisms needs to be characterized as well.
67. Swan et al., *supra* note 40, at 6.
68. For an overview of this process, see Daniel Kane, Carbon Sequestration Potential on Agricultural Lands: A Review of Current Science and Available Practices 5-11 (2015).
69. Cheryl Palm et al., *Conservation Agriculture and Ecosystem Services: An Overview*, 187 Agric. Ecosystems & Env't 87, 90 (2014).
70. David R. Huggins & John P. Reganold, *No-Till: The Quiet Revolution*, Sci. Am., July 2008, at 71, 73; Rattan Lal, Editorial, *Evolution of the Plow Over 10,000 Years and the Rationale for No-Till Farming*, 93 Soil & Tillage Res. 1, 6-7 (2007).
71. Frank Lessiter, *From 3.3 to 96.4 Million Acres*, No-Till Farmer, July 1, 2014, https://www.no-tillfarmer.com/articles/3918-from-33-to-964-million-acres?v=preview.
72. National Agricultural Statistics Service, USDA, 2012 Census of Agriculture, Highlights: Conservation 1.
73. *Id*.
74. Unlike other crops, however, corn yields on no-till farms typically do not improve over time, resulting in lower yields than corn produced with conventional tillage. Cameron M. Pittelkow et al., *When Does No-Till Work? A Global Meta-Analysis*, 183 Field Crops Res. 156, 159 (2015).
75. Erica Goode, *Farmers Put Down Plow for More Productive Soil*, N.Y. Times, Mar. 9, 2015, at D1; Claire O'Connor, *Farmers Reap Benefits as No-Till Adoption Rises*, Nat. Resources Def. Council, Nov. 15, 2013, https://www.nrdc.org/experts/claire-oconnor/farmers-reap-benefits-no-till-adoption-rises.
76. USDA aims to increase no-till farming by 33 million acres as part of its goal to increase carbon sequestration by 120 MMT CO_2 eq. annually by 2025. USDA, Factsheet: USDA's Building Blocks for Climate Smart Agriculture and Forestry (2015).
77. *See, e.g.*, Monsanto, Climate Change Mitigation and Agriculture, http://discover.monsanto.com/climate-change-mitigation (last visited July 6, 2017).
78. See, e.g., A.J. VandenBygaart, Commentary, *The Myth That No-Till Can Mitigate Global Climate Change*, 216 Agric. Ecosystems & Env't 98 (2016); David S. Powlson et al., *Perspective Limited Potential of No-Till Agriculture for Climate Change Mitigation*, 4 Nature Climate Change 678 (2014). *Contra* Henry Neufeldt et al., Correspondence, *No-Till Agriculture and Climate Change*, 5 Nature Climate Change 488 (2015) (responding to Powlson et al.'s argument that no-till's potential to mitigate climate change is overstated).
79. John M. Baker et al., *Commentary, Tillage and Soil Carbon Sequestration—What Do We Really Know?*, 118 Agric. Ecosystems & Env't 1, 2-3 (2007).

increased earthworm activity can independently cancel out any carbon sequestration effects from no-till, at least in the short term.[80] Nonetheless, the evidence suggests that no-till agriculture can increase soil carbon stocks in many regions, although its effect varies considerably by soil type and location.[81] A 2013 meta-analysis also found that no-till significantly decreases nitrous oxide emissions after five years, especially in dry climates.[82]

Researchers have also expressed concerns about the fact that no-till farming as practiced by commercial farmers often differs considerably from how it is implemented on research fields.[83] The available data suggest that many farmers who consider their methods "no-till" actually till their fields periodically.[84] This has important consequences, because even a single tillage event can lead to the loss of carbon built up through years of no-tillage.[85] One expert estimates that less than a third of no-till farms in the United States are truly no-till, and that the number of these continuous no-till farms is likely decreasing.[86] Nonetheless, estimates of carbon sequestration from no-tillage often assume continuous no-till,[87] and so the aggregate climate benefits of no-till agriculture as practiced currently may be overestimated.

While most no-till systems rely on herbicide applications to eliminate weeds, organic no-till systems are being investigated and could offer significantly higher levels of carbon sequestration. The Rodale Institute has developed a mechanical mounted roller that knocks down and kills cover crops, suppressing weed growth without herbicides.[88] Short-term studies of organic no-till systems indicate that they likely sequester more carbon than conventional no-till farming.[89] Although the Rodale Institute's field results are promising, it is still conducting trials, and commercial farmers in the United States have yet to adopt organic no-till.[90]

Given the uncertainties of the climate benefits of no-till as currently practiced, it may not deserve the attention it is getting as a strategy to fight climate change. Yet, its many other well-documented environmental benefits suggest that it should continue to be studied, refined, and integrated with other climate-friendly practices to optimize its climate impact. By leaving more plant residue and organic matter in and on the soil, it can improve soil quality, reduce erosion, provide food and cover for wildlife, and reduce dust and diesel pollution from tillage.[91] However, conservation tillage as commonly practiced in the United States often requires higher levels of herbicides than conventional tillage systems.[92]

c. Increase Carbon Inputs From Plants Through Cover Crops and Crop Rotations

Farmers can also foster soil carbon by increasing carbon inputs from plants. Cover cropping and conservation crop rotation are among the most common practices designed to do this in annual crop systems. Cover crops are plants grown to enhance soil conditions rather than to produce an agricultural product. They are generally grown during the late fall and winter when common commodity crops such as corn, wheat, and soy are not in season. In addition to increasing soil organic carbon by increasing carbon inputs, cover crops have also been shown to significantly reduce nitrate loss, thereby indirectly reducing

But see A.N. Kravechenko & G.P. Roberston, *Whole-Profile Carbon Stocks: The Danger of Assuming Too Much From Analyses of Too Little*, 75 Soil & Water Mgmt. & Conservation 235, 240 (2011) (arguing that Baker et al. and similar analyses do not properly analyze carbon stock differences as a function of depth).

80. Ingrid Lubbers et al., *Reduced Greenhouse Gas Mitigation Potential of No-Tillage Soils Through Earthworm Activity*, Sci. Rep., Sept. 2015, at 1.
81. Keith Paustian, *Carbon Sequestration in Agricultural Systems*, *in* Encyclopedia of Agriculture and Food Systems 140, 146 (Neal K. Van Alfen ed., Academic Press 2014).
82. Chris van Kessel, *Climate, Duration, and N Placement Determine N_2O Emissions in Reduced Tillage Systems: A Meta Analysis*, 19 Global Change Biology 33, 33 (2013). *But see* Claudio Stöckle et al., *Carbon Storage and Nitrous Oxide Emissions of Cropping Systems in Eastern Washington: A Simulation Study*, 67 J. Soil & Water Conservation 365, 376 (2012) (finding that increases in nitrous oxide offset gains in soil carbon sequestration at no-till sites in eastern Washington).
83. Bram Govaerts et al., *Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality*, 28 Critical Rev. Plant Sci. 97, 111 (2009).
84. An extensive survey conducted from 1994-1999 found that no-till farms in Indiana and Illinois tilled their fields every 2.5 years on average, while no-till farms in Minnesota were tilled every 1.4 years on average. Peter R. Hill, *Use of Continuous No-Till and Rotational Tillage Systems in the Central and Northern Corn Belt*, 56 J. Soil & Water Conservation 286, 289 (2001). Anecdotally, periodic tillage remains common on no-till farms throughout the United States. The writer and sustainable farmer Gene Logdson, for example, wrote in 2011 that "[a]lmost all farmers, in my neck of the woods anyway, are finding it necessary to do quite a bit of soil tillage but because they use a 'no-till' planter, [the USDA NRCS] allows them to act out the farce of saying they are practicing no tillage." Gene Logsdon, *No Till Farming Not So Great After All*, Contrary Farmer, Dec. 28, 2011, https://thecontraryfarmer.wordpress.com/2011/12/28/no-till-farming-not-so-great-after-all/. *See also* Tara Wade et al., USDA, Conservation-Practice Adoption Rates Vary Widely by Crop and Region 3 (2015) (EIB-147) (describing why some no-till farmers periodically till their fields).
85. Richard Conant et al., *Impacts of Periodic Tillage on Soil C Stocks: A Synthesis*, 95 Soil & Tillage Res. 1, 4 (2007).
86. Brad Reagan, *Plowing Through the Confusing Data on No-Till Farming*, Wall St. J., Oct. 15, 2012, https://www.wsj.com/articles/SB10000872396390443855804577602931348705646.
87. *See* VandenBygaart, *supra* note 78, at 99.
88. Rodale Institute, *Our Work: Organic No-Till*, http://rodaleinstitute.org/our-work/organic-no-till/ (last visited Apr. 12, 2018).
89. Patrick Carr et al., *Impacts of Organic Zero Tillage Systems on Crops, Weeds, and Soil Quality*, 5 Sustainability 3172, 3184 (2013).
90. Toensmeier, *supra* note 1, at 69. Other researchers and practitioners are also working to develop functional and productive no-till systems. *See*, *e.g.*, Jan-Hendrik Cropp, Webinar: Rotational No-Till, Mulching, and Conservation Tillage for Organic Vegetable Farms (Jan. 20, 2015), http://articles.extension.org/pages/71822/rotational-no-till-and-mulching-systems-for-organic-vegetable-farms-webinar.
91. Swan et al., *supra* note 40, at 4-5. Conservation tillage can increase the number of small mammals in fields, resulting in crop loss; however, such damage is generally controllable. *Conservation Tillage Systems and Wildlife*, Fish & Wildlife Literature Rev. Summary (USDA, NRCS), Sept. 1999, at 1.
92. Lionel Alletto et al., *Tillage Management Effects on Pesticide Fate in Soils: A Review*, 30 Agronomy Sustainable Dev. 367, 369 (2010).

nitrous oxide emissions.[93] Cover cropping with legumes also increases biological nitrogen fixation, reducing the need for nitrogen fertilizers.[94]

Conservation crop rotations refer to planting systems designed to decrease the frequency at which fields are left uncultivated (fallow) and to rotate between a diverse set of crops, thereby increasing carbon inputs.[95] Crop rotations that include perennial plants, such as alfalfa or grass hay, can be especially effective at sequestering carbon.[96] Iowa State University researchers have shown that three- and four-year rotations that include alfalfa increase yields and result in reduced fertilizer and herbicide use.[97] While most crops are rotated on a seasonal basis, producers with perennial crops in their rotation may not return to annual crops for one to three years.[98]

Although neither of these methods offers transformative climate benefits when practiced in isolation, they both have the potential to play an important role in reducing net agricultural emissions when integrated into climate-friendly systems. Diversified crop rotations, for example, are even more effective at increasing soil carbon when combined with cover cropping,[99] although likely sequestration rates have not been established.[100] Cover cropping has also been shown to sequester carbon more quickly when used in conjunction with no-till agriculture and it likely has a synergistic effect with other environmentally friendly practices as well.[101] As cover crops also use water, they may affect the water available for the cash crop. However, by reducing evaporation, they may also conserve water; the best practices for cover cropping will depend on the region.

Practices that increase carbon inputs from plants also offer a range of ecosystem benefits. Both cover cropping and diversified crop rotations have been shown to improve soil health, nutrient cycling, pest regulation, and crop productivity,[102] while reducing herbicide and fertilizer use.[103]

d. Add Soil Amendments

Soil application of amendments such as manure or other organic fertilizers can lower emissions by decreasing manure waste, reducing emissions from the production of synthetic fertilizers,[104] and increasing soil carbon stocks.[105] While livestock manure remains the dominant source of organic fertilizer for agriculture, the United States has large amounts of compostable solid waste and solid residues from sewage treatment plants, called biosolids, which also can be, and now often already are, used as soil amendments.[106] Chapters 25 (Bioenergy Feedstocks) and 26 (Production and Delivery of Low-Carbon Gaseous Fuels) recommend using biosolids as feedstock for biofuels as part of a strategy to decarbonize the natural gas supply. Uses for biosolids that offer greater emissions reductions than soil application, such as this, should be prioritized. Nonetheless, converting biosolids as soil amendments may remain the most beneficial use in some locations.

Additionally, a type of charcoal called biochar may be able to store even more carbon than traditional organic amendments.[107] Biochar is produced by pyrolysis—the thermal decomposition of organic material at high temperatures in the absence of oxygen. This process results in a carbon-rich char that is more stable than uncharred plant material, although local environmental conditions, such as climate and soil type, play an important role in determining how long it persists in soils.[108] Biochar pri-

93. Andrea Basche et al., *Do Cover Crops Increase or Decrease Nitrous Oxide Emissions? A Meta-analysis*, 69 J. Soil & Water Conservation 471, 479-80 (2014).
94. *See* Seth M. Dabney et al., *Using Winter Cover Crops to Improve Soil and Water Quality*, 32 Comm. Soil Sci. & Plant Analysis 1221, 1224, 1228 (2001).
95. Increasing crop diversity influences soil carbon and nitrogen concentrations, microbial communities, and soil ecosystem functions, often resulting in higher soil carbon levels. Marshall D. McDaniel et al., *Does Agricultural Crop Diversity Enhance Soil Microbial Biomass and Organic Matter Dynamics? A Meta-Analysis*, 24 Ecological Applications 560, 560 (2014).
96. Alison J. Eagle et al., Nicholas Institute for Environmental Policy Solutions, Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature 15 (2012). Perennial grasses grown for livestock may not be appropriate for water-scarce regions.
97. Union of Concerned Scientists, Rotating Crops, Turning Profits 3-4 (2017).
98. Eagle et al, *supra* note 96.
99. *See* McDaniel et al., *supra* note 95, at 560.
100. Telephone Interview With Amy Swan, Research Associate, Colorado State University, and Mark Easter, Senior Research Associate, Colorado State University (May 20, 2016).
101. *See* Humberto Blanco-Canqui, *Cover Crops and Ecosystem Services: Insights From Studies in Temperate Soils*, 107 Agronomy J. 2449, 2450 (2015); *see generally* Rattan Lal, *A System Approach to Conservation Agriculture*, 70 J. Soil & Water Conservation 82A, 82A (2015) (arguing that basic components of conservation agriculture, including cover cropping, must be implemented together in order to maximize their benefits).
102. *See* Meagan Shipanski et al., *A Framework for Evaluating Ecosystem Services Provided by Cover Crops in Agroecosystems*, 125 Agric. Systems 12, 13 (2014); Union of Concerned Scientists, *supra* note 97, at 5; Riccardo Bommarco et al., *Ecological Intensification: Harnessing Ecosystem Services for Food Security*, 28 Trends Ecology & Evolution 230, 233-34, 236 (2013).
103. *See, e.g.*, Union of Concerned Scientists, *supra* note 97; Raphaël A. Wittwer et al., *Cover Crops Support Ecological Intensification of Arable Cropping Systems*, Sci. Rep., Feb. 3, 2017, at 1.
104. *See infra* Section V.A.1 for a discussion of upstream emissions from synthetic fertilizers.
105. *See, e.g.*, Maysoon M. Mikha & Charles W. Rice, *Tillage and Manure Effects on Soil and Aggregate-Associated Carbon and Nitrogen*, 68 Soil Sci. Soc'y Am. J. 809, 809, 815 (2004) (discussing manure's impact on soil carbon content).
106. Half of all biosolids produced in the United States are applied to agricultural land, although this accounts for the nutrient needs of less than 1% of the country's farmland. EPA, *Frequent Questions About Biosolids*, https://www.epa.gov/biosolids/frequent-questions-about-biosolids (last updated Feb. 22, 2018).
107. Emissions from the production of biochar must be taken into account, however. Certain production methods negate some or all of its sequestration benefits. Dominic Woolf et al., *Sustainable Biochar to Mitigate Global Climate Change*, Nature Comm., Aug. 10, 2010, at 1, 3.
108. Samuel Abiven et al., *Biochar by Design*, 7 Nature 326, 326 (2014).

marily reduces emissions by stabilizing and adding to carbon stores in the soil[109]; however, it may also reduce nitrous oxide emissions and fertilizer requirements.[110] Biochar as a means of removing carbon dioxide from the atmosphere is further discussed in Chapter 29 (Negative Emissions Technologies and Direct Air Capture).

Both organic fertilizer and biochar can increase agricultural productivity, particularly in degraded soils, and reduce irrigation and fertilizer requirements.[111] Organic soil amendments also have some potentially negative environmental impacts. If not managed well, they can result in odor and particulate pollution, nitrate runoff, and phosphorus loading.[112] As with synthetic fertilizers, application timing, methods, and rates must also be managed carefully to minimize nitrous oxide emissions.[113]

e. Employ Organic Farming and Other More Climate-Friendly Farming Systems[114]

There are several agricultural systems, including organic agriculture, permaculture, agroecology (which includes practices such as crop rotations, integration, and diversification), and regenerative agriculture, that are all built upon the fundamental premise that soil health and natural ecological systems, such as the nutrient cycle between livestock and crops, are paramount to long-term productivity. This subsection focuses on organic agriculture, since it is well studied and there are already USDA national organic standards in place,[115] making it easier to classify. However, certified organic operations are not necessarily more climate friendly than noncertified operations implementing these other models; all can have significant climate benefits.

Organic farming generally seeks to enhance production by supporting natural soil fertility and biological activity and prohibits the use of synthetic pesticides or fertilizers.[116] USDA, which sets standards for organic products in the United States, defines it as a form of agriculture that uses methods designed to "support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity."[117] It encourages many of the practices mentioned here, such as cover cropping, crop rotation, and the incorporation of diverse elements on cropland including forestry and livestock. Its primary climate benefits are reduced nitrous oxide emissions, lower energy requirements, and increased soil carbon sequestration.[118] Some studies suggest that organic farming can obtain equivalent yields to conventional farming,[119] or come close in certain contexts,[120] while others suggest that the lower per-acre yields would reduce the climate benefits of the system by requiring more cropland.[121]

Organic agriculture offers a wide range of environmental and social benefits in addition to its potential to reduce net agricultural emissions. As the organic industry has grown, so too has the number of industrial-scale, capital-intensive organic operations, dampening these benefits according to some.[122] Nonetheless, research consistently indicates that organic agriculture increases soil stability and fertility, on-farm biodiversity, and crop resilience to weather shocks, while reducing energy use (e.g., by reducing tractor usage) and the need for synthetic inputs.[123] Organic farms can also directly benefit people, especially in rural communities, who can enjoy better landscape preservation, less agricultural pollution,[124] reduced dietary

109. Woolf et al., *supra* note 107, at 2.
110. Lukas Van Zwieten et al., *The Effects on Nitrous Oxide and Methane Emissions From Soil*, *in* Biochar for Environmental Management: Science, Technology, and Implementation 490-91 (Johannes Lehmann & Stephen Joseph eds., Routledge 2d ed. 2015); Saran P. Sohi et al., *A Review of Biochar and Its Use and Function in Soil*, 105 Advances Agronomy 47, 70-72 (2010).
111. Melissa Leach et al., STEPS Centre, Working Paper No. 41, Biocharred Pathways to Sustainability? Triple Wins, Livelihoods, and Politics of Technological Promise 26-28 (2010) (discussing biochar's impact on productivity); Andrew Crane-Droesch, *Heterogeneous Global Crop Yield Response to Biochar: A Meta-Regression Analysis*, 8 Envtl. Res. Letters (2013) (finding that biochar's impact on yield varies considerably across different soil environments); Annette Cowie et al., *Biochar, Carbon Accounting, and Climate Change*, *in* Biochar for Environmental Management: Science, Technology, and Implementation 767, 771, 774 (Johannes Lehmann & Stephen Joseph eds., Routledge 2d ed. 2015) (describing biochar's potential to reduce the need for irrigation and fertilizer inputs).
112. Eagle et al., *supra* note 96, at 88.
113. Swan et al., *supra* note 40, at 7.
114. The discussion here of organic and other climate-friendly farming systems also applies to animal agriculture. It is not repeated below.
115. *See*, *e.g.*, 7 C.F.R. §205.203 (2016) (establishing the soil fertility and crop nutrient management standard).
116. Certified organic products in the United States, for example, must be "produced and handled without the use of synthetic chemicals." 7 U.S.C. §6504.
117. USDA, Introduction to Organic Practices (2015).
118. Tiziano Gomiero et al., *Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture*, 30 Critical Rev. Plant Sci. 95, 101-04, 109-11 (2011) (summarizing research indicating that organic farming increases soil carbon levels and reduces energy requirements); Søren Petersen et al., *Nitrous Oxide Emissions From Organic and Conventional Crops in Five European Countries*, 112 Agric. Ecosystems & Env't 200, 203 (2006) (finding that nitrous oxide emissions from conventional crop rotations were higher than those in organic crop rotations in four out of five countries). *Contra* Hanna Tuomisto, *Does Organic Farming Reduce Environmental Impacts? A Meta-Analysis of European Research*, 15 J. Envtl. Mgmt. 309, 313 (2015) (concluding that nitrous oxide emissions are 31% lower in organic systems per unit of field area, but 8% higher per unit of product).
119. Rodale Institute, The Farming Systems Trial: Celebrating 30 Years 4, 9-10 (2012).
120. Verena Seufert et al., *Comparing the Yields of Organic and Conventional Agriculture*, 485 Nature 229, 231 (2012) (demonstrating that organic agriculture nearly matches conventional yields in certain environments); Lauren Ponisio et al., *Diversification Practices Reduce Organic to Conventional Yield Gap*, 282 Proc. Royal Soc'y B 1, 4 (2014) (finding that diversified organic systems were much closer to conventional yields than organic monocultures).
121. *See* Gomiero et al., *supra* note 118, at 111.
122. *See*, *e.g.*, Julie Guthman, Agrarian Dreams 1-22 (2004) (arguing that the organic industry has "replicated what it set out to oppose").
123. *See* Gomiero et al., *supra* note 118, at 100-13.
124. *Id.* at 106-08, 114.

exposure to pesticides,[125] and, according to some researchers, greater civic engagement.[126]

f. Expand Agroforestry

Agroforestry is a collective name for agricultural systems that integrate management of woody perennials and agricultural crops or animals[127] on the same piece of land.[128] By adding trees to agricultural lands, which substantially increases above- and below-ground biomass, agroforestry increases both annual sequestration rates and the overall amount of carbon that a piece of land can store. Agroforestry can also increase soil organic carbon levels on agricultural or previously uncultivated land.[129] As a result, agroforestry's per-acre sequestration potential is far higher than that found in annual crop systems.[130] Over time, agroforestry can also reduce indirect emissions of nitrous oxide by reducing nitrogen runoff.[131]

In the United States, agroforestry typically involves the use of trees and shrubs to act as windbreaks, buffers, and hedges on otherwise conventionally managed cropland; however, it also includes alley cropping, the side-by-side planting of annual crops with trees in adjacent rows. Using data from a 2003 literature review, USDA estimated that alley cropping generally sequesters about one to two metric tons of carbon dioxide equivalent annually per acre through additional biomass.[132] This is roughly the equivalent of taking one car off the road for every three to six acres thus managed; if done on just a quarter of U.S. cropland, it would be the equivalent of taking 26 million cars off the road.

Although not a form of agroforestry, a system of row crop production integrated with strategically placed native perennial grasses, called prairie strips, was developed by scientists at Iowa State University and modeled on agroforestry practices. The project, Science-Based Trials of Rowcrops Integrated With Prairie Strips (STRIPS), is designed to create a scalable, resilient, and environmentally responsible system of agriculture in the Midwest.[133] Further research is needed to accurately measure its impact on net emissions, but scientists estimate that prairie strips sequester approximately one metric ton of carbon dioxide equivalent per acre, about three times the sequestration rate of no-till farming.[134]

In addition to its enormous potential for carbon sequestration, agroforestry reduces surface water runoff and erosion, improves soil health, enhances wildlife and insect habitat, and decreases nutrient and chemical runoff.[135] Agroforestry practices can also increase productivity as measured by yield.[136] Windbreaks improve air quality and protect plants from wind-related damage, although they may reduce light infiltration very close to the trees, slightly reducing yields.[137] Finally, riparian forest buffers are effective at protecting rivers and streams from bacterial contamination,[138] surface runoff, and pesticide drift.[139]

g. Shift From Annual Crops to Perennial Crops

As with agroforestry, perennial crops offer a way to substantially improve upon the carbon storage potential of annual crops. They eliminate the need for tillage,[140] generally reduce irrigation and fertilizer needs, and sequester additional carbon through their considerable biomass and deep root systems. In the United States, there are several common perennial crops grown, mostly in monocultures, including grapes, apples, blueberries, stone fruits, citrus,

125. Brian Baker et al., *Pesticide Residues in Conventional, IPM-Grown and Organic Foods: Insights From Three U.S. Data Sets*, 19 Food Additives & Contaminants 427-446 (2002); Chengsheng Lu et al., *Organic Diets Significantly Lower Dietary Exposure to Organophosphorous Pesticides* 114 Envt'l Health Persp. 260-263 (2006).
126. Jessica Goldberger, *Conventionalization, Civic Engagement, and the Sustainability of Organic Agriculture*, 27 J. Rural Stud. 288, 295 (2011).
127. Systems that combine livestock and woody perennials are called silvopasture, which we examine in our discussion of grazing lands practices. *See infra* Section II.C.3.
128. Food and Agriculture Organization of the United Nations, *Agroforestry*, http://www.fao.org/forestry/agroforestry/80338/en/ (last updated Oct. 23, 2015).
129. Andrea DeStefano & Michael Jacobson, *Soil Carbon Sequestration in Agroforestry Systems: A Meta-Analysis*, 92 Agroforestry Systems 285-99 (2018).
130. In tropical climates, well-established agroforestry systems have even been shown to sequester more carbon than natural forests in upper soil layers in some circumstances. P.K. Ramachandran Nair et al., *Carbon Sequestration in Agroforestry Systems*, 108 Advances Agronomy 237, 272 (2010). The *United States Mid-Century Strategy for Deep Decarbonization* recognized agroforestry as a promising strategy for change mitigation and adaptation. *See* The White House, United States Mid-century Strategy for Deep Decarbonization 78-79 (2016), http://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf.
131. The loss of nitrogen as nitrate can result in indirect emissions of nitrous oxide when the nitrate is deposited in downstream ecosystems and converted to nitrous oxide by soil bacteria. EPA estimates that indirect emissions of nitrous oxide accounted for 18% of nitrous oxide emissions from agricultural soils in 2015. EPA, *supra* note 9, at 5-24 to 5-25 tbls. 5-17, 5-18. Over time, agroforestry practices like riparian tree buffers can prevent the loss of nitrate and thereby prevent its downstream conversion to nitrous oxide. Ranjith P. Udawatta et al., *Agroforestry Practices, Runoff, and Nutrient Loss: A Paired Watershed Comparison*, 31 J. Envtl. Quality 1214, 1224-25 (2002).
132. Swan et al., *supra* note 40, at 29 (using P.K. Ramachandran Nair & Vimala Nair, *Carbon Storage in North American Agroforestry Systems*, *in* The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (John M. Kimble et al. eds., Lewis Publishers 2003)).
133. Meghann Jarchow & Matt Liebman, Iowa State University Extension, Incorporating Prairies Into Multifunctional Landscapes 14-15 (2011) (PMR 1007).
134. *Id.* at 20-21.
135. Swan et al., *supra* note 40, at 23.
136. Jo Smith et al., *Reconciling Productivity With Protection of the Environment: Is Temperate Agroforestry the Answer?*, 20 Renewable Agric. & Food Systems 80, 81-82 (2013).
137. Swan et al., *supra* note 40, at 25.
138. *See, e.g.*, Rob Collins & Kit Rutherford, *Modeling Bacterial Water Quality in Streams Draining Pastoral Land*, 38 Water Res. 700, 710-11 (2004).
139. Swan et al., *supra* note 40, at 27.
140. Perennial root crops normally require digging for harvesting, however, and therefore do not offer the same carbon sequestration benefits as other perennials.

and almonds and other nuts. Expansion of these products could make healthy food more accessible.

There are also perennial crops that are able to produce ample quantities of feedstock for biofuels, such as switchgrass, that could take the place of the annual crops now grown for this purpose.[141] In part due to different fertilizer and water needs of switchgrass and corn, the life-cycle carbon intensity of switchgrass biofuel is less than that of gasoline while that of corn ethanol is greater.[142] Other perennials can be a source of edible oils that are now largely produced by annual crops such as rape or soy. While there are now no perennial grains ready for commercial use, the Land Institute, a nonprofit research organization dedicated to developing perennial staple crops, has been making promising progress.[143] Returning to more pasture-based systems of raising livestock also effectively switches the feed from an annual to a perennial crop. For any new crops, of course, affordable mechanized harvesting and processing tools must be developed for them to be cost effective.

Some researchers have speculated that annuals could be bred with root systems mimicking the extensive root systems of perennials, considerably increasing their carbon sequestration potential.[144] The United States Mid-century Strategy for Deep Decarbonization highlighted the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) support for research in this area.[145] In 2016, ARPA-E announced $35 million in funding for research to develop and advance crop varieties with deeper and more extensive root masses in order to increase carbon accumulation by 50%, decrease nitrous oxide emissions by 50%, and increase water productivity by 25%.[146] While much of the research will be applicable to perennial crops, ARPA-E is also funding research on commodity crop annuals, including at least two projects designed to increase the root mass of sorghum.[147] A 2016 study assessed the potential for increased root production—one of the mechanisms by which perennials reduce net emissions—to increase soil carbon sequestration in the United States. The study found that increasing root mass on all U.S. cropland with appropriate soil types, which includes 87% of the country's cropland, would sequester an additional 107 to 800 million metric tons of carbon dioxide equivalent each year.[148]

The ecosystem benefits of using perennial crops are well established.[149] Perennial crops generally have deeper rooting levels, reducing erosion risk and allowing them to conserve water more effectively.[150] Their extensive root systems also absorb nutrients more efficiently, reducing fertilizer runoff.[151] Additionally, perennial crops require less fertilizer and herbicide since the soil on which they sit is exposed and disturbed much less frequently than in annual systems.[152] Integrating livestock or additional crops into perennial systems can increase biodiversity, improve natural pest control, raise yields, and increase system resilience.[153]

h. Shift to More Ecologically Efficient Crop Use

Analyses of agricultural productivity generally focus on inputs, including labor, and crop yield. While these factors are important, they fail to provide an accurate account of whether a crop is a truly efficient use of land and energy from the perspective of fulfilling human needs. A crop with high yields and low labor requirements may be ineffi-

141. Approximately 40% of the corn grown in the United States is now devoted to ethanol production. *See* Peter Riley, *Interaction Between Ethanol, Crop, and Livestock Markets*, *in* U.S. Ethanol: An Examination of Policy, Production, Use, Distribution, and Market Interactions 27 (James A. Duffield et al. eds., USDA 2015). Soybean processing can produce soy oil for biofuels and protein for animal feed at the same time, so little to no soy is grown exclusively as a biofuel; however, approximately 30% of the soybean oil produced in 2013 was used for biodiesel. Jeremy Martin, *Biodiesel Update: Now With More Soy*, Union Concerned Scientists, Jan. 2, 2014, http://blog.ucsusa.org/jeremy-martin/biodiesel-update-now-with-more-soy-360.

142. An analysis conducted by the Environmental Working Group found that the life-cycle carbon intensity of biofuel produced from switchgrass was 47% lower than that of gasoline. Emily Cassidy, Environmental Working Group, Better Biofuels Ahead: The Road to Low-Carbon Fuels 5 (2015). In contrast, the life-cycle carbon intensity of ethanol produced from corn is greater than that of gasoline, resulting in a net increase in carbon dioxide emissions from its use. John DeCicco et al., *Carbon Balance Effects of U.S. Biofuel Production and Use*, 138 Climatic Change 667, 677 (2016). Perennial biofuels have also been shown to increase biodiversity and reduce nitrate runoff in comparison to annual biofuels. David DeGennaro, National Wildlife Federation, Fueling Destruction: The Unintended Consequences of the Renewable Fuel Standard on Land, Water, and Wildlife 14, 16 (2016).

143. *See*, *e.g.*, Pheonah Nabukalu & Thomas Cox, *Response to Selection in the Initial Stages of a Perennial Sorghum Breeding Program*, 209 Euphytica 103, 108-10 (2016); The Land Institute, Land Report No. 113 (2015).

144. See Douglas B. Kell, *Breeding Crop Plants With Deep Roots: Their Role in Sustainable Carbon, Nutrient, and Water Sequestration*, 108 Annals Botany 407, 410 (2011).

145. The White House, *supra* note 130, at 78.

146. Press Release, ARPA-E, ARPA-E Announces $70 Million in Funding for New Programs to Power Transportation and Store Carbon in Soil (Dec. 15, 2016) (on file with authors).

147. *See* ARPA-E, Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS): Project Descriptions.

148. The amount sequestered would depend on a number of factors, including variations in nitrous oxide fluxes, fertilizer emissions, and root depth and mass. Keith Paustian et al., Assessment of Potential Greenhouse Gas Mitigation From Changes to Crop Root Mass and Architecture 2 (2016). At the low end, a 25% increase in root production with no downward shift in root length would sequester 107 MMT CO_2 eq. annually. *Id.* at 26 tbl. 13. At the high end, a doubling of root production accompanied by an extreme downward shift in root length could sequester up to 800 MMT CO_2 eq. annually. *Id.*

149. *See* J.D. Glover et al., *Increased Food and Ecosystem Security via Perennial Grains*, 328 Science 1638, 1638 (2010); Ben Werling et al., *Perennial Grasslands Enhance Biodiversity and Multiple Ecosystem Services in Bioenergy Landscapes*, 111 Proc. Nat'l Acad. Sci. U.S. Am., 1652, 1654-55 (2014) (demonstrating the ecosystem and biodiversity benefits of perennial biofuel feedstocks over annual ones).

150. Glover et al., *supra* note 149.

151. *Id.*

152. See id.

153. *See* Brenda Lin, *Resilience in Agriculture Through Crop Diversification: Adaptive Management for Environmental Change*, 61 BioScience 183, 183-87 (2011).

cient if it is integrated into an energy-intensive value chain, such as grain destined for a feedlot, or if it does not provide consumers with a nutritious end product, such as corn processed into high-fructose corn syrup.

Shifting production away from crops intended to feed animals with a high conversion rate (of pounds feed to pounds meat), feedstock for biofuels with high life-cycle carbon emissions, or processed foods, while boosting the production of crops intended for human consumption as whole foods, would therefore improve the efficiency of crop use. This efficiency could allow for the production of an adequate food supply on fewer acres than would be required otherwise. This in turn would reduce direct emissions associated with the cultivation of the excess acreage, as well as allow the restoration of grassland and forestland that can function as carbon sinks.

A 2013 study estimated that 67% of the calories and 80% of the protein in crops produced in the United States are diverted to animal feed.[154] This represents an inherently inefficient use of potential food. For example, it typically takes six pounds of grain to increase the live weight of a beef cow by one pound,[155] and only 40% of the animal's live weight is consumable as beef.[156] In the United States, however, cows usually spend the first 12-18 months of their lives on pasture, consuming grass instead of feed.[157] They are then typically "finished" on feedlots, where they spend 4-6 months consuming feedstuff composed largely of grain.[158] About 40% of a cow's final weight will be gained during finishing under normal circumstances, although this can vary significantly from cow to cow.[159] This means that approximately 6 pounds of grain are used for each pound of beef produced.[160] In the United States, approximately 70 million acres of cropland are used to produce corn and soybean for animal feed.[161] The same calories and protein currently provided by animal products could be produced with a much smaller land footprint if crops were consumed directly rather than fed to animals.

The study further found that up to an additional 6% of both calories and protein of U.S. crops were diverted to biofuel production in 2000.[162] Neither the calories nor the protein were available for human consumption. Notably, this estimate predated enactment of the Renewable Fuel Standard (RFS) that spurred demand for biofuels in the United States, and the percentage of potential food lost to biofuel production is much higher today.[163] About 40% of each corn harvest in the United States has been used to make ethanol since the 2010-2011 marketing year.[164] A switch from the dominant biofuel—corn ethanol—to biofuels derived from perennial crops grown on lands that are less suitable to food crops (see Chapter 25, Bioenergy Feedstocks) would help to reduce competition for human food and relieve additional acreage from food production.[165]

In addition, the U.S. diet now relies heavily on processed and "ultra-processed" foods[166]; an estimated 75% of the average person's calories comes from such food.[167] Heavily processed foods largely rely on corn, wheat, and soy as well as some animal products, leading to a "commodity-based diet" in wealthy countries.[168] These diets are deficient in nutrients and other beneficial compounds found in whole or minimally processed foods[169] and are associ-

154. Cassidy et al., *supra* note 25.
155. Dan Shike, Assistant Professor, University of Illinois, Beef Cattle Feed Efficiency, Address at the Driftless Region Beef Conference (Jan. 31, 2013).
156. Holland et al., *supra* note 24, at 3.
157. *See* Kenneth H. Mathews, Jr. & Rachel J. Johnson, Econ. Research Service, USDA Alternative Beef Production Systems: Issues and Implications 5 fig. 1 (2013).
158. *Id.* at 6-7.
159. According to USDA, the typically steer enters a feedlot weighing 600-900 pounds and is slaughtered after gaining 400-500 pounds. *Id.* at 5, 18.
160. A total of 6 pounds of grain to one pound of beef was derived by dividing the number of pounds of grain during the finishing stage to one pound of live weight gain (2.4/0.4 = 6). Grain byproducts account for an increasing share of cattle feed. *Id.* at 7. Since byproducts are generally not fit for human consumption, it is sometimes argued that their contribution should be excluded when estimating the extent to which cattle feed displaces human-edible crops. This is misleading. Byproducts from the production of corn ethanol are the main source of industrial byproducts in cattle feed and, as discussed further below, corn raised for ethanol production displaces crops intended for human consumption. The use of corn ethanol byproducts in animal feed contributes to the profitability of the corn ethanol industry, effectively subsidizing this inefficient use of agricultural land and resources.
161. Estimates of acres cultivated for corn and soybean used for animal feed were derived by multiplying total corn and soybean acreage in marketing year 2014/2015 (90.6 and 83.3 million acres planted, respectively) by the proportion of the corn supply used for animal feed (0.34) or the proportion of the soybean supply crushed (0.46), and multiplying this product by the proportion of the corn and soybean supply due to production in that year (0.92 and 0.97, respectively). For corn data, see USDA, Feed Grains: Yearbook Tables (last updated June 14, 2017), and for soybean, see USDA, Oil Crops Yearbook (last updated Mar. 29, 2017).
162. Cassidy et al., *supra* note 25.
163. DeGennaro, *supra* note 142, at 5-6. The Emily Cassidy et al. analysis, *supra* notes 25, 142, and 162, was based on data from 1997-2003. Cassidy et al. note that the share of corn production in the United States devoted to the production of corn ethanol increased from 6% in 2000 to 38% in 2010. Cassidy et al., *supra* note 25, at 4.
164. USDA, ERS, U.S. Bioenergy Statistics, https://www.ers.usda.gov/data-products/us-bioenergy-statistics/ (last updated June 6, 2018).
165. *See* Cassidy, *supra* note 142, at 6.
166. The term was popularized by Carlos Monteiro, who argues, "The issue is not foods, nor nutrients, so much as processing." Carlos Monteiro, Commentary, *Increasing Consumption of Ultra-Processed Foods and Likely Impact on Human Health: Evidence From Brazil*, 12 Pub. Health Nutrition 729, 729 (2009). In a subsequent study, Monteiro and his collaborators divided food products into three groups: unprocessed or minimally processed, processed, and ultra-processed. Carlos Monteiro et al., *Increasing Consumption of Ultra-Processed Foods and Likely Impact on Human Health: Evidence From Brazil*, 14 Pub. Health Nutrition 5, 7 (2010). Ultra-processed foods are produced using industrial processes "designed to create durable, accessible, convenient, attractive ready-to-eat or ready-to-heat products." *Id.* Additionally, "they are formulated to reduce microbial deterioration ('long shelf-life'), to be transportable for long distances, to be extremely palatable ('high organoleptic quality') and often to be habit forming." *Id.* For a list of the industrial processes used in the production of ultra-processed foods, see *id.* at 7-8.
167. Jennifer Poti et al., *Is the Degree of Food Processing and Convenience Linked With the Nutritional Quality of Foods Purchased by US Households*, 101 Am. J. Clinical Nutrition 1251, 1251 (2015).
168. David Ludwig, Commentary, *Technology, Diet, and the Burden of Chronic Disease*, 305 JAMA 1352, 1352 (2011).
169. *Id.*

ated with higher overall cancer risk.[170] The production of an adequate supply of nutritious foods without a corresponding reduction in production of commodities used in processed foods may not be feasible. Research suggests that higher atmospheric carbon dioxide levels will decrease the protein and mineral content of common staples such as wheat, rice, and soybeans, further increasing the need for a more ecologically efficient and nutritious food supply chain.[171] Shifting away from such high reliance on heavily processed foods could further reduce inefficiencies in the food system and result in substantial health as well as climate benefits.[172]

i. Optimize Flood Irrigation and Drainage in Rice Cultivation

Rice cultivation results in methane emissions due to flood irrigation of rice fields, which creates anaerobic conditions in which methane-producing bacteria thrive.[173] While rice cultivation is a relatively small source of U.S. greenhouse gas emissions at the national level, accounting for about 0.3% of U.S. emissions and less than 3% of U.S. agricultural emissions in 2016,[174] the concentration of rice production in two regions, the lower Mississippi River basin and California, makes it an important consideration for policymakers in these areas.[175] Furthermore, increased atmospheric carbon dioxide concentrations, temperatures, and natural flood risks may increase methane emissions from rice cultivation over time; one study estimated that emissions per ton of rice may double by 2100.[176]

Rice farmers can reduce methane emissions by reducing the continuous flooding during the growing season by alternate wetting and drying. Periodic drainage temporarily restores aerobic conditions, which rapidly diminishes the amount of methane-producing bacteria and stimulates other bacteria that metabolize methane for energy.[177] The Intergovernmental Panel on Climate Change estimated that, on average, draining once per season reduces emissions by 40% while draining multiple times reduces emissions by 48%.[178] In 2016, California approved a protocol for rice farmers to quantify reductions at the farm level as the basis for generating credits under the state's cap-and-trade program, which may incentivize the adoption of mitigation practices in the rice industry.[179] Periodic drainage, which requires a suspension of irrigation, also reduces the use of irrigation water, benefiting both farmers and broader communities in areas that experience water shortages.[180]

3. Grazing Land

Grazing lands cover almost one-third of the contiguous United States.[181] More than 80% of this land is rangeland, uncultivated land with minimal inputs, while the

170. Thibault Fiolet et al., *Consumption of Ultra-Processed Foods and Cancer Risk: Results From NutriNet-Santé Prospective Cohort*, 360 BMJ k322-k330 (2018).
171. Samuel S. Myers et al., Letter, *Increasing CO_2 Threatens Human Nutrition*, 510 Nature 139-142 (2014); Irakli Loladze, *Hidden Shift of The Ionome of Plants Exposed to Elevated CO_2 Depletes Minerals at the Base of Human Nutrition*, 3 eLife e02245 (2014). Climate change will also continue to negatively affect fruit and vegetable production. *See, e.g.*, Tapan B. Pathak et al., *Climate Change Trends and Impacts on California Agriculture: A Detailed Review*, 8 Agronomy 25 (2018). A 2016 *Lancet* study found that the climate change is likely to decrease fruit and vegetable consumption in the United States as a result, leading to the premature deaths of millions. Marco Springmann et al., *Global and Regional Health Effects of Future Food Production Under Climate Change: A Modelling Study*, 387 Lancet 1937, 1942 (2016).
172. *See* Carlos Monteiro et al., *Dietary Guidelines to Nourish Humanity and the Planet in the Twenty-First Century. A Blueprint From Brazil*, 18 Pub. Health Nutrition 2311, 2317 (2015) (describing how dietary guidelines can enhance both human health and the environment by reducing the consumption of processed foods); Dariush Mozzaffarian & David Ludwig, Commentary, *Dietary Guidelines in the 21st Century—A Time for Food*, 304 JAMA 681, 681-82 (2010) (emphasizing the importance of whole and minimally processed foods for human health); K.R. Siegel et al., *Association of Higher Consumption of Foods Derived From Subsidized Commodities With Adverse Cardiometabolic Risk Among US Adults*, 176 JAMA Internal Med. 1124, 1124 (2016) (showing an association between consumption of subsidized food commodities and higher cardiometabolic risks). The Scientific Report of the 2015 Dietary Guidelines Advisory Committee also noted that diets with lower levels of animals products were associated with healthier outcomes and generally resulted in reduced greenhouse gas emissions. *See* Scientific Report of the 2015 Dietary Guidelines Advisory Committee pt. D ch. 5 (2015).
173. EPA, *supra* note 9, at 5-17.
174. *Id*. at 2-3 to 2-4 tbl. 2-1, 5-2 tbl. 5.1.
175. *See id*. at 5-18 to 5-19. Arkansas, Louisiana, Mississippi, and Missouri accounted for 75% of methane emissions from rice cultivation in 2012. California accounted for 17%, and Texas accounted for the remaining 8%. *See id*. at 5-18 tbl. 5-11.
176. Tapan K. Adhya et al., World Resources Institute, Working Paper Installment No. 8 of Creating a Sustainable Food Future, Wetting and Drying: Reducing Greenhouse Gas Emissions and Saving Water From Rice Production 5 (2014). The increase in the greenhouse gas intensity of rice cultivation would be due both to the direct effects of increasing atmospheric carbon dioxide concentrations, which increases the availability of carbon used by methanogens to generate methane, and to declines in yields due to increasing temperatures and natural flood risks, which would necessitate the cultivation of additional land for rice production. Flood irrigation and the resulting anaerobic conditions would increase methane emissions from the cultivated land. *Id*.
177. *Id*. at 6.
178. 4 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories: Agriculture, Forestry and Other Land Use 5.44-5.53 (2006).
179. *See* California Environmental Protection Agency, Air Resources Board (CARB), *Potential New Compliance Offset Protocol Rice Cultivation Projects*, https://www.arb.ca.gov/cc/capandtrade/protocols/riceprotocol.htm (last reviewed Dec. 2, 2014). Microsoft just purchased some such offsets. USDA, NRCS, *Nature's Stewards: U.S. Rice Farmers Embrace Sustainable Agriculture and Earn First-Ever Carbon Credits for Rice Production*, http://nrcs.maps.arcgis.com/apps/Cascade/index.html?appid=c00a7710dbe04790823c4133777e49c0 (last visited Apr. 12, 2018).
180. In addition to reducing irrigation requirements, periodic drainage can increase water savings by decreasing the amount of water lost to percolation and, in some cases, evaporation. Adhya et al., *supra* note 176, at 8.
181. Of the 1,937.7 million acres of nonfederal land in the contiguous United States, 130.9 million are pastureland, 417.9 are rangeland, and 56.1 are grazed forestland. Nickerson et al., *supra* note 4, at 7. USDA's data for the 48 contiguous states do not include federal lands, however, which account for a significant proportion of national grazing lands. *Id*. at 6. *See also* T.M. Sobecki et al., *A Broad-scale Perspective on the Extent, Distribution, and Characteristics of U.S. Grazing Lands*, *in* The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect 21, 29 (Ronald F. Follett et al. eds., CRC Press 2001).

remainder is cultivated and more intensively managed grazing land, or pasture.[182] Pasture has greater potential for carbon sequestration as a result of its higher biomass unit production, but it requires irrigation or high precipitation levels, making it impractical in much of the arid West.[183] (And degraded pasture has higher potential for new sequestration given the lower baseline.) Regardless of whether ranchers are utilizing pasture or rangeland, however, they can generally reduce emissions and increase soil carbon sequestration through better grazing management, and by optimizing feed, breed, and herd health. Emerging research indicates that new practices, such as spreading organic soil amendments, may be able to further improve carbon sequestration on grazing lands. Researchers have also established that well-managed silvopasture systems, which integrate the production of woody perennials and livestock on the same land, offer substantially more climate benefits than conventional grazing systems.

a. Improve Grazing Management

A variety of management practices can increase carbon sequestration on grazing lands. Several factors influence the types of practices appropriate for any given location, including climate, precipitation, topography, local plant communities, soil type, and ranch size. However, rotation and stocking rates are important regardless of the grazing ecosystem. Management systems that rotate livestock through a series of pastures, if implemented well, may improve soil conditions and grassland productivity, thereby increasing soil organic carbon.[184] At the same time, continuous systems, which allow unrestricted grazing, are more likely to lead to poor soil quality and carbon loss.[185]

The USDA Natural Resources Conservation Service (NRCS) calls rotational systems that rotate livestock in order to foster optimal plant and animal health "prescribed grazing." There are different types of prescribed grazing systems, such as management-intensive grazing and less intensive forms of rotational and planned grazing. While not widely adopted, there are numerous such operations that appear to be successful in restoring rangelands, increasing soil carbon, and enhancing other ecological benefits while producing livestock.[186] These can be viewed as models for other farms, education programs, and government incentives. The ability of individual systems to sequester carbon has been vigorously debated,[187] varies by region and land use history,[188] and hits an upper limit when soils become saturated.[189] Environmental factors beyond the control of ranchers, such as drought conditions, can also overshadow and overwhelm the impact of even the most effective management practices, particularly in arid rangelands.[190] Nonetheless, prescribed grazing has been shown to offer significant carbon sequestration potential in some ecosystems.

Prescribed grazing co-benefits include increased species diversity, decreased erosion, improved soil quality, better quantity and quality of wildlife habitat, improved water quality, and improved riparian ecosystem health and watershed quality.[191]

b. Optimize Feed, Breed, and Herd Health

Grazing practices have been the subject of significant attention and debate; however, ranchers can also take important steps to reduce net emissions through improved feed, breed, and animal health management. By carefully managing their herds' feed and forage options, operators may be able to decrease enteric emissions.[192] Operators can also reduce emissions by maintaining herd health and choosing or developing breeds best adapted to the local environment.[193] The capacity of different breeds to thrive in local conditions, such as weather and native plant communities, affects how quickly they mature. Breeds opti-

182. Eagle et al., *supra* note 96, at 36.

183. The majority of pasture is east of the Missouri River, where precipitation levels are higher. R.R. Schnabel et al., *The Effects of Pasture Management Practices*, *in* The Potential for U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect 291, 293 (Ronald F. Follett et al. eds., CRC Press 2001).

184. Richard Conant et al., *Land Use Effects on Soil Carbon Fractions in the Southeastern United States. I. Management Intensive Versus Extensive Grazing*, 38 Biology & Fertility Soils 386, 391 (2003); Chad Hellwinckel & Jennifer Phillips, *Land Use Carbon Implications of a Reduction in Ethanol Production and an Increase in Well-managed Pastures*, 3 Carbon Mgmt. 27, 28 (2012). *Contra* David D. Briske et al., *Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence*, 61 Rangeland Ecology & Mgmt. 3, 11 (2008) (arguing that rotational grazing offers few, if any, benefits over other systems of grazing according to experimental evidence).

185. *See*, *e.g.*, Carter et al., *supra* note 31, at 202.

186. *E.g.*, Brown's Ranch, http://brownsranch.us/ (last visited Apr. 12, 2018); Pinhook Farm, http://pinhookfarm.blogspot.com/ (last visited Apr. 12, 2018); LeftCoast Grassfed, http://www.leftcoastgrassfed.com/ (last visited Apr. 12, 2018). *See generally* Regeneration International, http://regenerationinternational.org/ (last visited Apr. 12, 2018); Savory International, http://www.savory.global/ (last visited Apr. 12, 2018).

187. *See*, *e.g.*, John Carter et al., *Holistic Management: Misinformation on the Science of Grazed Ecosystems*, 2014 Int'l J. Biodiversity 1, 5-7 (2014).

188. Megan McSherry & Mark Ritchie, *Effects of Grazing on Grassland Soil Carbon: A Global Review*, 19 Global Change Biology 1347, 1347 (2013).

189. Stewart et al., *supra* note 35, at 25-28; Stockmann et al., *supra* note 34, at 94-95.

190. Kayje Booker et al., *What Can Ecological Science Tell Us About Opportunities for Carbon Sequestration on Arid Rangelands in the United States?*, 23 Global Envtl. Change 240, 240-44 (2013).

191. Swan et al., *supra* note 40, at 34.

192. Doug Gurian-Sherman, Union of Concerned Scientists, Raising the Steaks: Global Warming and Pasture-Raised Beef Production in the United States 13-19 (2011) (summarizing practices to reduce methane emissions through improved feed and forage); Karen A. Beauchemin et al., *Mitigation of Greenhouse Gas Emissions From Beef Production in Western Canada—Evaluation Using Farm-Based Life Cycle Assessment*, 166/167 Animal Feed Sci. & Tech. 663, 674-75 (2011).

193. Global Research Alliance on Agricultural Greenhouse Gases et al., Reducing Greenhouse Gas Emissions From Livestock: Best Practice and Emerging Options 12-14, 20-23 (Karin Andeweg & Andy Reisinger eds., 2015).

mized for local conditions will therefore reach slaughter weight more quickly, reducing their impact on emissions.

c. Add Soil Amendments

New research has demonstrated that organic soil amendments like compost may be able to boost carbon sequestration on grazing land. Over the course of three years, researchers found that a single application of composted organic matter to rangeland increased net carbon storage by 25%-70%,[194] while also increasing the production of grass for feed and thereby making rangelands more productive.[195] Some scientists have expressed concern that applying compost on natural grasslands could negatively alter soil chemistry and water quality, favor invasive plants species, and decrease native plant diversity.[196] A study by proponents of soil amendments found that while the application of compost to grasslands in California did not result in shifts in species abundance overall, the abundance of particular species was altered.[197] Further study and field trials will need to confirm these results and measure results in different ecosystems.[198]

d. Expand Silvopasture

Silvopasture refers to the practice of planting woody perennials on grazing lands. As with agroforestry on cropland, silvopasture offers significant greenhouse gas mitigation potential. Adding trees to pasture and rangelands adds a substantial new source of carbon storage, while also increasing livestock productivity (due to additional shade and reduced heat stress loss), and in some cases, adding an additional source of income for producers. Silvopasture systems have the potential to sequester more carbon than either forests or grasslands, since they can integrate perennial grasses and trees, each of which offers distinct sequestration avenues as described above.[199] A 2012 literature review estimated that silvopasture systems would sequester an average of 2.5 metric tons of carbon dioxide equivalent per acre annually in the United States through both additional biomass and increased soil carbon storage.[200] USDA's estimated range for sequestration rates for silvopasture systems, while substantially lower, still markedly outperforms conventional grazing.[201]

Co-benefits of silvopasture systems include improved water quality, reduced erosion, and additional habitat for wildlife.[202]

4. Animal Feeding Operations

Animal feeding operations (AFOs) are lots or facilities in which confined animals are fed, raised, and maintained.[203] Unlike farms that allow livestock to graze or be integrated into crop production, AFOs are focused on one task: maximizing the production of meat, dairy, or eggs. EPA classifies AFOs as concentrated animal feeding operations (CAFOs) if they exceed a certain size threshold or, in some circumstances, if they discharge waste into surface waters.[204]

There are roughly 450,000 AFOs[205] in the United States, including 20,000 CAFOs.[206] CAFOs alone hold the majority of the country's food-producing animals.[207] While AFOs are credited with lowering consumer costs for animal products, they have considerable externalities. They can harm animal welfare, increase antibiotic resistance due to the routine use of antibiotics,[208] emit air and water pollution,[209] depress property values,[210] hurt small-scale farms and businesses,[211] and diminish quality of life in rural communities.[212]

194. Rebecca Ryals & Whendee Silver, *Effects of Organic Matter Amendments on Net Primary Productivity and Greenhouse Gas Emissions in Annual Grasslands*, 23 Ecological Applications 46, 56 (2013). This total does not include the carbon directly added to the soil from the compost. *Id.* at 46.
195. *Id.* at 51. Biodegradable waste appropriate for compost includes animal manure, crop residues, composted urban waste, and sewage sludge. *Id.* at 46.
196. Kelly Gravuer, Agronomic Rates of Compost Application for California Croplands and Rangelands to Support a CDFA Healthy Soils Initiative Program, Version 1.0, at 10-11 (2016).
197. Rebecca Ryals et al., *Grassland Compost Amendments Increase Plant Production Without Changing Plant Communities*, 7 Ecosphere 1, 7-8 (2016).
198. The original study was followed by a modeling study demonstrating the possibility for long-term effect. Rebecca Ryals et al., *Long-Term Climate Change Mitigation Potential With Organic Matter Management on Grasslands*, 25 Ecological Applications 531, 531 (2015).
199. Udawatta & Jose, *supra* note 30, at 227.
200. *Id.* at 230.
201. Swan et al., *supra* note 40, at 33.
202. *Id.*
203. EPA, *National Pollutant Discharge Elimination System (NPDES): Animal Feeding Operations (AFOs)*, https://www.epa.gov/npdes/animal-feeding-operations-afos (last updated Jan. 17, 2017).
204. 40 C.F.R. §122.23(b)-(c) (2016). "Large CAFOs" are defined as CAFOs by EPA solely due to the number of animals they hold, "Medium CAFOs" are operations that exceed a smaller size threshold, but discharge waste into surface water, and "Small CAFOs" are facilities that do not meet any size threshold, but have been designated as "significant contributor[s] of pollutants to waters" by regulatory authorities. *Id.*
205. USDA, NRCS, *Animal Feeding Operations*, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/plantsanimals/livestock/afo/ (last visited Apr. 12, 2018).
206. EPA, National Pollutant Discharge Elimination System, 2017 CAFO Permitting Status Report (2017).
207. *See* Marc Ribaudo et al., USDA, Manure Management for Water Quality: Costs to Animal Feeding Operations of Applying Manure Nutrients to Land iii (2003) (noting that while CAFOs make up less than 5% of AFOs, they contain 50% of all animals and produce more than 65% of all manure).
208. David Tillman et al., *Agricultural Sustainability and Intensive Production Practices*, 418 Nature 671, 674 (2002); Ellen Silbergeld et al., *Industrial Food Animal Production, Antimicrobial Resistance, and Human Health*, 29 Ann. Rev. Pub. Health 151, 162-63 (2008).
209. Tillman et al., *supra* note 208.
210. Kelley Donham et al., *Community Health and Socioeconomic Issues Surrounding Concentrated Animal Feeding Operations*, 115 Envtl. Health Persp. 317, 319 (2007).
211. *Id.* at 317.
212. *See id.*; Steve Wing & Susanne Wolf, *Intensive Livestock Operations, Health, and Quality of Life Among Eastern North Carolina Residents*, 108 Envtl.

There are AFO systems for production of all types of meat—beef, pork, and chicken—as well as production of eggs and dairy products. While the details vary, in general, swine and dairy AFOs often rely on liquid manure systems, chicken and egg AFOs produce a dry litter, and cattle feedlots leave the animal waste on the open ground. In liquid systems, the manure is washed from the animal pens to a storage lagoon, usually uncovered, where it is eventually pumped out and spread onto fields.

AFO manure management systems also produce much more methane than manure in pasture-based livestock operations. When manure is left as a solid, as naturally happens on grazing lands and pasturelands, it typically decomposes aerobically and produces little to no methane. However, when it is stored or handled in a system that creates an anaerobic environment, such as a lagoon, it releases large amounts of methane.[213] Anaerobic environments can result in methane emission rates as much as 90 times higher than those in grazing systems.[214]

AFOs can produce an enormous amount of waste and greenhouse gases. Iowa's 5,000 hog AFOs generated more than 50 million tons of manure in 2007,[215] for example, almost 200 times the amount of human excreta produced by the state's residents.[216] Wisconsin's 8,600 dairy farms, meanwhile, are expected to generate almost 28 million tons of manure in 2018[217]—more than 50 times the amount of human excreta produced within the state.[218] And, since human waste must be treated before being released into the environment, reducing both the threat of pathogens[219] and volume of organic material discharged, the relative impact from CAFO waste is even more stark—a CAFO with 250 dairy cows produces more organic waste than a city the size of Albany each day.[220] As a result of their reliance on anaerobic storage practices, dairy and hog operations are responsible for almost 90% of methane emissions from manure management.[221] When comparing net greenhouse gas emissions from AFOs to other animal production systems, however, it is important to take into account other factors as well, including enteric emissions and the greater length of time that may be needed for animals to reach market weight in pasture-based systems.

This subsection evaluates four different strategies for reducing emissions from AFOs. The first, transitioning to integrated crop-livestock systems, offers the most significant co-benefits, although its impact on greenhouse gas emissions will vary considerably by animal type and breed, the local environment, and other factors. The second section discusses the benefits of eliminating concentrated liquid manure, which, as discussed above, is the dominant source of emissions from manure management. The third section considers strategies for reducing emissions from liquid manure. The final section evaluates research into feed additives and vaccines designed to reduce enteric emissions from ruminants.

a. Reincorporate Animals Into Croplands

The most effective way to reduce emissions from AFOs would be to replace them with well-managed integrated crop-livestock systems. Traditionally, most farms incorporated animals into cropping systems by allowing them to forage on plant residues after harvest, but early agricultural scientists and extension agents discouraged this practice, perceiving it as archaic and inefficient. As scientists have begun to understand the ecology of agriculture better, however, they have started to encourage it as an environmentally friendly way to intensify agricultural

Health Persp. 233, 235-37 (2000).

213. While dry management can reduce methane emissions, switching to dry management can increase nitrous oxide emissions. Pete Smith et al., *Greenhouse Gas Mitigation in Agriculture*, 363 Phil. Transactions Royal Soc'y B 789, 794 (2008). Dry management does not always increase nitrous oxide emissions, however, and increases in nitrous oxide emissions resulting from dry management are likely to be exceeded by decreases in methane emissions. *See*, *e.g.*, Justine J. Owen et al., Nicholas Institute, Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of Emissions and Mitigation Potential of Animal Manure Management and Land Application of Manure 7 tbl. 4 (2014) (showing emission estimates of cows in California by manure management system).

214. Paul Jun et al., Intergovernmental Panel on Climate Change, CH_4 and N_2O Emissions From Livestock Manure 388 tbl. 10 (1996).

215. Cynthia Cambardella et al., *Soil and Cover Crop Responses to Liquid Swine Manure Application*, Iowa Manure Matters—Odor & Nutrient Mgmt. (Iowa State University Extension Service, Ames, Iowa), Fall 2007, at 1.

216. Iowa residents produced an estimated 271,808 tons of human waste in 2007 (calculated by the authors). *Compare* EPA, Risk Assessment Evaluation for Concentrated Animal Feeding Operations 9 tbl. 3.3 (2004) (estimating that the average 150 pound person produces 182.5 pounds of excreta each year), *with* State Library of Iowa, State Data Center Program, Total Population Estimates, Numeric and Percent Change, and Components of Population Change for Iowa: 2000-2009 (listing Iowa's population as 2,978,719 on July 1, 2017).

217. Calculated by the authors. *Compare* National Agricultural Statistics Service, USDA,Milk Cows Numbers, Wisconsin (2018), https://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Dairy/Historical_Data_Series/milkcowno.pdf (estimating Wisconsin's dairy cow population to be 1,274,000), *with* Riverkeeper, Inc. v. Seggos, slip op. 28141, at 2 n.5 (N.Y. Sup. Ct. Apr. 23, 2018) (noting that cows produce 120 pounds of manure each day).

218. Wisconsin residents will produce an estimated 528,837 tons of human waste in 2018 (calculated by the authors). *Compare* EPA, *supra* note 216 (estimating that the average 150 pound person produces 182.5 pounds of excreta each year), *with* U.S. Census Bureau, QuickFacts: Wisconsin (2017), https://www.census.gov/quickfacts/WI (listing Wisconsin's population as 5,795,483 on July 1, 2017).

219. EPA, Report to Congress: Impacts and Control of CSOs and SSOs 4-3 (EPA 833-R-04-001) (2004).

220. Calculated by the authors. *Seggos*, at 2 n.5 (noting that cow's produce 120 pounds of manure each day), *with* Nat'l Res. Council, Use of Reclaimed Water and Sludge in Food Crop Production 46-47 (1996) (discussing research showing that the typical person produces about .30 lb of post-treatment sludge each day), *and* U.S. Census Bureau, QuickFacts: Albany City, New York (2017), https://www.census.gov/quickfacts/fact/table/albanycitynewyork/PST045216 (listing Albany's population as 98,111 on July 1, 2017). *See* Eve C. Gartner, Letter to the Editor, *Environment Group to Cornell: We Stand by Our Numbers on Animal v. Human Waste*, The Post-Standard, July 27, 2017, http://www.syracuse.com/opinion/index.ssf/2017/07/environment_group_to_cornell_our_numbers_on_animal_v_human_waste_are_right.html.

221. EPA, *supra* note 9, at 5-10 tbl. 5-6.

production.[222] Some even argue that crop-livestock farms are economically and environmentally optimal, creating an efficient nutrient cycle between plants and animals.[223]

Mixed crop-livestock systems encourage crop and animal rotations and also help break down plant residue, all of which increases soil health and carbon sequestration. They can substantially reduce methane emissions from manure management since manure in integrated systems is typically left to decompose aerobically.[224] As noted above, however, both animal growth rates and enteric emissions must be taken into account when comparing net emissions from different systems of animal agriculture.

In addition to their climate benefits, properly managed crop-livestock systems naturally control pest and weed populations[225] and can improve soil structure, animal health, water quality, and biodiversity.[226]

b. Transition to Dry Manure Management Systems

Dairy and swine operations accounted for 90% of methane emissions from manure management in 2016,[227] largely due to their reliance—in the United States, at least—on liquid management systems.[228] Nearly all hog producers, for example, wash waste into giant "lagoons" or hold it in large "slurry pits" below the slatted floors of production facilities until it is applied to land, ostensibly as nitrogen fertilizer.[229] In dry management systems, by contrast, aerobic conditions are maintained and methane emissions are minimized.[230] For example, manure may be drained and dried, or dry matter like straw may be added to absorb moisture and solidify it.[231] Solids can then be stacked until land application.[232] A transition from liquid to dry management in these operations would maintain aerobic conditions, stymie the growth of methane-producing bacteria, and reduce methane emissions. A 2015 meta-analysis of field studies measuring dairy manure management emissions found that liquid manure storage systems have the highest per-head methane emission rates, while dry systems had among the lowest.[233]

Dry manure can be composted and used as a soil amendment, which, as discussed above in Section II can increase soil carbon sequestration and provide a number of environmental co-benefits. However, dry management may also increase emissions of particulate matter, nitrous oxide, and volatile organic compounds.[234]

c. Improve Management of Concentrated Liquid Manure

Liquid manure is typically stored in lagoons and then spread or sprayed on fields. Measures can be taken to reduce emissions from both stages. Anaerobic digesters, which work by converting volatile solids in organic matter to biogas and a material called digestate, can be added to manure lagoons. The biogas, which is predominantly methane and carbon dioxide, releases carbon dioxide when burned for energy. The digestate can be applied to fields as a fertilizer, which lowers net emissions by offsetting synthetic fertilizers and increasing carbon sequestration, or can be composted and used as bedding.[235]

Anaerobic digesters are relatively rare in the United States due to their high costs and the lax regulation of alternative management methods: for every digester in operation there are about 80 CAFOs producing undigested waste.[236] Anaerobic digesters are primarily used on dairy farms in North America, but they can also run on hog, beef, and poultry manure. Of the approximately 250 anaerobic digesters operating in the United States, about

222. *See*, *e.g.*, Michael Russelle et al., *Reconsidering Integrated Crop-Livestock Systems in North America*, 99 Agronomy J. 325, 325 (2007); Gilles Lemaire et al., *Integrated Crop-Livestock Systems: Strategies to Achieve Synergy Between Agricultural Production and Environmental Quality*, 190 Agric. Ecosystems & Env't 4, 4 (2014); Paulo Cesar de Faccio Carvalho et al., *Managing Grazing Animals to Achieve Nutrient Cycling and Soil Improvement in No-Till Integrated Systems*, 88 Nutrient Cycling Agroecosystems 259, 271 (2010) (examining the environmental and productivity benefits of integrating livestock into a no-tillage crop system in southern Brazil).

223. Patrick Veysset et al., *Mixed Crop-Livestock Farming Systems: A Sustainable Way to Produce Beef? Commercial Farms Results, Questions, and Perspectives*, 8 Animal 1218, 1218 (2014). The authors acknowledge that the current policy and market environment disincentive crop-livestock systems, making it less than optimal in the real world. *Id*. at 1225-26.

224. Unmanaged manure deposited on grassland by grazing animals still emits significant amounts of nitrous oxide, however. *See* EPA, *supra* note 9, at 5-24 tbl. 5-17, 5-34 to 5-35.

225. Lemaire et al., *supra* note 222, at 4-5.

226. Bertrand Dumont et al., *Prospects From Agroecology and Industrial Ecology for Animal Production in the 21st Century*, 7 Animal 1028, 1030-38 (2013).

227. EPA, *supra* note 9, at 5-11 tbl. 5-7.

228. Nigel Key et al., USDA, Trends and Developments in Hog Manure Management: 1998-2009, at 11 (2011).

229. *Id*.

230. National Research Council, Air Emissions From Animal Feeding Operations 54 (2003).

231. Jeff Lorimor et al., Michigan State University Extension, Manure Characteristics 4 (2004) (MWPS-18).

232. *Id*.

233. Justine J. Owen & Whendee L. Silver, *Greenhouse Gas Emissions From Dairy Manure Management: A Review of Fieldbased Studies*, 21 Global Change Biology 550, 558 fig. 3 (2014). Dry management does not always increase nitrous oxide emissions, however, and increases in nitrous oxide emissions resulting from dry management are likely to be exceeded by decreases in methane emissions. *See*, *e.g.*, Owen et al., *supra* note 213.

234. California Environmental Associates, Greenhouse Gas Mitigation Strategies for California Dairies 52 (2015).

235. It is not clear yet whether nitrous oxide emission rates differ for synthetic or organic fertilizers; however, organic fertilizers can offset emissions from nitrogen-based fertilizer manufacturing plants, which are a significant source of carbon dioxide as discussed *infra* Sections V.A and V.B.

236. In 2017, there were 19,961 CAFOs and 250 anaerobic digesters in the United States according to EPA. EPA, *supra* note 206; EPA, *AgSTAR Data and Trends*, https://www.epa.gov/agstar/agstar-data-and-trends (last updated Jan. 12, 2018).

200 rely on dairy operations.[237] Digesters eliminate most methane emissions from manure, although methane gas leakage from anaerobic digestion has not been carefully studied, and may reduce their effectiveness.[238]

Anaerobic digesters can reduce water pollution, odor, pathogens, and weed seeds, and increase availability of high-quality fertilizer, when compared to AFOs utilizing lagoons or other conventional manure management systems.[239]

Improvements can also be made regarding the spreading of the liquid manure. The Clean Water Act requires that the manure be spread at "agronomic rates"—that is in quantities that the plants need and can use.[240] That provision is often ignored, however, with the result that manure can pollute nearby waters and release greenhouse gases.[241] There is some evidence that specific practices relating to manure spreading can also affect emissions and soil carbon sequestration levels. Spreading on frozen or saturated soils, for example, tends to lead to water pollution and higher nitrous oxide emissions since the manure is more likely to enter waterways instead of being incorporated into the soil.[242]

d. Develop Methane Inhibitors and Vaccines

A number of feed additives have been demonstrated to decrease methane emissions from livestock in short-term experiments.[243] When studied over the long term, however, these effects disappear or decrease significantly as the microflora in livestock's rumen adapt to the new diet.[244] Nonetheless, scientists are studying novel approaches that they hope will remain effective throughout a ruminant's life-span. One promising study documented a 30% decrease in enteric methane emissions over 12 weeks with the addition of 3-nitrooxypropanol, a chemical compound that blocks an enzyme critical to methane formation.[245]

Other researchers have focused on developing vaccines designed to reduce methane emissions. A New Zealand team is currently researching the viability of a vaccine that would target methanogenic archaea, reducing their prevalence in the rumen.[246] Industry officials estimate that the vaccine could reduce enteric emissions by 25%-30%[247]; however, as with methane inhibitors, the vaccine has yet to be proven safe, effective, or financially feasible.

Finally, research indicates that eliminating antibiotic use in livestock may reduce the prevalence of methane-producing archaea. As a result, eliminating the nontherapeutic use of antibiotics in animals could have an effect on emissions similar to that of methane inhibitors and vaccines. Antibiotics are routinely administered to animals in confined production facilities to increase animal growth rates and to prevent disease.[248] This alters the microbiota of confined animals, affecting their health and physiology,[249] and may increase the amount of methane-producing microflora. For example, a 2016 study showed that tetracycline, a common antibiotic used in livestock production, nearly doubled methane emissions from cow dung.[250] Future research will be necessary to test additional classes of antibiotics and confirm that the effect will hold for enteric emissions.[251] Nonetheless, these initial results are promising.

Eliminating nontherapeutic antibiotic use in livestock would reduce the development of new resistance genes and the transmission of antibiotic resistance from animals to

237. . EPA, *supra* note 236.

238. Eastern Research Group, Inc., Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures 20 (2011) (noting both a lack of research into leakage and its importance when estimating emissions); *see Methodological Tool: "Project and Leakage Emissions From Anaerobic Digesters,"* U.N. Framework Convention on Climate Change, Clean Development Mechanism-Executive Board, EB 66 Report Annex 32, at 7 (2012) (estimating leakage rates of 2.8%-10% depending on digester type).

239. Emmanuel Yiridoe et al., *Nonmarket Cobenefits and Economic Feasibility of On-Farm Biogas Energy Production*, 37 Energy Pol'y 1170, 1171-73 (2009).

240. 40 C.F.R. §503.14 (2016).

241. *See, e.g.,* Olga Naidenko et al., Envtl. Working Group, Troubled Waters Farm Pollution Threatens Drinking Water 7, 11, & 14 (2012) (explaining that the over-application of manure is one of the primary sources of nutrient pollution); Michael Mallin & Lawrence Cahoon, *Industrialized Animal Production—A Major Source of Nutrient and Microbial Pollution to Aquatic Ecosystems*, 24 Population & Env't 369, 377-78 (2003) (discussing runoff from manure spreading).

242. Andrew C. VanderZaag et al., *Strategies to Mitigate Nitrous Oxide Emissions From Land Applied Manure*, 166/167 Animal Feed Sci. & Tech. 464, 469-70 (2011).

243. Mario Herrero et al., *Greenhouse Gas Mitigation Potentials in the Livestock Sector*, 6 Nature Climate Change 452, 454 (2016).

244. *Id.*

245. Alexander Hristov et al., *An Inhibitor Persistently Decreased Enteric Methane Emission From Dairy Cows With No Negative Effect on Milk Production*, 112 Proc. Nat'l Acad. Sci. U.S. Am. 10663, 10663 (2015).

246. D. Neil Wedlock et al., *Progress in the Development of Vaccines Against Rumen Methanogens*, 7 Animal 244, 244 (2015).

247. Lucie Bell, *New Zealand Vaccine to Reduce Cattle Methane Emissions for Dairy and Beef Industry Reaches Testing Stage*, ABC Rural, Nov. 9, 2015, http://www.abc.net.au/news/rural/2015-11-10/mitigating-methane-emissions-from-cattle-via-vaccine/6925676.

248. In 2012, the Food and Drug Administration released a guidance calling for the voluntary phaseout of antibiotic use in animals for growth promotion. However, livestock antibiotic use has increased by nearly 5% since the start of the phaseout program. Food and Drug Administration, 2014 Summary Report on Antimicrobials Sold or Distributed for Use in Food-producing Animals 40 (2015).

The agency is unlikely to realize lower usage rates without more active regulation and enforcement. *See* Frank Aaerestrup, Comment, *Get Pigs off Antibiotics*, 486 Nature 465, 465-66 (2012) (on the inadequacy of bans that fail to set and enforce reduction goals).

249. Nadia Gaci et al., *Archaea and the Human Gut: New Beginning of an Old Story*, 20 World J. Gastroenterology 16062, 16071 (2014).

250. Tobin Hammer et al., *Treating Cattle With Antibiotics Affects Greenhouse Gas Emissions, and Microbiota in Dung and Dung Beetles*, 283 Proc. Royal Soc'y B 1, 5 (2016).

251. The effect may not hold for other forms of manure management due to a variety of factors including the timing of manure collection and aeration, which inhibits methanogenesis. E-mail From Tobin Hammer, Ph.D. Candidate, University of Colorado, Boulder, to Nathan Rosenberg, Visiting Assistant Professor, University of Arkansas School of Law (June 3, 2016).

humans.[252] While new chemical inhibitors and vaccines may prove to be an effective and important pathway for reducing greenhouse gas emissions, they are unlikely to have significant social or environmental co-benefits. As with any feed additive or animal drug, their effects on animal welfare and human food safety should be rigorously assessed prior to marketing.

D. *Agriculture's Maximum Possible Contribution to Reducing Carbon*

This chapter lays out the pathways necessary for agriculture to achieve carbon neutrality. Even greater reductions in net greenhouse gas emissions may be technologically feasible. Nonetheless, net carbon neutrality is a much more ambitious target than those set by the Deep Decarbonization Pathways Project and the United States Mid-century Strategy for Deep Decarbonization. The Deep Decarbonization Pathways Project proposes an 8% cut in nitrous oxide emissions and a 6% decrease in methane emissions from the agricultural sector and does not address agricultural carbon emissions or carbon sequestration.[253] The United States Mid-century Strategy for Deep Decarbonization is slightly more aggressive, calling for a 25% reduction in non-carbon dioxide emissions from agriculture.[254] It also highlights soil carbon sequestration on agricultural soils as a promising method for reducing net emissions, although it does not include soil carbon sequestration in its modeling results.[255]

The maximum possible contribution of agriculture to deep decarbonization is difficult to estimate. While an understanding of the chemical and biological processes that result in agricultural emissions and sinks is advancing rapidly, there is still much to learn. Additionally, greenhouse gas emissions and sequestration rates vary significantly according to a number of local variables, including climate, historical land use, the composition of microbes in the soil, and other factors. Finally, high rates of soil carbon sequestration cannot continue indefinitely; soil eventually becomes saturated with carbon, eliminating its ability to provide further decarbonization.

In addition, there are often trade offs resulting from actions taken to reduce net agricultural emissions. Manure digesters capture methane but may increase incentives for concentration in livestock production; organic approaches may lower productivity, necessitating the use of more land; and no-till and cover cropping usually require greater use of herbicides. These trade offs must be considered in any plan. Nonetheless, it is clear that carbon neutrality in agriculture is both a technologically and economically feasible goal, if an ambitious one.

The vast majority of nitrous oxide emissions result from the application of fertilizers, which can be reduced with the adoption of climate-friendly practices. Additionally, manure can be used to fertilize fields or produce energy in ways that dramatically decrease methane emissions as well as further decrease the need for synthetic fertilizers. There are innumerable other strategies, practices, and tools available to cut agricultural emissions, many of which simultaneously increase soil carbon and make farms or ranches better able to handle changing weather patterns.

Not all of these practices can be used together, and among those that can, it is not always clear how their interactions will affect net emissions. Additionally, of course, not all practices can be adopted in all geographies and their impact will vary according to local climate and soil conditions, among other variables. Thus, it is not possible to simply subtract the sum of the aggregate soil carbon sequestration possibilities from total emissions. Nonetheless, the potential of climate-friendly practices to reduce the 563 million metric tons of carbon dioxide equivalent emitted by the agricultural sector in 2016, coupled with the potential of these practices to significantly increase soil carbon storage, makes carbon neutrality a realistic goal.

Table 1 includes the average annual net emissions reductions of the practices discussed in this chapter for which quantitative data are available. The table offers the possible maximum acreage on which a practice could be used, a range of net emissions reductions, and the total potential tonnage assuming maximum acreage and the lower end of per-acre impact. Given the diversity of geographies and uncertainties of these practices, these totals are only illustrative. As the table indicates, these practices alone could make agricultural land a carbon sink if adopted widely enough.

While these practices can be cost beneficial for farmers or ranchers, and have important additional benefits, uptake of new approaches can be slow and may require significant incentives, outreach and education, and even more robust regulatory requirements. Whether agriculture will ultimately achieve carbon neutrality will depend on

252. Bonnie Marshall & Stuart Levy, *Food Animals and Antimicrobials: Impacts on Human Health*, 24 Clinical Microbiology Rev. 718, 729 (2011).

253. James H. Williams et al., Pathways to Deep Decarbonization in the United States, U.S. 2050 Report, Volume 1: Technical Report 52 tbl. 9 (Deep Decarbonization Pathways Project & Energy and Environmental Economics, Inc., 2015), *available at* http://usddpp.org/downloads/2014-technical-report.pdf [hereinafter DDPP Technical Report].

The Deep Decarbonization Pathways Project specifically calls for a 9% decrease in nitrous oxide emissions from agricultural soils, which account for 93% of nitrous oxide emissions from agriculture, and a 9% decrease in methane emissions from enteric fermentation, which is responsible for 68% of methane emissions from agriculture. EPA, *supra* note 9, at 5-2 tbl. 5-1 (showing annual emissions from agriculture by source).

254. The White House, *supra* note 130, at 91.

255. *Id.* at 77-79.

Table 1
Average Annual Net Emissions Reductions of Select Agricultural Practices*

Practice	Maximum applicable area (million acres)	Average annual net emissions reductions (metric ton CO_2 eq. per acre)	Possible annual sequestration potential (million metric tons CO_2 eq.)
Cropland			
Improved synthetic fertilizer management	230	0.06-0.15	14
Reduced till	178	0.17-0.20	30
No-till	232	0.31-0.33	72
Cover cropping	126-245	0.26-0.37	33
Conservation crop rotations	310**	0.21-0.26	65
Organic amendments	Unknown	1.00-1.75***	Unknown
Biochar	306	0.26-7.90	80
Alley cropping	198	0.81-1.74	160
Windbreaks	11	1.09-2.09	12
Riparian buffers	2	1.08-2.47	2
Perennial biofuels and feedstock****	Unknown	1.74-2.43	Unknown
Grazing land			
Prescribed grazing	Unknown	0.18-0.26	Unknown
Organic amendments	Unknown	0.85-1.90	Unknown
Silvopasture	173	0.66-1.34	114

* Data are derived from Alison J. Eagle et al., Nicholas Institute for Environmental Policy Solutions, Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature (2012); Amy Swan et al., COMET-Planner: Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning; P.K. Ramachandran Nair & Vimala Nair, *Carbon Storage in North American Agroforestry Systems, in* The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (John M. Kimble et al. eds., Lewis Publishers 2003).
** Calculated by the authors. *Compare* Amy Swan et al., COMET-Planner: Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning 8 (noting that conservation crop rotations are possible on all cropland where at least one annually-planted crop is included in the crop rotation), *with* 2012 Census of Agriculture, U.S. National Level Data, *supra* note 43, at 16 tbl. 8 & 27-32 tbl. 37 (reporting the total number of harvested acres with annually planted crops).
*** This total does not account for nitrous oxide emissions. Amy Swan et al., COMET-Planner: Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning 7.
**** The perennials studied include poplar, willow, and switchgrass. R. Lemus & R. Lal, *Bioenergy Crops and Carbon Sequestration*, 24 Critical Rev. Plant Sci. 1, 15 (2005).

whether policies with that goal are adopted—and that is ultimately a question of political will, not a scientific one. Below, the chapter outlines legal pathways for reaching this objective.

III. Public Law Pathways to Reducing Net Agricultural Greenhouse Gas Emissions

At first glance, reducing net agricultural greenhouse gas emissions through public law poses a considerable challenge. Agriculture operates on a "parallel regulatory framework," in which farms are provided safe harbors from regulations in a number of areas, including labor, antitrust, and the environment.[256] Indeed, the industry's exemptions from environmental regulations are so ubiquitous that the environmental regulation of agriculture has been referred to as a body of "anti-law."[257]

While the federal government has largely declined to regulate agriculture's negative externalities, the industry relies on considerable government support. It has its own cabinet position and an agency charged with ensuring the sector's financial well-being, which it does through funding for research, training, crop insurance, loans, and numerous other programs. The industry has also sought to "privatize profits and socialize losses" through subsidies, often with great success.[258] Nonetheless, there are a number of ways to use these existing forms of gov-

256. Susan Schneider, *A Reconsideration of Agricultural Law: A Call for the Law of Food, Farming, and Sustainability*, 34 Wm. & Mary Envtl. L. & Pol'y Rev. 935, 937 (2010).

257. J.B. Ruhl, *Farms, Their Environmental Harms, and Environmental Law*, 27 Ecology L.Q. 263, 263 (2000). See Margot Pollans, *Drinking Water Protection and Agricultural Exceptionalism*, 77 Ohio St. L.J. 1195, 1213-24 (2016), for a discussion of agricultural exceptionalism in the context of drinking water contamination.

258. James C. Scott, *Forward* to Bill Winders, The Politics of Food Supply: U.S. Agricultural Policy in the World Economy xi (2009).

ernment support to reduce net agricultural greenhouse gas emissions.

Critical to the political reality of many proposals here, practices that reduce greenhouse gas emissions and increase soil carbon to mitigate climate change can also reduce costs, increase soil health and fertility, and make farms and grazing lands more resilient to climate change, and thus can all be urged and supported for those reasons. Indeed, advocacy should always emphasize the triple benefits of soil health, climate mitigation, and climate resilience.

The federal government spends almost $3 billion annually on agricultural research, development, and extension programs, much of which can be used to support climate mitigation efforts. Congress should require USDA to do so while providing increased funding for the agency to quickly develop and disseminate climate-friendly practices and crop varieties. Agricultural operations that do not follow basic conservation practices should not be eligible to receive funds through USDA, whether through subsidies, insurance, or conservation programs. Funding for conservation should also prioritize programs that offer the greatest climate benefits, while funding that benefits environmentally harmful operations, such as CAFOs, should be reduced or eliminated. Ultimately, however, Congress should adopt a system focused on payments for ecosystem services in place of much or all of the current farm safety net. Such a system would be independent of the volatile commodity markets and the variability of weather, both of which create the perceived need for the safety net, and thus could provide farmers, rural communities, and the environment with greater and more stable benefits.

In addition to farm programs, the public sector provides significant benefits to farms through tax policy and subsidized lending programs. Tax policy should be used at all levels of government to discourage agricultural practices that increase greenhouse gas emissions and to encourage practices that decrease emissions and sequester carbon. Likewise, lending institutions operated or subsidized by the federal government should offer more favorable rates to farmers utilizing climate-friendly practices.

The federal government's regulatory options, addressed in detail in Chapter 33 (Methane and Climate Change) and Chapter 35 (Nitrous Oxide), are summarized below. While EPA has the authority to regulate methane and nitrous oxide emissions from agricultural operations, state and local governments can also stop the most harmful agricultural practices. The Bureau of Land Management (BLM) and U.S. Forest Service, which oversee more than a third of all grazing lands in the United States, have the ability to regulate grazing on those lands, but have so far failed to sufficiently regulate practices that result in increased emissions. Finally, greenhouse gas pricing, addressed in Chapter 2 (Carbon Pricing), and other market approaches are briefly summarized at the conclusion of the section.

A. *Research, Development, and Extension Programs*

Congress' expressed purpose for supporting agricultural research and extension is not only to increase the productivity of agriculture in the United States,[259] but also to "[maintain and enhance] the natural resource base on which rural America and the United States agricultural economy depend."[260] As a result, many USDA programs already focus on conservation, giving the agency significant leeway to increase funding for climate-friendly practices through already existing programs. Doing so, whether through congressional or agency action, will be crucial for decarbonizing agriculture. State governments and land-grant institutions should also provide funding for research focused on climate-friendly practices, particularly in the absence of strong federal research support.

Congress should couple increased financial support for climate-related agricultural research with generous funding to disseminate climate-friendly practices and research. By creating a nationwide network of climate extension professionals, while significantly increasing funding for climate-related outreach, education, and technical assistance, Congress can provide carbon farming with the support it needs to rapidly expand.

1. Research and Development

Congress appropriated more than $2 billion annually to agricultural research and development in 2014, slightly less than the amount it appropriated to research and development for energy projects.[261] The overwhelming majority of these funds go to two USDA agencies: the National Institute of Food and Agriculture (NIFA) and the Agricultural Research Service (ARS). ARS is USDA's in-house research agency, while NIFA primarily funds research at land-grant universities and administers grants to organizations outside of USDA.

About 20% of ARS' fiscal year (FY) 2017 research budget is allocated to environmental research, which includes research on climate change.[262] ARS' climate change research is focused on adaptation, however, with relatively

259. Agricultural research includes basic, applied, and developmental research. *See* 7 U.S.C. §3101. The term "research" in this chapter thus encompasses the development of new technologies, practices, and products in addition to basic and applied research.
260. *Id.*
261. National Science Foundation, Federal Budget Authority for R&D and R&D Plant, by Budget Function, Ordered by FY 2014 R&D and R&D Plant Total: FYs 2014-16 (2017).
262. USDA, FY 2017 Budget Summary 88.

few resources allocated toward mitigation.[263] The majority of ARS' funding should be reoriented to research projects that include mitigation components; however, this does not mean that ARS will not be able to meet other research priorities at the same time. For example, 27% of ARS' 2017 budget was dedicated to livestock and crop production.[264] The agency could increase its support for research that advances production and mitigation simultaneously, such as projects to develop productive livestock breeds, better plant materials for cover crops, and high-yielding crops that facilitate lower emissions and sequester more carbon. This strategy would help farmers prepare for a decarbonized economy, while helping the United States meet its emissions goals.

NIFA administers dozens of programs authorized through the farm bill and other pieces of legislation. However, little NIFA funding goes to climate.[265] Of the $375 million requested in President Obama's 2017 budget for NIFA's competitive research program, for example, only $15 million was sought to support research on climate adaptation and resiliency and none was requested for mitigation.[266] On its own or with direction from Congress, NIFA, like ARS, should steadily increase the portion of funding for climate mitigation and adaptation, shifting research funding to projects designed to reduce greenhouse gas emissions or increase carbon sequestration, while improving soil health and resilience.

Both agencies should also prioritize funding for research into agroecology, which has a much greater potential to positively impact the climate than conventional systems.[267] Research into agroforestry and perennial agriculture in particular are severely underfunded.[268] Since research into these systems is unlikely to develop highly profitable products for agrochemical and seed corporations—agroforestry and perennial farmers do not need new seeds each year and require much lower rates of chemical inputs—privately funded agricultural research in this area is likely to remain minimal.[269] A USDA report on agricultural research spending, for example, found that agricultural research in several critical areas, including the environment and nutrition, was entirely reliant on public funding in 2013, the most recent year analyzed in the report.[270] Publicly funded research into these practices will be critical for kick-starting these systems, ultimately bringing farmers, consumers, and local communities significant social, environmental, and economic returns.

Increasing agricultural research will also be critical for maintaining agricultural productivity as weather patterns become more extreme and unpredictable due to climate change. As farming is perhaps the sector hardest hit by changing weather patterns, farmers have a particularly strong interest in adaptation to, and mitigation of, climate change. Many adaptation measures work in synergy with mitigation strategies; however, that is not always the case.[271] For example, adaptation strategies for livestock often include the expansion of cooling and ventilation systems, which increase energy use and therefore may result in higher emissions, depending on the energy source.[272] Government-funded research into adaptation practices should be increased, and strongly prioritize those that reinforce mitigation strategies. Similarly, USDA research designed to advance objectives other than mitigation, such as crop productivity or food safety, should be designed to bolster, and work in conjunction with, climate-friendly systems. Climate-friendly practices will be more readily adopted—and ultimately more sustainable—if they meet other human needs in addition to climate stability.

Congress will need to significantly expand funding for agricultural research in order to achieve carbon neutrality while maintaining crop and livestock productivity. Indeed, agricultural productivity is expected to stagnate without significant increases in public support for research even without taking climate change into account.[273] In 2016, despite this urgent need and a much larger budget, relative funding for research was at a historical low, with less than 2% of USDA's total budget devoted to agricultural research. Between 1940 and 1980, a period when agricultural productivity rose dramatically—in large part due to research funded by USDA—about 4% of USDA's budget was dedicated to research.[274]

263. *Id.*
264. *Id.* at 90.
265. Marcia DeLonge et al., *Investing in the Transition to Sustainable Agriculture*, 55 Envtl. Sci. & Pol'y 266, 269 (2016).
266. NIFA, USDA, FY 2017 President's Budget Proposal 8 (2016).
267. DeLonge et al., *supra* note 265.
268. *Id.*
269. The public sector remains responsible for "much of the fundamental research that creates the building blocks for major agricultural innovations," in large part because private research "[gravitates] toward technologies that are easy to patent or otherwise protect intellectual property rights." Matthew Clancy et al., *U.S. Agricultural R&D in an Era of Falling Public Funding*, Amber Waves, Nov. 10, 2016, *at* https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-rd-in-an-era-of-falling-public-funding/.
270. Clancy et al., *supra* note 269.
271. Cynthia Rosenzweig & Francesco Nicola Tubiello, *Adaptation and Mitigation Strategies in Agriculture: An Analysis of Potential Synergies*, 12 Mitigation & Adaptation Strategies for Global Change 855, 866-67 (2007); Pete Smith & J.E. Olesen, *Synergies Between the Mitigation of, and Adaptation to, Climate Change in Agriculture*, 148 J. Agric. Sci. 543, 550 (2010).
272. *See* Rosenzweig & Tubiello, *supra* note 271, at 866; *See* Daniel Tobin et al., USDA, Northeast and Northern Forests Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies 23 (Terry Anderson ed., 2015) (recommending the enhancement of cooling and ventilation systems as an adaptation strategy).
273. Paul W. Heisey et al., USDA, Public Agricultural Research Spending and Future U.S. Agricultural Productivity Growth: Scenarios for 2010-2050 (Economic Brief No. 17) (2011).
274. *The Role and Development of Public Agricultural Research*, *in* An Assessment of the U.S. Food and Agricultural Research System 9 (Congress Office of Technology Assessment 1981) (providing historical data on USDA's research expenditures); Jim Monke, Congressional Research Service,

Public funding for agricultural research is also declining in real terms: between 2003 and 2011, public funding fell from $6 billion to $4.5 billion after adjusting for inflation.[275] Prior to this period, the public sector enjoyed much larger investments in agricultural research than the private sector.[276] Public-sector investment in agricultural research increased rapidly as public funding began to decrease, however, and by 2010 private expenditures had surpassed public expenditures for the first time since the USDA Economic Research Servicebegan tracking funding in the 1970s.[277] In 2013, the most recent year for which data are available, private-sector funding was approximately 40% higher than public funding.[278] As a result, North America is the only region in the world where private agricultural research spending is higher than public spending,[279] and the United States now devotes only a tiny share of its total public research budget to agriculture—much less than almost every other advanced economy in the world.[280] This has important consequences since, as discussed above, private-sector research primarily supports practices that require the purchase of agrochemicals or other patentable products.

Several surveys of publicly funded agricultural research have concluded that public research into sustainable systems is, as one such survey put it, "woefully underresourced."[281] In light of the challenge presented by climate change—and the current dearth of funding for sustainable farming systems—Congress should at a minimum restore the research budget to at least its prior level within the agency. Devoting 4% of USDA's budget to research in 2016 would have resulted in an additional $3.1 billion for agricultural research.[282] Public funding would once again exceed private funding, if only slightly, and agriculture's share of total public research spending in the United States would be closer to the level of investment enjoyed by other advanced economies. Such an investment would have significant economic benefits: every dollar spent on publicly funded agricultural research yields roughly $20 in benefits.[283] USDA should allocate these funds to develop the tools, monitoring and measurement protocols, crops, and practices necessary to achieve carbon neutrality in agriculture. While significant, this is only a fraction of the roughly $20 billion estimated to be spent annually on crop insurance and other subsidies,[284] which, over time, could be reduced if the research points to practices that make farms more resilient to climate change.

Congress should also increase funding for the Sustainable Agriculture Research and Education (SARE) program, which provides funding for on-farm research and efforts to increase knowledge about sustainable agricultural practices among farmers and agricultural professionals.[285] Administered by NIFA, SARE is the only USDA competitive grants program that focuses exclusively on sustainable agriculture.[286] Its annual funding ranged from $19 to $27 million between 2013 and 2016.[287] Given SARE's important role in developing and disseminating sustainable practices—many of which are climate friendly—Congress should dramatically increase its annual budget, while also specifically appropriating funds for SARE to use to support the development of carbon farming.

While federally funded research will be critical for the development of carbon farming, states and foundations can also play an important role in stimulating research into adaptation and mitigation strategies. One mechanism is a nonprofit nongovernmental organization called the Foundation for Food and Agriculture Research (FFAR) established by the 2014 Farm Bill to support "agricultural research focused on addressing key problems of national and international significance," including, among other focus areas, "renewable resources, natural resources, and the environment."[288] Designed to spur public-private partnerships, Congress allocated FFAR $200 million to use as matching funds for nonfederal dollars.[289] Since its incorporation in 2014, FFAR has identified seven "challenge areas" on which to focus its efforts, including "healthy soils, thriving farms," which is likely to benefit mitiga-

Agricultural Research: Background and Issues (2016) (describing the role of publicly funded agricultural research in productivity gains).

275. Clancy et al., *supra* note 269.
276. *Id.*
277. *Id.*
278. *See id.*
279. Paul W. Heisey & Keith O. Fuglie, USDA ERS, Econ. Res. Report No. 249, Agricultural Research Investment and Polic Reform in High-Income Countries 14 tbl. 3.2 (2018).
280. Among the 31 advanced economies included in USDA's survey of public agricultural research expenditures between 2009 and 2013, only Greece and Luxembourg devoted a smaller share of their public research budgets to agriculture. *Id.* at 23 fig. 4.1.
281. Liz Carlisle & Albie Miles, *Closing the Knowledge Gap: How the USDA Could Tap the Potential of Biologically Diversified Farming Systems*, 4 J. Agric. Food Systems & Community Dev. 219, 221 (2013) (arguing that a lack of research has limited organic agriculture's development); *see also* Urs Niggli et al., Research Institute of Organic Agriculture, A Global Vision and Strategy for Organic Farming Research 19 (2016) (arguing that a lack of research has limited organic agriculture's development).
282. Calculated by the authors. *Compare* American Association for the Advancement of Science, Guide to the President's Budget: Research & Development FY 2017, at 10 tbl. 1 (2016) (listing USDA's research and development budget at $2.45 billion in fiscal year 2015), *with* USDA, FY 2017 Budget Summary 2 (2016) (giving USDA's total outlays in FY 2015 as $139 billion).
283. *See* Julian M. Alston et al., *The Economic Returns to U.S. Public Agricultural Research*, 93 Am. J. Agric. Econ. 1257, 1270 tbl. 6 (2011).
284. *See* USDA, Economic Research Service (ERS), *Projected Spending Under the 2014 Farm Bill*, https://www.ers.usda.gov/topics/farm-economy/farm-commodity-policy/projected-spending-under-the-2014-farm-bill.aspx (last updated Jan. 16, 2018).
285. 7 U.S.C. §§5801-5832.
286. National Sustainable Agriculture Coalition (NSAC), *Sustainable Agriculture Research and Education Program*, http://sustainableagriculture.net/publications/grassrootsguide/sustainable-organic-research/sustainable-agriculture-research-and-education-program/ (last updated Oct. 2016).
287. *Id.*
288. 7 U.S.C. §5939.
289. *Id.*

tion strategies due to the relationship between healthy soil and soil carbon sequestration.[290] FFAR announced its first healthy soils, thriving farms investment in March 2017, a $2.2 million grant that was matched with $4.4 million from a private foundation to create the National Crop Cover Initiative.[291]

Efforts to increase the private sector's involvement in public research should be evaluated carefully. Privately funded agricultural research is focused on technologies that are part of patentable products or services and neglects research objectives that are unlikely to be profitable for private industry, such as practices that conserve environmental resources.[292] As a result, despite being advertised as win-win propositions for farmers and the environment, public-private research partnerships too often fail both. Unlike the public—or farmers—large corporations are able to advance their own priorities by directly contributing funds to public-private research efforts or by providing funding for private foundations and nonprofits to do so. While FFAR shows promise, Congress should consider expanding its initial grant only after it has demonstrated its independence from industry interests.

State governments and land-grant institutions played a critical role in the growth of sustainable and organic agriculture before the federal government began providing consistent, if relatively meager, research funding in the 1990s.[293] The University of California, Iowa State University, the University of Maine, and others developed sustainable agriculture research and extension programs to help improve and spread sustainable practices. States are beginning to do the same for climate-friendly practices. Both Maryland and Hawaii, for example, passed legislation in 2017 providing support for research, education, and technical assistance focused on agricultural practices that build healthy soils and sequester carbon.[294] The California Department of Food and Agriculture also appropriated $7.5 million in FY 2016/2017 for the Healthy Soils Program, an incentive and demonstration program for farmers and ranchers designed to increase soil carbon sequestration and reduce agricultural greenhouse gas emissions.[295] Other state legislatures, agencies, and land-grant institutions should expand on these efforts, giving programs designed to spread climate-friendly practices sufficient funding to develop robust research, education, and technical assistance arms.[296]

The Leopold Center for Sustainable Agriculture at Iowa State University provides an attractive example for future state efforts. While the Iowa Legislature eliminated the center's funding in 2017, putting its future in doubt,[297] its enabling legislation provides a compelling funding model for states with more favorable political environments. Established by the 1987 Iowa Groundwater Protection Act to conduct research designed to reduce the environmental harms of agriculture and to help promulgate sustainable practices,[298] the center received approximately $1.5 million annually until 2017 from a fund consisting of revenue from a small fee on nitrogen fertilizer sales and pesticide registrations. The fee on nitrogen fertilizer sales was set at 75 cents per ton of anhydrous ammonia—less than 0.2% of the average price paid by individual farmers.[299] While the center's $2 million annual budget represented only a tiny portion of the amount spent nationally on agricultural research, it has an impressive record in fostering sustainable practices and has developed a national reputation for its groundbreaking research.

2. Extension Service

One of the most significant challenges facing carbon farming may be the difficulty inherent in learning, adopting, and disseminating new agricultural practices. Even if food processing is dominated by a few large corporations, farming operations themselves are generally run by relatively small, family-operated firms that lack the resources to experiment with new practices.[300] Even large-scale farm operations, whether family run or not, may be loath to try new practices since they have previously invested significant sums in infrastructure and equipment designed for conventional practices.[301] And unlike in other industries where reducing emissions often entails the adoption of widely applicable practices or technology, each farm operation must contend with a range of unique variables, such

290. FFAR, *Healthy Soils, Thriving Farms*, http://foundationfar.org/challenge/healthy-soils-thriving-farms/ (last visited Apr. 12, 2018).
291. FFAR, *National Cover Crop Initiative*, http://foundationfar.org/challenge/healthy-soils-thriving-farms/national-cover-crop-initiative/ (last visited Apr. 12, 2018).
292. Matthew Clancy et al., *U.S. Agricultural R&D in an Era of Falling Public Funding*, Amber Waves, Nov. 10, 2016, at https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-rd-in-an-era-of-falling-public-funding/.
293. Urs Niggli et al., *supra* note 281, at 55-56.
294. Md. Code Ann., Agric. §2-1901 (West 2017); 2017 Haw. Legis. Serv. 33 (West).
295. California Department of Food and Agriculture, *Healthy Soils Programs*, https://www.cdfa.ca.gov/oefi/healthysoils/ (last visited Apr. 12, 2018).
296. *An Act to Promote Healthy Soils: Hearing on H.3713 Before the Joint Comm. on Envt., Nat. Resources, &Agric.*, 2017 Leg., 190th Gen. Court (Mass. 2017) (statement of Peter Lehner, Director, Sustainable Food & Farming, Earthjustice) (identifying state legislative efforts to foster healthy soils).
297. Brianne Pfannenstiel & Jeff Charis-Carlson, *Branstad Defends Defunding of Leopold Center*, Des Moines Reg., May 15, 2017.
298. Iowa Code §266.39 (2017).
299. The retail price of anhydrous ammonia was $467 per ton in July 2017. Russ Quinn, *DTN Retail Fertilizer Trends: Anhydrous Breaks 8% Lower*, DTN/Progressive Farmer, July 7, 2017, https://www.dtnpf.com/agriculture/web/ag/news/article/2017/07/12/anhydrous-breaks-8-lower.
300. In 2012, 97% of the farms in the United States were family farms, accounting for 89% of its farmland. *See* National Agricultural Statistics Service, USDA, 2012 Census of Agriculture, Farm Typology 1 (2015).
301. Almost 60,000 family farms received more than $1 million in gross income in 2012; however, average production expenses for these large-scale farms exceeded $1 million as well. *See id.* at 1-2.

as soil and climate conditions. Finally, some measures, like reducing nitrogen fertilizer overapplication, may seem too risky given all the other uncertainties of farming.

State extension services have proven remarkably effective at disseminating and perpetuating new agricultural practices.[302] No-till farming has spread more deeply and more rapidly, for example, in states where extension services have advocated for its use.[303] Research also indicates that farmers are more receptive to learning new information and practices from extension programs than they are from other government bodies. An extensive survey of Corn Belt farmers found that 63% of the respondents believed that extension services should help farmers prepare for "increased weather variability"—despite the fact that only 41% of the surveyed farmers believed that climate change was caused by human activity.[304] In contrast, only 43% believed that state and federal agencies should help farmers to prepare for changing weather patterns.[305] While extension's importance has diminished over the past half century as agribusiness advisers and consultants have grown in number and influence,[306] extension services will be needed to foster carbon farming practices.

In 2016, NIFA received $426 million to administer the extension system and help fund state extension services.[307] This funding is more than matched by state and local support for extension services, which provide approximately 90% of public funding for the extension system.[308] NIFA currently does little to support climate mitigation through the extension system.

NIFA should immediately begin offering resources for carbon farming within the extension system, as it does for other issues, such as weed control and youth education. The system's national website, for instance, has 68 different "resource areas" for extension officials, researchers, and consumers, on issues ranging from feral hogs to science for youth.[309] While some address clean energy, virtually none of these resource areas focus on carbon farming.[310] NIFA should also work with states to ensure that all extension agents are knowledgeable about climate-friendly practices and fund specialists who focus primarily on climate mitigation practices in order to ensure an in-house constituency and expertise.

Just as the extension service played an important role in disseminating modern agricultural practices in the 20th century, Congress should either expressly expand the mandate of existing extension services or fund a new climate extension service. This extension capacity can build on the base of the existing (as of 2018) Climate Hubs, 10 regional centers established by USDA in 2014 to provide much-needed support for climate mitigation and adaptation efforts by translating climate research into tools, materials, and methods for extension and outreach.[311] All such efforts should emphasize that climate mitigation practices also increase soil health and farm resilience. Although funding for the extension service largely comes from state and local sources, federal funding for climate-related extension will be critical—particularly in states where policymakers deny anthropogenic climate change.[312] Any climate-focused extension program will also need to have a clear climate-focused mission and retain institutional independence to ensure that its efforts are not compromised by local political dynamics.

As with federal funding for agricultural research, funding for the extension system is historically low. The federal government spent approximately the same amount on the extension system in 2014 as it did in 1982 *without* accounting for inflation.[313] When the amount is adjusted for inflation, the extension service's budget was more than twice as high in 1982 as it was in 2014. Congress should at a minimum double the extension system's budget to $900 million, designating the additional funds for climate-related education, programming, and services. Distribution of these funds should favor states providing matching funds in order to reward states that invest in carbon farming and to help win local buy-in for the new extension program.

302. *See, e.g.*, Irwin Feller, *Technology Transfer, Public Policy, and the Cooperative Extension Service—OMB Imbroglio*, 6 J. Pol'y Analysis & Mgmt. 307, 307 (1987) ("The Cooperative Extension Service has come to represent the best of both an articulated but decentralized political arrangement and of a technology transfer system."); George McDowell, *Engaged Universities: Lessons From the Land Grant Universities and Extension*, 585 Annals Am. Acad. Pol. & Soc. Sci. 31, 35-36 (2003).

303. "We also struggle with the fact if a practice is not supported and sold by Oklahoma State University and Oklahoma State Extension, it's slow to be adopted." John Dobberstein, *No-Till Movement in U.S. Continues to Grow*, No-Till Farmer, Aug. 1, 2014, https://www.no-tillfarmer.com/articles/489-no-till-movement-in-us-continues-to-grow?v=preview.

304. J. Gordon Arbuckle Jr., *Corn Belt Farmers Are Concerned, Support Adaptation Action in the Ag Community*, *in* Resilient Agriculture 22 (Lynn Laws ed., Sustainable Corn Project 2014).

305. Additionally, only 52% believed that farmer organizations should help farmers to prepare. *Id*.

306. Linda Stalker Prokopy et al., *Extension's Role in Disseminating Information About Climate Change to Agricultural Stakeholders in the United States*, 130 Climatic Change 261, 268 (2015).

307. Consolidated Appropriations Act, 2016, Pub. L. No. 114-113, 129 Stat. 2250 (2015).

308. Marsha Mercer, *Cooperative Extension Reinvents Itself for the 21st Century*, PEW Charitable Tr., Sept. 9, 2014, http://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2014/09/09/cooperative-extension-reinvents-itself-for-the-21st-century.

309. eXtension, *Our Resource Areas*, http://articles.extension.org/main/communities (last visited Apr. 12, 2018).

310. *See id.*

311. *See* USDA, Climate Hubs, USDA Regional Hubs for Risk Adaptation and Mitigation to Climate Change 1.

312. Federal funding currently accounts for about 10% of extension's funding—a historical low. Mercer, *supra* note 308.

313. *See* National Research Council, Colleges of Agriculture at the Land Grant Universities: A Profile 68 (1995).

3. Coordinating Research, Development, and Extension

USDA is a massive bureaucracy, with 35 agencies and offices, many of which work at cross-purposes.[314] Yet in order to achieve carbon neutrality in agriculture, USDA should address emissions in a systematic fashion, organizing its research, development, and extension arms around common goals and priorities. USDA can build off the base of the existing Climate Hubs to translate new climate-related research into tools, materials, and methods for outreach and education, support applied research, and coordinate USDA's climate-related activities in each region.[315]

A year after establishing Climate Hubs, USDA released its "Building Blocks" plan to reduce or offset greenhouse gas emissions through agriculture and forestry by 120 million metric tons of carbon dioxide equivalent per year by 2025, which would have the same impact as taking 23 million passenger vehicles off the road.[316] Nonetheless, the plan has several weaknesses: its soil carbon sequestration goals are modest,[317] it favors practices preferred by agribusiness companies rather than those with demonstrated long-term climate benefits,[318] and it relies on voluntary incentives, which are often impermanent and ineffective in storing soil carbon.[319] Even if the planned emissions reductions materialized, the plan would not come close to achieving carbon neutrality in agriculture due to its overwhelming reliance on nonagricultural sectors, such as forestry and housing energy, for greenhouse gas reductions.[320] Nonetheless, as USDA's first long-term plan to reducing net agricultural emissions, it sets an important precedent. Congress should build on these efforts by funding Climate Hubs for each state and mandating more ambitious national sequestration targets.

B. *Public Subsidy and Conservation Programs*

The federal government supports farms through three main avenues: crop insurance, conservation payments, and commodity programs. Collectively referred to as the "farm safety net," these three categories of programs provide farming operations with about $20 billion per year (for the period 2014-2018), making up 96% of farm bill appropriations outside of the Supplemental Nutrition Assistance Program (SNAP) (formerly "food stamps").[321] Each of these categories is examined in turn below, with an emphasis on how existing programs can be adapted to help decarbonize agriculture. Ultimately, however, new legislation should be passed to optimize government support for carbon farming. This section therefore concludes with recommendations on how Congress could create a farm safety net that would more effectively meet the social and environmental needs of the nation.

When crafting new agricultural legislation, regulations, or programs, it is important to recognize that the ability of farming operations to integrate new practices and absorb additional transactional costs varies considerably. While many climate-friendly techniques are cost effective regardless of a farm's scale, some requirements may nonetheless disadvantage small and midsized operations. The Food Safety Modernization Act attempted to account for this by exempting certain farms with gross sales below $500,000 from its requirements.[322] New regulations and requirements could also be similarly tiered so that farmers with small and midsized operations, or those who receive only a small portion of their household income from farming, face minimal new costs or paperwork.[323] Additionally, USDA and the extension service should offer assistance and incentives to help small and midsized farms transition to climate-friendly practices.

1. Crop Insurance

Crop insurance is the largest farm program in the United States.[324] The 2014 Farm Bill eliminated most forms of direct payments to farmers, while expanding crop insurance.[325] Almost half of the estimated $20 billion flowing

314. USDA's support for agricultural commodities, for example, often undermines its dietary recommendations.
315. USDA, Climate Hubs, *supra* note 311.
316. *See* EPA, *Greenhouse Gas Equivalencies Calculator*, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (last updated Mar. 13, 2018).
317. The plan calls for only 4-18 MMT CO_2 eq. of soil carbon to be sequestered each year through climate-friendly agricultural practices by 2025. USDA, USDA Building Blocks for Climate Smart Agriculture and Forestry: Implementation Plan and Progress Report 4 (2016).
318. Building Blocks prioritizes the synthetic fertilizer industry's best management practices, conventional no-till agriculture, and manure management systems for AFOs. *See id.* The climate benefits of these practices are much lower than other feasible options available to farm managers.
319. As discussed *infra* Section III.B.3, any climate benefits derived from temporary voluntary programs such as the Conservation Reserve Program (CRP) are not permanent. Conserving sensitive lands through the CRP is one of the main elements of Building Blocks. *See id.* at 8.
320. Approximately 70% of the greenhouse gas reductions are in nonagricultural sectors. *See id.*
321. Letter From Douglas Elmendorf, Director, Congressional Budget Office, to Frank Lucas, Chairman of the House Committee on Agriculture (Jan. 28, 2014) (on file with Congressional Budget Office). Funding for these programs expires with the 2014 Farm Bill at the end of FY 2018.
322. *See, e.g.,* FDA Food Safety Modernization Act, Pub. L. No. 111-353, §418(l)(1)-(2), 124 Stat. 3885, 3892 (2011).
323. Farms with gross earnings above $500,000 often have multiple employees, relationships with consultants, advisers, and extension staff, and are more likely to be able to afford accountants, attorneys, and other professionals to respond to new regulations and optimize their earnings. They also produce the majority of agricultural products in the United States and receive a disproportionate share of farm subsidies.
324. Ralph Chite et al., Congressional Research Service, The 2014 Farm Bill (P.L. 113-79): Summary and Side-by-Side 4 (2014).
325. *Id.* at 6, 17.

to subsidies each year through farm safety net programs now goes to crop insurance.[326] Its expansion is likely due to the fact that it is highly profitable for large-scale operations, politically more palatable to the general public,[327] and compliant with international trade agreements. Proponents of the current crop insurance system often portray it as a safety net for farmers in the case of natural disaster.[328] But in addition to protecting farmers from crop losses—routine or not—its use of revenue guarantees also ensures that covered crops remain lucrative in the face of lower prices. Despite large increases in funding in recent years, crop insurance continues to primarily serve large-scale producers of commodity crops. According to the Congressional Research Service, more than 70% of the acres covered by crop insurance are devoted to one of four crops—corn, cotton, soybeans, and wheat.[329] The 2014 Farm Bill opened crop insurance up to a wider range of products, and the USDA agency in charge of crop insurance programs, the Risk Management Agency (RMA), has taken important steps to open up crop insurance to diversified and organic farms.[330] Nonetheless, many farms, particularly small and medium-scale operations, continue to find it impractical or unavailable.[331] In addition to bolstering large-scale operations, crop insurance has also motivated farmers to bring more land under cultivation, particularly wetlands and other marginal lands, leading to increased emissions.[332]

There are three steps USDA should take to make its crop insurance programs more climate friendly. First, the RMA should ensure that its crop insurance policies do not interfere with cover cropping or other proven decarbonizing practices or conversely encourage less beneficial practices. Farmers using innovative or sustainable methods often have difficulty receiving crop insurance, since the agency requires producers to use "good farming practices" that are "generally recognized by agricultural experts" in their immediate geographic area.[333] This effectively disallows farmers from using many innovative climate-friendly practices, such as alley cropping or integrated crop-livestock systems, with which agricultural experts in their area are unlikely to be familiar.[334] Crop insurance requirements may push farmers to plant at suboptimal times and do not encourage wider rotations. In a 2014 report on climate change and federal insurance programs, the Government Accountability Office (GAO) noted that the agency's good farming practices policies discourage climate adaptation and mitigation, while incentivizing practices that "increase vulnerability to climate change."[335]

In 2015, the RMA began allowing organic farmers to use opinions from organic agriculture experts outside of their immediate geographic area.[336] In part due to this change, the amount of organic acreage enrolled in crop insurance, while still small, increased by 34% during the first year of the new policy.[337] The RMA made this change as a result of the Agriculture Risk Protection Act of 2000, which provides that good farming practices include "scientifically sound sustainable and organic farming practices."[338] The RMA should likewise create a new standard for carbon farming—a scientifically sound sustainable farming system—that would allow farmers to use carbon farming experts outside of their immediate area, while encouraging agricultural experts to take climate change into account when assessing "good farming practices." Ideally, basic conservation practices would be required to meet the "good farming practices" threshold on the basis that, over the long run, they will improve the financial soundness of the insurance system.

326. *Id.* at 4.
327. *See* North Star Opinion Research, National Survey of Registered Voters Regarding Crop Insurance (2016) (showing that voters support government-subsidized crop insurance by a four-to-one margin when told that claims are paid "only in the event of bad weather or low prices").
328. *See*, *e.g.*, Iowa Secretary of Agriculture Bill Northey on crop insurance: "Farmers rely on crop insurance as an important safety net and protection from devastating losses from natural disasters." Memorandum From Bill Northey, Iowa Secretary of Agriculture, to Iowa Reporters and Editors (Oct. 28, 2015) (on file with authors).
329. Dennis Shields, Congressional Research Service, Federal Crop Insurance: Background 2 (2015).
330. *Have Access Improvements to the Federal Crop Insurance Program Gone Far Enough?*, NSAC, July 28, 2016, http://sustainableagriculture.net/blog/crop-insurance-access-data/.
331. *Id.*
332. Daniel Sumner & Carl Zulauf, Council on Food, Agricultural & Resource Economics, Economic & Environmental Effects of Agricultural Insurance Programs 10-12 (2012).
333. *See* Chad G. Marzen & J. Grant Ballard, *Climate Change and Federal Crop Insurance*, 43 Envtl. Aff. 387, 398 (2016).
334. The most recent version of the RMA's *Good Farming Practices Handbook*, released in December 2015, included some important changes. For the first time, the RMA states that practices promoted by USDA's NRCS will generally be recognized by agricultural experts as "good farming practices." RMA, USDA, Good Farming Practice Determination Standards Handbook 33 (2016) [hereinafter Good Farming Practice Determination Standards Handbook]. This could make it much easier for farmers with crop insurance to adopt climate-friendly NRCS practices, since they are often deterred from doing so by the good farming practices requirement. However, the handbook considerably weakens the new provision by giving insurance companies the power to prohibit certain practices through the terms and conditions of their policies, and by indicating that both the RMA and insurance companies may prohibit practices that do not maximize yields. *Unified Support for Conservation as Good Farming Practice Needed at USDA*, NSAC, Dec. 16, 2016, http://sustainableagriculture.net/blog/gfp-updated-at-rma.
335. GAO, Climate Change: Better Management of Exposure to Potential Future Losses Is Needed for Federal Flood and Crop Insurance 24 (2014) (GAO-15-28).
336. 7 C.F.R. §457.8 (2015); Good Farming Practice Determination Standards Handbook, *supra* note 334, at 32.
337. Calculated by the authors using USDA data. *Compare* RMA, USDA, Federal Crop Insurance Summary of Business for Organic Production 2 (2015) (showing 777,966 organic acres enrolled in federal crop insurance in 2014), *with* RMA, USDA, Federal Crop Insurance Summary of Business for Organic Production 2 (2016) (showing 1,043,403 organic acres enrolled in federal crop insurance in 2015).
338. 7 U.S.C. §1508(a)(3)(iii).

Current RMA guidelines also hinder beneficiaries from using cover crops.[339] As a result, some farmers using cover cropping are unable to benefit from crop insurance, while others forgo cover cropping in order to receive crop insurance. While the agency has made it easier to adopt practices promoted by NRCS,[340] including cover cropping,[341] it needs to further revise its guidelines to not only eliminate remaining barriers to cover cropping but actually to encourage it as a risk-mitigating technique. The RMA should also conduct outreach encouraging the practice in order to dispel the widespread fear that it interferes with crop insurance coverage.

Second, publicly funded crop insurance policies should treat carbon-intensive practices as risk enhancing and reduce or eliminate their premium subsidies accordingly.[342] In fact, the Federal Crop Insurance Corporation (FCIC) may be compelled to consider the climate impact of practices when establishing policies and premiums. Congress requires the FCIC to adopt rates and policies "that will improve the actuarial soundness" of its insurance operations.[343] Encouraging practices that both reduce climate change and make farms more resilient to it will clearly make the program more actuarially sound. A 2014 GAO report on federal flood and crop insurance and climate change noted that crop insurance losses are expected to increase considerably by 2040 absent significant climate change mitigation.[344] FCIC regulations also require it to seek the RMA's assessment as to whether insurance policies and premiums are "consistent with USDA's policy goals" when reviewing them.[345] If the plan or premium under review is not consistent with USDA's policy goals, then the FCIC may reject it.[346] Climate change mitigation is an express policy goal of USDA and the FCIC should ensure publicly funded crop insurance programs are furthering that goal.[347]

Third, as discussed below in Section III.B.5, current conservation compliance requirements should be expanded to require key conservation practices for all operations receiving crop insurance.

2. Commodity Programs

The commodities title of the 2014 Farm Bill replaced direct payments to farmers with two new programs: Agricultural Risk Coverage (ARC) and Price Loss Coverage (PLC).[348] Commodity programs now constitute the smallest portion of the farm safety net, but they still distribute more than $4 billion each year—about 22% of average annual farm safety net expenditures under the 2014 Farm Bill.[349] These programs supplement crop insurance for specified commodities, such as wheat, corn, sorghum, and rice, by enhancing price or revenue protection for producers.[350] Unlike crop insurance, ARC and PLC payments are generally made according to historical plantings, or "base acres," rather than planted acres.[351] This gives producers greater flexibility in their planting decisions since they can try new crops or use crop rotations while still receiving payments based on historic crop allocations. While PLC payments are triggered when a season average market price for a crop is below that crop's reference price (set by Congress), ARC compensates farmers when per-acre market revenue falls below the ARC's per-acre revenue guarantee.

In order to receive ARC or PLC payments, farm owners must agree to not grow crops on highly erodible land without a conservation plan or on unconverted wetlands under any circumstances due to statutory conservation compliance requirements discussed below in Section III.B.5. Under §9018 of the agriculture title, farmers must also control noxious weeds and "otherwise maintain the land in accordance with sound agricultural practices," which are determined at the discretion of the secretary of agriculture.[352] Congress gave USDA significant leeway in enforcing this section, authorizing it to issue rules "the Secretary considers necessary to ensure producer compliance" with these requirements.[353] While there is no case law directly on point,[354] §9018 appears to give USDA the authority to require farmers to implement mitigation strategies in order to receive commodity payments. This argument is strengthened by the law's explicit requirement

339. *See, e.g.*, Todd Neeley, *Grassley Asks Vilsack to Fix Crop Insurance, Cover Crops Glitches*, DTN/Progressive Farmer: Ag Pol'y Blog, June 28, 2016; a 2015 survey found that the most commonly cited reason among farmers for not adopting cover cropping was the concern that doing so would interfere with crop insurance. John Dobberstein, *Crop Insurance Rules Still Hinder Cover Crop Adoption*, No-Till Farmer, Oct. 14, 2015.
340. *See supra* note 334.
341. USDA also established an interagency working group with NRCS, the RMA, and the Farm Security Administration to "develop consistent, simple, and flexible policy" on cover crop practices, making it easier for operators to plant cover crops in accordance with federal rules. *See* RMA, USDA, NRCS Cover Crop Termination Guidelines 1 (2014).
342. *See* Claire O'Connor, Natural Resources Defense Council, Soil Matters: How the Federal Crop Insurance Program Should Be Reformed to Encourage Low-Risk Farming Methods With High-Reward Environmental Outcomes 10 (2013).
343. 7 U.S.C. §1508(i)(1).
344. GAO, *supra* note 335, at 14.
345. 7 C.F.R. §400.706(b)(4) (2016).
346. *Id.* §400.706(h)(5) (2016).
347. The agency's comprehensive expression of its policy goals, its 2014-2018 Strategic Plan, lists as a strategic goal: "Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources." It also states the agency's objective to "lead efforts to mitigate and adapt to climate change." USDA, Strategic Plan: FY 2014-2018, at 3, 15 (2014).
348. *See generally* Agricultural Act of 2014, Pub. L. No. 113-79, 128 Stat. 649.
349. Chite et al., *supra* note 324, at 4.
350. *Id.* at 6.
351. *Id.* at 7.
352. 7 U.S.C. §9018(a)(1).
353. *Id.* §9018(a)(2). The agency has not yet used this authority.
354. Romany Webb & Steven Weissman, University of California, Berkeley, School of Law, Addressing Climate Change Without Legislation, Volume 3: USDA 43 (2014).

that recipients of commodity payments must not degrade highly erodible land or wetlands, indicating that Congress intended to tie environmental protections to ARC and PLC. To help address the threat climate change poses to agricultural land, USDA should use its rulemaking authority to require farmers receiving commodity payments to adopt cost-effective climate-friendly practices. These requirements could be instituted slowly, ensuring that farmers have time to adapt.

3. Conservation Payments

This section examines USDA's three largest conservation programs, recommending both executive and legislative actions that would ensure they more effectively address climate change. The 2014 Farm Bill allocated approximately $5.8 billion annually to conservation programs, primarily the Conservation Reserve Program (CRP), the Environmental Quality Incentives Program (EQIP), and the Conservation Stewardship Program (CSP).[355]

a. CRP

Under the 2014 Farm Bill, 37% of conservation spending went to the CRP, which pays farmers to take environmentally sensitive land out of agricultural production for 10-15 years. Approximately 24 million acres were enrolled in the program in 2016.[356] USDA estimated that the CRP sequestered more than 43 million metric tons of carbon dioxide equivalent in 2014, about 7% of agriculture's greenhouse gas emissions.[357] If accurate, this would translate into about 1.8 metric tons of carbon dioxide sequestered per acre.[358]

The CRP's advertised climate benefits are often temporary, however. After their CRP contract has expired, many producers bring their CRP acres back into production, quickly releasing any carbon stored during the term of the contract.[359] Between 2006 and 2014, for example, an estimated 14 million acres previously protected by the CRP were returned to agricultural production.[360]

While the CRP is popular, funding for it was reduced in the 2014 Farm Bill. Congress should both restore some of the reduced funding and reform the program to provide sustained climate benefits by offering farmers 30-year agreements or permanent easements to protect environmentally sensitive land.[361] There have been proposals to expand certain productive activities on CRP land in order to increase interest in the program[362]; Congress should consider this only for activities with proven climate benefits.

Congress should also increase funding for the Conservation Reserve Enhancement Program (CREP), which gives farmers higher payments for participating in targeted conservation efforts organized by state and local officials.[363] Due to its higher annual payments, which are on average almost three times as high as general CRP payments,[364] the CREP has remained popular with farmers even when increasing commodity prices have reduced acreage reenrollment in the CRP overall.[365]

b. EQIP

Receiving about 29% of conservation spending, the EQIP provides farmers with funding and technical assistance for conservation practices. The EQIP is managed by the USDA Natural Resources Conservation Service (NRCS), which was established by Congress in 1936 to reduce "the wastage of soil and moisture resources on farm, grazing, and forest lands."[366] Congress has authorized NRCS to pay producers up to 75% of the costs associated with the development and implementation of a new conservation practice and/or 100% of the income foregone by the producer as a result of a new practice.[367] Producers cannot receive funding for a preexisting practice through the EQIP, regardless of how environmentally beneficial it may be. Under the 2014 Farm Bill, NRCS is required by statute to allocate at least 60% of its EQIP payments to livestock produc-

355. USDA, ERS, *Conservation Programs—Background*, https://www.ers.usda.gov/topics/natural-resources-environment/conservation-programs/background.aspx (last updated Oct. 17, 2016).
356. Press Release USDA, USDA Announces Conservation Reserve Program Results (May 5, 2016).
357. USDA, Farm Service Agency Strategic Plan: Fiscal Year 2016-2018 Update 25, 28.
358. In contrast, a 2009 literature review of carbon sequestration rates on CRP acres estimated that they sequester slightly less than one metric ton CO_2 eq. per acre annually. Gervasio Piñeiro et al., *Set-Asides Can Be Better Climate Investment Than Corn Ethanol*, 19 Ecological Applications 277, 279 (2009).
359. Soren Rundquist & Craig Cox, Environmental Working Group, Fooling Ourselves: Executive Summary (2016) (finding that CRP water quality benefits were counteracted by losses from farmers exiting the program); Tyler Lark et al., *Cropland Expansion Outpaces Agricultural and Biofuel Policies in the United States*, 10 Envtl. Res. Letters 9 (2015) (finding that up to 42% of all land converted to cropland came from land exiting the CRP). Wetland acreage protected by the CRP still have climate benefits, however, since their annual methane emissions while in the program are not lost if the land is converted back into production.
360. Craig Cox et al., Environmental Working Group, Paradise Lost: Conservation Programs Falter as Agricultural Economy Booms 4 (2013).
361. *See id.* at 4-5; *USDA Freezes New Enrollments in Continuous Conservation Reserve Program*, NSAC, May 4, 2017, http://sustainableagriculture.net/blog/usda-freezes-ccrp-enrollment/.
362. *See, e.g.*, Press Release, Senator John Thune, Thune Farm Bill Proposals Would Improve Conservation Program Management (Apr. 10, 2017) (on file with authors).
363. *See Digging Deeper Into Continuous CRP Enrollments*, NSAC, Mar. 24, 2015, http://sustainableagriculture.net/blog/ccrp-enrollment-2015/; Cox et al., *supra* note 360.
364. States provide additional funding for the CREP, bringing the average yearly CREP payments to $140 per acre. In contrast, general sign-up payments are $51 per acre. *Digging Deeper Into Continuous CRP Enrollments*, *supra* note 363.
365. Cox et al., *supra* note 360.
366. 16 U.S.C. §590a. The agency was originally called the Soil Conservation Service, but was renamed in 1994.
367. *Id.* §3839aa-2(d)(2).

ers; Congress should consider reducing this percentage to advantage less carbon-intensive products.[368]

Funding decisions are made through a process that combines national, state, and local priorities. National priorities are determined by NRCS in accordance with the program's statutory guidelines, which require the agency to finance practices that promote one or more of the following:

- Soil health
- Water quality and quantity improvement
- Nutrient management
- Pest management
- Air quality improvement
- Wildlife habitat development
- Invasive species management[369]

State priorities are set by the head NRCS administrator of each state in consultation with stakeholders, while local priorities are set by "local working groups," composed of stakeholders such as producers and industry representatives. Since farmers using sustainable management methods are generally in the minority in any given region, they are unlikely to be given equal representation—or even any representation—in local working groups or statewide stakeholder committees. As a result, the process can disadvantage applications for truly innovative and sustainable practices.[370] According to an analysis of USDA data conducted by the Environmental Working Group, only 14% of EQIP funding went to conservation practices that USDA has identified as producing the most environmental benefits for water quality, water quantity, soil health, air quality, and fish and wildlife.[371] Congress or NRCS should address this disparity by requiring greater representation of sustainable farming approaches on working groups and allocating more funds—or a larger cost-share percentage—to practices demonstrated to have the greatest benefits.[372]

Environmentalists and small-scale farming advocates have also criticized NRCS for subsidizing large-scale, environmentally harmful operations through the EQIP.[373] Since its inception in 1997, more than $1.6 billion has gone to support irrigation systems through the EQIP, making it the most well-funded set of practices financed by the program.[374] Instead of conserving water, however, support for efficient irrigation systems often leads to land conversion and increased water usage as farmers use their savings to expand irrigated crop production, switch to more water-intensive crops, or both.[375] NRCS should prioritize making existing irrigation systems more efficient.

Similarly, waste storage facilities for concentrated animal facilities received a larger share of payments than any other single practice supported by the program; a survey of EQIP funding from 1997 to 2007 showed that these accounted for almost 15% of all EQIP payments.[376] NRCS' support for large-scale AFOs has continued since then: in FY 2015, about 12% of total EQIP funding—more than $100 million—went to such facilities.[377] While some waste management systems, such as anaerobic digesters, can be highly effective at reducing feedlot emissions, sustainable agriculture and environmental justice groups have been highly critical of government efforts to finance them. Even if digesters reduce feedlot emissions, they argue, CAFOs are still bad for the environment, animal welfare, and rural communities. As noted above, pasture-based systems, in contrast, lead to aerobic decomposition and much lower rates of methane production. The National Sustainable Agriculture Coalition, for example, has come out against USDA's policy of supporting new or expanding CAFOs through the EQIP, arguing that USDA is subsidizing fundamentally unsustainable practices by doing so.[378] This funding effectively subsidizes a carbon-intensive form of animal production and may be a factor in the continuing consolidation of the industry noted earlier.

368. *Id.* §3839aa-2(f)(1).
369. *Id.* §3839aa-2(d)(3).
370. For example, a 2008 report on the EQIP in Iowa, Minnesota, and Missouri found that state-level priorities favored the worst polluting operations and disadvantaged applications from producers using sustainable management methods, such as crop rotation. Elanor Starmer, Campaign for Family Farms and the Environment, Industrial Livestock at the Taxpayer Trough: How Large Hog and Dairy Operations Are Subsidized by the Environmental Quality Incentives Program 14 (2008).
371. Environmental Working Group, The EQIP Improvement Act (2018).
372. The EQIP Improvement Act, introduced in 2018, would prioritize funding at the state and county level for the most effective conservation practices, while also reducing the maximum cost-sharing from 75 to 40% for less beneficial practices. EQIP Improvement Act, S. 2624, 115th Cong. (2018).
373. Andrew Martin, *In the Farm Bill, a Creature From the Black Lagoon?*, N.Y. Times, Jan. 13, 2008 (suggesting that the program's name should be changed to the "Factory Farm Incentive Program"), http://www.nytimes.com/2008/01/13/business/13feed.html; Tom Laskaway, *Stop the Environmental Subsidy for Factory Farms*, Grist, Apr. 17, 2009, http://grist.org/article/stop-the-environmental-subsidy-for-factory-farms/; National Sustainable Agriculture Coalition, *CAFOs and Cover Crops: A Closer Look at 2015 EQIP Dollars*, Nov. 20, 2015, http://sustainableagriculture.net/blog/fy15-general-eqip-update/.
374. Environmental Working Group, *Environmental Quality Incentives Program (EQIP) Practice Suite Payments in the United States, 1997-2015*, https://conservation.ewg.org/eqip_practice_suite.php?fips=00000&regionname=theUnitedStates.
375. Frank Ward & Manuel Pulido-Velazquez, *Water Conservation in Irrigation Can Increase Water Use*, 105 Proc. Nat'l Acad. Sci. U.S. Am. 18215 (2008); Lisa Pfeiffer & C.-Y. Cynthia Lin, *Does Efficient Irrigation Technology Lead to Reduced Groundwater Extraction? Empirical Evidence*, 67 J. Envtl. Econ. Mgmt. 189 (2014).
376. Melissa Bailey & Kathleen Merrigan, *Rating Sustainability: An Opinion Survey of National Conservation Practices Funded Through the Environmental Quality Incentives Program*, 65 J. Soil & Water Conservation 21A, 23A (2010).
377. National Sustainable Agriculture Coalition, *supra* note 373.
378. *Id.*

With capital costs often exceeding $1 million, anaerobic digesters are also beyond the price range of most dairy farmers in the United States. According to EPA, digestion systems are generally not economically viable for operations with fewer than 500 cows, even with current cost-sharing programs.[379] This significantly limits their use—more than 90% of dairy farms in the United States have fewer than 500 cows, accounting for 40% of all dairy cows in the country.[380] Of these, many do not use liquid manure systems. However, the largest 10% of dairies—which account for 60% of the dairy cow population—could more feasibly be required to install digesters. Rather than subsidize concentrated animal facilities with EQIP funds, USDA or EPA should consider imposing regulatory methane emissions limits, which could drive most large-scale operations to install digesters. (Biodigesters that accept both manure and other biological waste can be profitable energy sources, so creative and flexible approaches might prove politically feasible.) A team at the University of Maryland is currently working to develop low-cost digesters similar to those available in tropical climates in order to make anaerobic digesters feasible for small-scale dairies. Although their model is not market ready, their initial design was promising, costing only $16,800, while reaching methane reduction levels similar to those achieved through more expensive systems.[381]

Congress and USDA should redirect EQIP funds, to the extent possible, to support farms and ranches working to significantly reduce emissions or sequester carbon. While Congress should eliminate payments to environmentally harmful operations through legislative action, the agency can—and should—eliminate or reduce these payments before Congress acts. Several rural, environmental, and family farming organizations have called for the EQIP's payment cap to be lowered or to disallow payments to large-scale AFOs.[382] Congress initially set the payment cap at $50,000, but then raised it nine-fold in the 2002 Farm Bill to $450,000.[383] The cap was lowered to $300,000 in the 2008 Farm Bill after Barack Obama promised to reduce it in his presidential campaign,[384] but it was ultimately raised back to $450,000 in the 2014 Farm Bill.[385] Congress should lower the cap for all operations, or at a minimum, create a lower cap for AFOs.[386]

The agency itself has the ability to redirect funding to more climate-friendly practices. NRCS has significant leeway in determining which practices are prioritized and can set aside considerable funding for carbon farming practices.[387] The agency's Organic Initiative provides an instructive example for how this might be accomplished. In the early 2000s, many organic producers were concerned that the program's reliance on local administrators and the high demand for EQIP funding from conventional producers disadvantaged applicants seeking funding for organic practices. In response, Congress in the 2008 Farm Bill required the agency to set aside EQIP funds specifically to assist organic producers or producers transitioning to organic production.[388] Producers applying for funds from the Organic Initiative are eligible for up to $20,000 per year and $80,000 over six years. Farmers can still apply to the general funding pool for larger amounts, but the Organic Initiative ensures that a pool of money is set aside for organic practices each year.

Given NRCS' broad authority to determine which practices to support, the agency should create a similar pool to support carbon farming. While there is no carbon farming certification system equivalent to organic certification, the EQIP covers a number of practices that are long-lasting and sequester significant amounts of carbon, such as alley cropping, treed buffer strips, and silvopasture, and the agency should establish simple guidelines for determining whether an applicant is transitioning to, or practicing, carbon farming. In FY 2015, the EQIP paid out $861 million in financial assistance. The majority of EQIP funds should ultimately be used to support carbon farming, but even 10% of the total amount, $86 million, would significantly boost powerful sequestration methods, while advancing the EQIP's statutory priorities.

c. CSP

NRCS also administers the CSP, which pays farmers to improve, maintain, or adopt conservation practices on their farms. Farmers are paid annually under a five-year contract with the option to renew for an additional five years if they agree to adopt additional conservation objectives.[389] The agency revised the CSP in fall 2016 by,

379. EPA, *AgSTAR—Is Anaerobic Digestion Right for Your Farm?*, https://www.epa.gov/agstar/anaerobic-digestion-right-your-farm (last updated June 8, 2017).
380. 2012 Census of Agriculture, U.S. National Level Data, *supra* note 43, at 21 tbl. 17.
381. Stephanie Lansing et al., *Design and Validation of Field-scale Anaerobic Digesters Treating Dairy Manure for Small Farms*, 58 Transactions ASABE 441 (2015).
382. In 2007, for example, a coalition of 26 organizations called on Congress to prohibit funding for AFOs with more than 1,000 animals. Letter From the Campaign for Family Farms and the Environment et al., to the Senate (May 8, 2007).
383. Farm Security and Rural Investment Act of 2002, Pub. L. No. 107-171, §1240G, 116 Stat. 134, 257.
384. Food, Conservation, and Energy Act of 2008, Pub. L. No. 110-234, §2508, 122 Stat. 923, 1063; *see also* Obama/Biden Campaign, Real Leadership for Rural America 2.
385. Agricultural Act of 2014, Pub. L. No. 113-79, §2206, 128 Stat. 649, 730 (amending §1240G).
386. The EQIP Improvement Act would lower the payment cap to $150,000. EQIP Improvement Act, *supra* note 372.
387. Each of the program's statutorily mandated objectives can be promoted through carbon sequestration and carbon farming.
388. 16 U.S.C. §3839aa-2(i).
389. 7 C.F.R. §1470.26 (2016).

among other things, offering farmers 67 new practices that are eligible for funding through the program, including "planting for high carbon sequestration rate."[390] Like the EQIP, the CSP has the statutory authority to prioritize low-carbon practices and to create a funding pool for farmers transitioning to, or practicing, carbon farming.[391] NRCS should follow up on its revisions by doing both as quickly as possible. Congress should also expand funding for the CSP in upcoming farm bills by raising the average payment rate per acre that is authorized for the program to ensure higher-level conservation activities can be appropriately rewarded. In particular, climate-beneficial activities like resource-conserving crop rotations should be prioritized and receive a higher, supplemental payment to reflect the high-level environmental benefits of those practices.

4. Conservation Easements

Conservation easements are legal agreements between a landowner and a third party—usually a land trust or a government agency—that are designed to permanently restrict the use of the land. The restrictions commonly protect natural areas or resources, such as wildlife habitats or water quality, but they are also increasingly being used to preserve farmland and prevent it from being converted to non-farm uses. As of 2012, farmland owners had protected more than 13 million acres from development through conservation easements.[392] Agricultural easements, which protect agricultural land from development, can also have important climate benefits since even conventional farms generally have much lower emissions than developed land. An analysis of emissions in California's Central Valley, for example, found that emission rates on urbanized land were 70 times higher than emissions on an equivalent area of irrigated cropland.[393]

Conservation easements that protect wetlands and other environmentally sensitive land from being converted to farmland offer substantial climate benefits. The Environmental Working Group, for instance, estimates that the conversion of wetlands to farmland between 2008 and 2012 resulted in greenhouse gas emissions totaling 25-74 million metric tons of carbon dioxide equivalent annually[394]—the equivalent of adding five to 15 million cars to the road each year.[395] Others have studied the conversion of native grasslands to farmland, in large part to supply corn to ethanol plants, and similarly found significant soil carbon losses.[396] Expansion of programs to prevent such conversion can have substantial benefits and should be undertaken.

USDA has supported conservation easements on property owned by farm operators since 1990, preserving more than four million acres of farmland and environmentally sensitive lands in the process.[397] The 2014 Farm Bill consolidated USDA's three existing easement programs into the Agricultural Conservation Easement Program (ACEP).[398] Administered by NRCS, the program is designed to protect wetlands, grasslands, and productive farmland and has been fairly successful; it should be expanded.[399]

For permanent wetland easements, NRCS pays farm owners the lowest of the fair market value of the land or an offer made by the farm owner.[400] NRCS can also set geographical caps limiting payments within specific regions.[401] Alternatively, farm owners can apply for "long-term" wetland easements, which typically run for 30 years, and provide 50%-75% of the compensation due to an equivalent permanent easement.[402] For agricultural land easements, which protect working agricultural land, NRCS generally pays farm owners up to 50% of the fair market value of the easement, although NRCS may contribute up to 75% of the fair market value of an easement protecting grasslands of "special environmental significance."[403]

The ACEP receives substantially less funding than its predecessor programs. While the 2008 Farm Bill provided $691 million for easement programs each year from 2009-2013, the 2014 Farm Bill allocates about $368 million annually to the ACEP—slightly more than half of the amount its precursors enjoyed.[404] The ACEP also receives significantly less funding than the CRP, which the Congressional Budget Office projects will cost an average of $1.8 billion annually during the years addressed by the 2014 Farm Bill.[405] Unlike most ACEP easements, the CRP

390. News Release, USDA NRCS, USDA Announces Changes for Largest Conservation Program (Sept. 1, 2016); Marc Heller, *Revamps to Conservation Program Boost Options for Farmers*, Greenwire, Sept. 2, 2016.
391. 16 U.S.C. §3838g.
392. 2012 Census of Agriculture, U.S. National Level Data, *supra* note 43, at 50 tbl. 50.
393. California Energy Commission Climate Change Center, University of California, Davis, Adaptation Strategies for Agricultural Sustainability in Yolo County, California 106 (2012).
394. Emily Cassidy, Environmental Working Group, Ethanol's Broken Promise: Using Less Corn Ethanol Reduces Greenhouse Gas Emissions 4 (Nils Bruzelius ed., 2014).
395. Calculated by the authors using EPA estimates for passenger vehicle emissions. *See* EPA, *supra* note 316.
396. Lark et al., *supra* note 359, at 5.
397. NSAC, *Agricultural Conservation Easement Program*, http://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/agricultural-conservation-easement-program/ (last updated Oct. 2016).
398. 16 U.S.C. §3865.
399. *Id.* §3865(b).
400. *Id.* §3865c(b)(6)(a)(i).
401. *Id.*
402. *Id.* §3865c(b)(6)(a)(ii).
403. *Id.* §3865b(2).
404. 7 C.F.R. §1468 (2016); *see also* Bradley Lubben & James Pease, *Conservation and the Agricultural Act of 2014*, Choices, 2d Quarter 2014, at 1.
405. Calculated by the authors using Congressional Budget Office data and estimates. Congressional Budget Office, CBO's March 2015 Baseline for Farm Programs 26 (2015); Congressional Budget Office, CBO's March 2016 Baseline for Farm Programs 26 (2016).

protects environmentally sensitive land for a limited period, and therefore does not offer lasting climate benefits.

Congress should substantially expand the ACEP and ensure that protecting environmentally sensitive lands that provide the greatest climate benefits is among the program's priorities. Wetlands, for example, are estimated to emit between 405 and 1,215 metric tons of carbon dioxide equivalent per acre when converted to agricultural land.[406] Similarly, it should eliminate the ACEP's long-term easement option since its long-term climate benefits are dubious. The program should also be expanded to allow for easements on additional types of environmentally sensitive land, allowing USDA to protect terrestrial carbon pools in a wider variety of ecosystems.[407]

5. Conservation Compliance Requirements

Producers enrolled in a number of federal farm programs are prohibited from producing agricultural products on highly erodible land without a conservation plan[408] or on unconverted wetlands under any circumstances.[409] These requirements apply to the crop insurance program, each of the conservation programs, as well as many of the smaller programs administered by the Farm Service Agency and NRCS. They offer potentially important climate benefits since conventional farming on highly erodible land and wetlands results in significant greenhouse gas emissions.[410] Despite their clear environmental benefits, however, the agency has failed to consistently enforce these conservation requirements.[411] A 2016 USDA Office of Inspector General report, for example, found that the agency's auditing process had completely bypassed at least 10 states in 2015, apparently in error.[412]

At a minimum, USDA should vigorously enforce the farm bill's current conservation compliance provisions, withholding benefits from farmers that fail to meet their requirements.[413] Since compliance is often relatively easy to determine visually, including by satellite, USDA should be able to increase inspections at little additional cost. If USDA fails to do so, Congress should shift enforcement responsibility to EPA, while also enabling states, localities, and citizens to enforce the requirements, as is possible under most federal environmental statutes.[414]

Congress should also extend the conservation compliance requirement to farm programs that are not currently covered by the requirement, ensuring that all producers who receive federal subsidies are not causing significant environmental harm. In addition, Congress should expand the required practices to include those that protect soil carbon and water. For example, requiring buffer zones around streams or, where appropriate, cover crops (perhaps with the initial switch partially funded through the EQIP), would have significant climate benefits and co-benefits such as improved soil health, nutrient cycling, pest regulation, and crop productivity.[415] Requiring farm operations to adhere to basic climate-friendly practices in order to receive government benefits would be a cost-effective, quick, and fair way to catalyze widespread change.

6. Renewable Fuel Standard Grassland Conservation Compliance

In the United States in 2017, close to 30 million acres of corn were grown as feedstock for ethanol.[416] As noted in Section II.C.2, the purported climate change benefits of corn ethanol are widely disputed and modest at best. Ideally, Congress should reform the Renewable Fuel Standard (RFS) to support only those biofuels with significant climate benefits. (See Chapter 27, Production and Delivery of Biofuels.) Short of congressional reform of the RFS program, however, EPA should revise its "aggregate compliance" mechanism that is meant to ensure that nonagricultural land is not converted to growing corn as ethanol feedstock.

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406. Richard Plevin et al., *Greenhouse Gas Emissions From Biofuels' Indirect Land Use Change Are Uncertain but May Be Much Greater Than Previously Estimated*, 44 Envtl. Sci. & Tech. 8018 (2010). The Environmental Working Group estimated that 25 to 74 MMT CO_2 eq. were emitted each year between 2008 and 2012 due to the conversion of wetlands to farmland. Cassidy, *supra* note 394.

407. *See* Todd Neeley, *Conservation Controversy*, DTN/Progressive Farmer, Oct. 15, 2016, http://dtnpf-digital.com/article/Conservation_Controversy/1888630/239474/article.html.

408. 16 U.S.C. §§3811-3812.

409. *Id.* §3821. Wetlands drained or filled before December 23, 1985, are not protected. *Id.* §3822(b)(1)(A).

410. As mentioned above, wetlands are estimated to emit between 405 and 1,215 metric tons of CO_2 eq. per acre when converted to agricultural land. Plevin et al., *supra* note 406.

411. Laurie Ristino & Gabriela Steier, *Losing Ground: A Clarion Call for Food System Reform to Ensure a Food Secure Future*, 42 Colum. J. Envtl. L. 59, 96-102 (2016).

412. USDA Office of Inspector General, USDA Monitoring of Highly Erodible Land and Wetland Conservation Violations—Interim Report 3 (2016) (Audit Rep. 50601-0005-31); *see* Ristino & Steier, *supra* note 411, at 97.

413. In addition to failing to hold operators accountable, the agency has also failed to sufficiently monitor operators subject to the requirement. It must do both. *See* Joshua Ulan Galperin, *Trust Me I'm a Pragmatist: A Partially Pragmatic Critique of Pragmatic Activism*, 42 Colum. J. Envtl. L. 426, 487-89 (2017).

414. Most federal environmental statutes empower citizens to enforce compliance through citizen suit provisions, which have proven to be among the most effective methods available for holding regulatory subjects and government agencies accountable. *Id.* at 487.

415. Shipanski et al., *supra* note 102.

416. This figure was estimated for marketing year 2015/2016 as the proportion of 88 million acres planted to corn equal to the proportion of corn production used for ethanol for fuel. In that year, 43% of the corn supply was used for ethanol for fuel, and 88% of the corn supply was produced in the same year (88 million x 0.43 x 0.88 = 33 million). All data were obtained from USDA, ERS, *Feed Grains: Yearbook Tables*, https://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-yearbook-tables (last updated Mar. 13, 2018).

Conversion of native ecosystems for cultivation releases vast amounts of carbon dioxide. A 2008 study found that converting forest, grassland, or peatland for biofuel production can release 17-420 times more carbon dioxide than the annual greenhouse gas reductions these biofuels would provide by replacing fossil fuels.[417] To prevent this conversion of natural ecosystems, Congress in 2007 revised the 2005 RFS to exclude crops "harvested from land cleared or cultivated" after December 19, 2007, from its definition of "renewable biomass."[418]

EPA regulations implementing this provision, however, have rendered it meaningless. Though EPA's proposed rule required crop producers to comply with recordkeeping requirements to verify that feedstocks met Congress' definition, the Agency then worked with USDA to write a final rule that differed significantly from that proposal. In the final rule, the Agency adopted an "aggregate compliance" approach that instead deems all producers compliant with the standard as long as the net land area used for agriculture in the United States does not exceed its 2007 level of 402 million acres.[419] This approach has demonstrably failed to prevent significant land conversion, with satellite data analysis estimating that 4.2 million acres of land have been converted to agriculture for biofuel production since the adoption of the standard.[420] An earlier study estimated that between 2008 and 2012, 1.6 million acres of long-term grasslands (that is, grasslands that were uncultivated since 1992 and likely earlier) were converted.[421] Separately, the World Wildlife Fund (WWF) has estimated that between 2009 and 2015, 53 million acres of uncultivated grassland in the United States were converted.[422] (The WWF estimate likely exceeds the other estimates because it did not account for grassland that, while uncultivated in 2008, had been cultivated in earlier years.)

This "aggregate compliance" approach is also facially ineffective as millions of acres of agricultural land are converted each year for many reasons, such as urban development, roads, or energy production. Thus, an overall cap cannot prevent conversion. Given that this approach arguably violates both Congress' stated intent and clear language by removing the need for compliance on the specific harvest land, EPA should repeal the "aggregate compliance" standard and replace it with a mandate to demonstrate feedstock was produced on land cleared before December 7, 2007.

417. Joseph Fargione et al., *Land Clearing and the Biofuel Carbon Debt*, 319 Sci. 1235, 1235 (2008).
418. 42 U.S.C. §7545.
419. 40 C.F.R. §80.1454(g) (2016).
420. Christopher K. Wright, *Recent Grassland Losses Are Concentrated Around U.S. Ethanol Refineries*, 12 Envtl. Res. Letters 1 (2017).
421. Lark et al., *supra* note 359, at 5.
422. World Wildlife Fund, 2016 Plowprint Report 2 (2016).

7. Transforming the Farm Safety Net Through Legislative Action

The federal government radically transformed the farm sector in the 1930s through a series of laws that created a robust system of subsidies for commodity crop production, and provided for an ambitious set of new research and loan programs.[423] This flurry of legislation saved countless farms from bankruptcy during the Great Depression, but it also led to the rapid expansion of large-scale, capital-intensive farms and feedlots,[424] with scant concern for agriculture's environmental and social impacts. This policy shift was accompanied by significant technological change and mechanization as well.[425] These laws have since been modified, but their basic framework persists today—as does their emphasis on the large-scale production of commodity crops and meat.[426]

Agricultural law is long overdue for another transformation for a number of reasons, including the need to incorporate climate stability and resilience as a major goal. The new framework must recognize that the agricultural sector is now vastly different than it was when the laws were first shaped. It has evolved from a diversified and labor-intensive enterprise to a capital-intensive, specialized, and heavily mechanized operation, typically conducted on a massive scale.[427] The pastoral "family farm"—which has always been more myth than reality—is of little relevance to today's agricultural industry: 80% of food is produced by only 7% of farms and only 43% of farms earn a gross income of $10,000 or more.[428] Environmental laws typically exempt (or have been interpreted to exempt) most aspects of agricultural production from pollution limits and other safeguards. These exemptions are sometimes

423. By 1935, USDA's budget had expanded 12-fold from pre-Depression levels, making it the single largest agency in the United States. Ernest C. Pasour Jr., Agriculture and the State: Market Processes and Bureaucracy 235 (1990). In contrast, a Congressional Research Service report from 2006 found that only 3.4% of federal outlays went to USDA between 2001 and 2005, making it the fifth largest federal agency in terms of spending. The majority of USDA funding went to SNAP (formerly known as the Food Stamp Program), however, rather than to agricultural programs. When spending was analyzed by budget function, agriculture was found to be 12th, immediately following international affairs. Phillip D. Winters, Congressional Research Service, Federal Spending by Agency and Budget Function, FY2001-FY2005, at 10 (2006).
424. Nathan A. Rosenberg & Bryce Wilson Stucki, *The Butz Stops Here: Why the Food Movement Needs to Rethink Agricultural History*, 13 J. Food L. & Pol'y 12, 13-14 (2017).
425. The benefits of technological changes and mechanization were disproportionately distributed to large-scale landowners as the result of highly favorable federal programs. *Id*. at 20-21.
426. As historian Paul K. Conkin writes, the details of agricultural policy changed over the years, but "aspects of every policy option undertaken in the 1930s have endured until the present." Paul K. Conkin, A Revolution Down on The Farm: The Transformation of American Agriculture Since 1929, at 51 (2008).
427. Carolyn Dimitri et al., USDA, The 20th Century Transformation of U.S. Agriculture and Farm Policy (2005) (EIB-3).
428. Calculated by the authors using USDA data. *See* 2012 Census of Agriculture, U.S. National Level Data, *supra* note 43, at 9 tbl. 2.

presented as protecting small and midsized farms, but they often instead externalize the costs of large-scale, capital-intensive operations. The new framework should further recognize that industrial agriculture is now the largest source of water quality impairments, a major source of air pollution,[429] and a driver for much degradation of natural resources. This pollution often threatens human health, as do the predominant crops grown and subsidized[430]; about 60% of federal farm subsidies support corn, soy, and wheat, which are often processed into less healthy foods.[431]

As climate change intensifies, the need for programs designed around a different set of goals will become even more pressing. Instead of serving to expand the capital-intensive production of commodities, the farm safety net should directly compensate farmers for protecting the environment, mitigating climate change, growing healthy food, and strengthening rural communities.[432] As demonstrated above, USDA has significant leeway under current law to revise programs and move agriculture toward, and even to, carbon neutrality. However, a system providing for robust payments for ecosystem services could help realize this goal more quickly and efficiently than the current farm safety net, even with the changes recommended above.

Ecosystem services are benefits that humans derive from ecological resources such as farms, including food, carbon sequestration, wildlife habitat, and recreational enjoyment, among others.[433] A payments-for-ecosystem-services (PES) program is one that provides incentives to farmers or other landowners for provisioning such services. A 2014 study examining the societal value of soil carbon determined that farmers should be compensated at a rate of $16 an acre for implementing best management practices.[434] It would cost less than $15 billion annually to implement a PES program at this rate for all 914 million acres of farmland in the United States—billions less than we currently spend on crop insurance, commodity, and conservation programs each year.

Carbon farming will require new infrastructure and equipment, both off and on the farm. Paying farmers for implementing climate-friendly practices will facilitate this transition, helping to offset decades of experience and sunk costs in conventional agricultural practices. Reducing the waste that runs through the entire agriculture and food system would provide ample land and resources for a PES system.[435] Replacing a portion of the current farm safety net with a PES program would reduce or eliminate payments for crops with high climate impacts, especially those grown for animal feed, while increasing payments for crops with lower climate impacts, thus helping to make healthy food more affordable. Adopting a progressive payment system could also help small and midsized farms, thus increasing the economic well-being of rural communities, and reduce costs. Limiting payments to the first 1,000 acres of a farm, for example, would reduce the number of eligible acres by more than half.

Paying farmers directly for positive ecological services needed by society would also avoid problems associated with the "submerged state"—the collection of indirect subsidies and incentives granted to private parties by the government.[436] Crop insurance, for example, appears to be a private-sector form of insurance, but instead acts as a generous subsidy to large-scale farmers.[437] Such indirect funding can undermine public support for robust government action, making policy reform more difficult.[438] While such a large-scale shift of the farm subsidy system may be a radical and highly politically charged proposal, it should be considered. Indeed, there are already calls to reform the agriculture subsidy system from a number of perspectives, both right and left. A PES approach has the advantages of fostering transparency, while increasing efficiency. Congress should reform the farm safety net as soon as possible to shift to greater reliance on payments based on provision of what the country now needs most—climate stabilization and a healthier environment. In so doing, Congress would also be supporting a substantially more transparent, equitable, and sustainable agricultural system.

429. Industrial livestock facilities, often called CAFOs, produce the majority of ammonia emissions in the United States, in addition to large amounts of hydrogen sulfide, silica dust, and noxious odors. *See* D. Bruce Harris et al., EPA, Ammonia Emission Factors From Swine Finishing Operations 1 (2001) (noting that livestock facilities are responsible for 73% of ammonia emissions). *See generally* Dick Heederik et al., *Health Effects of Airborne Exposures From Concentrated Animal Feeding Operations*, 115 Envtl. Health Persp. 298 (2007) (summarizing research on toxic gases, vapors, and particles emitted from CAFOs).

430. Tamar Haspel, *Farm Bill: Why Don't Taxpayers Subsidize the Foods That Are Better for Us?*, Wash. Post, Feb. 18, 2014, https://www.washingtonpost.com/lifestyle/food/farm-bill-why-dont-taxpayers-subsidize-the-foods-that-are-better-for-us/2014/02/14/d7642a3c-9434-11e3-84e1-27626c5ef5fb_story.html?utm_term=.2087acab4d2e.

431. Diet-related diseases are responsible for more than a million deaths and hundreds of billions of dollars in medical costs in the United States each year. Institute of Medicine, A Framework for Assessing Effects of the Food System 3-6 (2015); *see also* Centers for Disease Control and Prevention, *Leading Causes of Death*, https://www.cdc.gov/nchs/fastats/leading-causes-of-death.htm (last updated Mar. 17, 2017).

432. *See* Alison Power, *Ecosystem Services and Agriculture: Tradeoffs and Synergies*, 365 Phil. Transactions Royal Soc'y B 2959, 2966-67 (2010) (noting that farm management can considerably enhance the ecosystem services provided by agriculture).

433. J.B. Ruhl, *Agriculture and Payments for Ecosystem Services in the Era of Climate Change*, *in* Research Handbook on Climate Change and Agricultural Law 315-16 (Mary Jane Angelo & Anél Du Plessis eds., Edward Elgar 2017).

434. Rattan Lal, *Societal Value of Carbon*, 69 J. Soil & Water Conservation 186A, 190A (2014).

435. *See* Peter Lehner, *Feed More With Less*, 34 Envtl. F. 42 (2017).

436. Suzanne Mettler, The Submerged State: How Indivisible Government Policies Undermine American Democracy 4 (2011).

437. *See* David Dayen, *The Farm Bill Still Gives Wads of Cash to Agribusiness. It's Just Sneakier About It.*, New Republic, Feb. 4, 2014, https://newrepublic.com/article/116470/farm-bill-2014-its-even-worse-old-farm-bill.

438. Mettler, *supra* note 436.

C. Trade Policy

Exports have played an increasingly important role in the domestic production of agricultural goods in recent years, accounting for roughly 20% of U.S. agricultural production by volume. Commodities such as cotton, rice, soybeans, and wheat generally have much higher export rates, often relying on foreign markets for the majority of their sales.[439] The United States' marketing of these products abroad not only has a significant impact on the nation's emissions, but it has also had negative economic and health consequences for many of its trade partners.[440]

Title III of the 2014 Farm Bill, which covers trade, authorizes and funds a number of export programs. It includes five distinct market development programs, which are designed to assist industry efforts to expand market demand for U.S. agricultural products abroad, and two export credit guarantee programs, which guarantee loans made by U.S. private financial institutions to buyers of U.S. agricultural products in emerging markets.[441] The federal government spends approximately $5.5 billion on these programs annually,[442] although this may increase in future years as agribusiness groups have increasingly focused on expanding export markets. Industry groups successfully lobbied for a provision in the 2014 Farm Bill, for example, requiring the creation of an undersecretary of trade and foreign agricultural affairs position at USDA,[443] which the Trump Administration subsequently established in 2017.[444]

U.S. trade policy should be aligned with the need to curb climate change and other environmental challenges. To continue to expand demand abroad for carbon-intensive products such as grain-fed meat—while simultaneously encouraging U.S. farmers to produce climate-friendly products through other policies—would send contradictory signals to farmers, industry groups, and citizens about U.S. agricultural policy, and directly undermine efforts to achieve carbon neutrality in agriculture. Congress should integrate climate concerns into agricultural trade policy, mandating that USDA and other government agencies focus on developing markets for climate-friendly products and discontinue support for carbon-intensive commodities.

439. USDA, ERS, *Exports Expand the Market for U.S. Agricultural Products*, https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=58396 (last updated Apr. 11, 2016).
440. *See, e.g.*, *Exporting Obesity: U.S. Farm and Trade Policy and the Transformation of the Mexican Consumer Food Environment*, 18 Int'l J. Occupational & Envtl. Health 53 (2012).
441. Mark A. McMinimy, Congressional Research Service, Agricultural Exports and 2014 Farm Bill Programs: Background and Issues 7-13 (2014).
442. *Id*. at 14 tbl. 6.
443. 7 U.S.C. §6935.
444. Press Release, USDA, Secretary Perdue Announces Creation of Undersecretary of Trade and USDA Reorganization (May 11, 2014) (on file with authors).

D. Tax Policy

While many aspects of tax policy may influence farming or ranching decisions, just as they can affect the decisions of any business, most are too complicated, indirect, or uncertain to allow generalizations as to how they would effectuate climate-friendly practices. However, there are a few direct taxing approaches that would be effective in enhancing climate-friendly practices.[445]

The majority of agricultural emissions are from nitrous oxide produced in soils, much of which is caused by the application of nitrogen fertilizer. Since, as noted in Section II.C.2, most producers routinely apply excess fertilizer, federal or state legislators should consider adopting a fertilizer fee that could both encourage more judicious use of fertilizer and help fund training on climate-friendly agricultural practices.[446] Unfortunately, economists long considered demand for nitrogen fertilizers to be relatively inelastic, meaning that farmers generally continued to buy about the same amount of nitrogen fertilizer barring drastic price changes.[447] More recent evidence, however, indicates that rising fertilizer prices have made farmers examine fertilizer use more carefully.[448] A 2011 study in the United States estimated that for every 1% increase in price for synthetic fertilizers, demand for the product would drop 1.87%.[449] At this rate, a 10% tax on nitrogen fertilizers would reduce application rates by 2.4 million tons annually,[450] and result in hundreds of millions of dollars of revenue, while having an insignificant effect on overall costs and prices.[451]

445. Tax incentives for climate-friendly practices should be avoided, since tax expenditures often erode support for direct government action on the issues they are designed to address. Mettler, *supra* note 436.
446. A 2012 report commissioned by the California Water Resources Control Board examining nitrate in California's drinking water found that a fee on fertilizer equal to the state's sales tax rate of 7.2% would raise $28 million in revenue annually and reduce nitrogen application by 1.6%. Fertilizer sales are currently exempt from California's sales tax. Thomas Harter et al., California State Water Resources Control Board, Addressing Nitrate in California's Drinking Water 33 (2012).
447. Sweden's tax on synthetic fertilizer, which lasted from 1984 to 2010, is estimated to have reduced the application of synthetic nitrogen fertilizers by only 2%. The estimated price elasticity of the average nitrogen application rate varied by crop, but it was estimated to have ranged from -0.3 to -0.5, meaning that for every 1% increase in the price of synthetic fertilizers, the application rate only dropped 0.3%-0.5%. Anne Prestvik et al., Norden, Agriculture and the Environment in the Nordic Countries: Policies for Sustainability and Green Growth 72 (2013).
448. After fertilizer prices rose in 2006, 32% of surveyed farmers in the United States reported reducing their fertilizer use. Jayson Beckman et al., USDA, Agriculture's Supply and Demand for Energy and Energy Products 17 (2013) (EIB-112).
449. James Williamson, *The Role of Information and Prices in the Nitrogen Fertilizer Management Decision: New Evidence From the Agricultural Resource Management Survey*, 36 J. Agric. Resource Econ. 552, 568 (2011).
450. A total of 12,840,000 tons of nitrogen fertilizer were applied in the United States in 2011. ERS, USDA, U.S. Consumption of Nitrogen, Phosphate, and Potash, 1960-2011, at 1 tbl. 1 (2013).
451. Nitrogen fertilizer prices have ranged from $351 to $847 per ton in recent years. *Id*.

States and local governments can also discourage carbon-intensive practices through taxation. Many states and local governments currently provide significant property tax reductions for farm owners, regardless of how large or profitable their farm operations are.[452] In Utah, for instance, property taxes can be reduced by more than 99% for farms and ranches.[453] These tax benefits can keep farms viable in areas where encroaching development might otherwise make property taxes unaffordable or inordinately burdensome. While protecting farmland from development can have climate benefits, states should also take farm practices into account when assessing farmland values. Highly profitable, highly polluting hog CAFOs are often eligible to receive agricultural use exemptions, for example. States and local governments should condition tax reductions for agriculture on the adoption of more climate-friendly practices, perhaps targeting more stringent requirements on larger farms or those with a larger than average (perhaps analyzed by size range) carbon impact.[454] States can also explore ways to expand tax incentives for carbon-friendly practices. For example, in New York, the governor has proposed to amend the Real Property Tax Law to allow certain forestland owners, who now can get a property tax reduction if they have a plan to harvest the timber, to get an equivalent tax reduction if they manage their forest to improve carbon sequestration and water quality.[455]

A number of federal, state, and local tax expenditures also support conservation easements. In 2015, Congress permanently extended an enhanced tax deduction for landowners donating a conservation easement to a land trust or government agency.[456] Among other benefits, the enhanced deduction allows farmers and ranchers to deduct up to 100% of their income.[457] Conservation easement donations also reduce state and local tax revenues by reducing the assessed value of the land, and, in some cases, through tax deductions and credits.[458] Thirty states allow tax deductions for conservation easement donations,[459] while 16 states grant tax credits, including New York and California.[460]

In order to be eligible for the federal enhanced tax deduction, a conservation easement must be created exclusively for "conservation purposes," as defined in the Internal Revenue Code.[461] The definition is broad, however, and includes the "preservation of open space," including farmland.[462] Maintaining the rural character of an area, for example, can be a sufficient conservation purpose.[463] State and local governments generally have similar requirements for tax deductions or credits. Federal, state, and local governments should all consider requiring farm owners to comply with basic climate-friendly practices, such as installing buffer strips next to streams, in order to receive tax benefits for agricultural easements.

E. *Regulatory Options*

Methane and nitrous oxide are the two main direct sources of agricultural emissions. EPA has several direct regulatory tools available to reduce emissions of these greenhouse gases, which are addressed in Chapters 33 (Methane and Climate Change) and 35 (Nitrous Oxide). These tools include recognizing the harm or "endangerment" caused by these pollutants and promulgating regulatory programs to require or support their reduction. These regulatory programs could include direct limits, prohibitions on certain activities or practices known to emit significant amounts, or increased support for known practices that reduce emissions.

As noted in Section III.B.6, EPA should also revise its regulations for ensuring compliance with Congress' mandate that the RFS not lead to conversion of nonagricultural land.

Federal and state governments can also reduce greenhouse gas emissions as incidental to their regulation of water or other pollution. Programs to reduce nitrate runoff from fields into rivers would (depending on the precise practices incentivized) likely reduce nitrous oxide emissions; programs to reduce erosion and sediment pollution from grazing could likely increase soil carbon; and pro-

452. *See*, *e.g.*, N.M. Stat. Ann. §7-36-20 (2016). For a complete list, see Lincoln Institute of Land Policy & George Washington Institute of Public Policy, *Significant Features of the Property Tax—Tax Treatment of Agricultural Property*, http://datatoolkits.lincolninst.edu/subcenters/significant-features-property-tax/Report_Tax_Treatment_of_Agricultural_Property.aspx (last visited Apr. 12, 2018).
453. Clark Israelsen et al., Utah State University Cooperative Extension, Utah Farmland Assessment Act (2009).
454. Many states have similar tax reduction programs for lands held for forestry. *See* Jane Malme, Preferential Property Tax Treatment of Land 9-11 (Lincoln Institute of Land Policy, Working Paper Product Code WP93JM1, 1993). Originally designed to encourage forest products industries, these programs should also be redesigned to prioritize carbon-friendly forestry programs and to require carbon-friendly core practices.
455. In New York, Real Property Tax Law §480-a provides the existing tax reduction. N.Y. Real Prop. Tax Law §480(b). In the 2017 State of the State report, Governor Cuomo proposed enactment of a §480-b to allow for expanded eligibility for tax reductions. Governor Andrew M. Cuomo, 2017 State of the State 240 (2017). The amendment did not pass in 2017 or 2018; however, it remains under consideration as of the date of this chapter.
456. I.R.C. §170(b)(1)(E) (2016).
457. *Id.* §170(b)(1)(E)(iv) (2016).
458. Gerald Korngold, *Government Conservation Easements: A Means to Advance Efficiency, Freedom From Coercion, Flexibility, and Democracy*, 78 Brook. L. Rev. 467, 471 (2013).
459. Jeffrey O. Sundberg, State Income Tax Credits for Conservation Easements: Do Additional Credits Create Additional Value? 3 (Lincoln Land Institute Working Paper WP11JSS1, 2011).
460. Land Trust Alliance, *Income Tax Incentives for Land Conservation*, https://www.landtrustalliance.org/topics/taxes/income-tax-incentives-land-conservation (last visited Apr. 12, 2018).
461. I.R.C. §170(h)(4)(A) (2016).
462. *Id.*
463. Internal Revenue Service, Conservation Easement Audit Techniques Guide 18 (2016).

grams to change manure management could reduce methane emissions.

The Clean Water Act establishes a national pollutant discharge elimination system (NPDES) to regulate operations that discharge pollutants directly into waters. While most field operations and irrigation water return flows are exempted from direct regulation,[464] other agricultural operations including CAFOs that do, or are likely to, discharge are covered.[465] The law requires point source dischargers to obtain an NPDES permit from EPA or authorized state authorities in order to operate.[466] States that have been authorized to act as a permitting authority may impose more stringent requirements than the federal government.[467] In addition, the Clean Water Act requires states to develop programs to address nonpoint source (runoff) pollution, including agricultural sources.[468]

EPA should strengthen its nationwide regulations in ways that would reduce greenhouse gas emissions as well as water pollution. Moreover, since states can be more stringent than the federal government, states with NPDES permitting authority should strengthen their programs in similar ways. For example, NPDES programs should clearly prohibit CAFOs from spreading manure on frozen or saturated lands, insist on vegetated buffer zones along water courses, limit application rates, or require dry manure management, which can also reduce methane emissions. Similarly, management of crop production should require or incentivize buffer zones to reduce nitrate emissions, and thus also nitrous oxide emissions.

Other statutes also give EPA regulatory options for reducing agricultural greenhouse gas emissions. The most common waste management systems at industrial livestock facilities produce massive quantities of toxic fumes of ammonia and hydrogen sulfide in addition to the greenhouse gases methane and nitrous oxide. EPA estimates that livestock facilities are responsible for 73% of the country's ammonia air emissions.[469] Many of the practices that would reduce these hazardous air emissions would also reduce methane and nitrous oxide emissions, and EPA should thus use its regulatory tools to achieve such reductions.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) require all facilities that release hazardous substances to report these emissions to federal, state, and local governments and emergency responders.[470] In 2008, EPA exempted livestock facilities from this reporting requirement.[471] In 2017, the D.C. Circuit struck down EPA's loophole as illegal.[472] Responding to pressure from the animal production industry, Congress passed a rider to the March 2018 budget bill excluding livestock facilities from CERCLA reporting requirements.[473] The following month, EPA set forth a new legal theory asserting that, as a result of the CERCLA exemption, the facilities were also exempt from EPCRA reporting.[474] Congress should pass new legislation eliminating both exemptions, ensuring that an estimated 33,000 facilities are covered, or, at a minimum, require reporting by medium and large CAFOs, which would impose reporting only on the largest facilties that produce the vast majority of the waste[475]

Similarly, the Resource Conservation and Recovery Act (RCRA)[476] has been successfully used by neighbors of a large animal facility to require the better management of stored and spread manure to limit groundwater contamination.[477] Again, manure management changes instigated by concerns for groundwater, including more significant changes such as to dry manure handling or installation of digesters, can also reduce greenhouse gases. Both EPA and Congress should resist efforts by the industry to amend RCRA to exempt animal manure.

The largest 0.4% of farms in the United States produce almost a third of all agricultural products in the country, while the top 7% are responsible for more than 80%.[478] The top 7% of producers also owns 60% of the harvested cropland,[479] receives almost half of all government farm payments,[480] and takes in almost 90% of all net farm income.[481] Policymakers should be attentive to the genuine challenges farming operations face when transitioning

464. 33 U.S.C. §1362(14).
465. *Id.*
466. *Id.* §1342.
467. 40 C.F.R. §123.25(a) (2016).
468. *Id.* §130.6 (2016).
469. D. Bruce Harris et al., EPA, Presentation at EPA Emissions Inventory Conference, Ammonia Emission Factors From Swine Finishing Operations (May 3, 2001).
470. 42 U.S.C. §§9603(a), 11004.
471. 40 C.F.R. §§302.6(e)(3); 355.31(g), (h) (2016).
472. Waterkeeper Alliance v. Environmental Prot. Agency, 853 F.3d 527 (D.C. Cir. 2017).
473. *See* Fair Agricultural Reporting Method (FARM) Act, 42 U.S.C. §9603 (2018).
474. EPA, *How Does the FARM Act Impact Reporting of Air Emissions From Animal Waste Under CERCLA Section 103 and Section 304?* (Apr. 27, 2018), https://www.epa.gov/sites/production/files/2018-04/documents/cercla_epcra_q_and_a_farm_act_4-28-18.pdf. *But see* Memorandum from the Congressional Research Service to Senate Comm. on Env't & Public Works (Mar. 13, 2018) (on file with authors) (explaining that the CERCLA exemption does not affect EPCRA reporting requirements).
475. EPA estimated that 33,000 facilities were exempted by its rule from CERCLA reporting. See regulatory docket at EPA-HQ-SFUND-2007-0469-1361.
476. 42 U.S.C. §6901.
477. Community Ass'n for Restoration of the Env't, Inc. et al. v. Cow Palace LLC, 80 F. Supp. 3d 1180 (E.D. Wash. 2015). *See* Caroline Simson, *Wash. Dairy Settles Enviros' Manure Contamination Suit*, Law360, May 12, 2015, https://www.law360.com/articles/654586.
478. Calculated by the authors using data from the Census of Agriculture. *See* 2012 Census of Agriculture, U.S. National Level Data, *supra* note 43, at 9 tbl. 2.
479. *Id.* at 100 tbl. 65.
480. They receive 44% of farm subsidies and 52% of crop insurance payments. *Id.* at 94, 100 tbl. 65.
481. *Id.* at 98 tbl. 65.

to climate-friendly practices, but most of these large commercial farms, which often earn millions each year, can afford to adopt basic conservation practices. Congress and USDA should require large-scale operations to curb their most environmentally damaging practices in exchange for support from government programs, while maintaining a robust regulatory approach focused on the largest farms. Small and midsized farms should also be required to adopt basic conservation practices in order to receive government support, but additional funds should be made available to provide them with the financial means to adopt climate-friendly practices.

Finally, state and local governments should improve on current federal regulations by passing their own legislation designed to reduce emissions from agricultural operations. The California State Legislature, for example, passed a law in 2014 directing the California Air Resources Board (CARB) to develop a comprehensive strategy to reduce short-lived climate pollutants, including methane.[482] Subsequent legislation required CARB to begin implementing the plan by 2018.[483] As discussed in Chapter 33 (Methane and Climate Change), CARB's strategy calls for significant decreases in emissions from dairy manure management with reductions of at least 20% in 2020, 50% in 2025, and 75% in 2030.[484] In 2015, Minnesota passed a pioneering law requiring permanent vegetative buffers on farmland abutting lakes and streams.[485] The law was designed to reduce runoff, but will also increase soil carbon sequestration on the new strips, thereby reducing greenhouse gas emissions within the state. There are a variety of practices that state legislatures and environmental agencies and local governments should require—such as riparian buffers—or prohibit—such as spreading manure on frozen land—in order to further reduce the environmental harms of modern industrial agriculture. This would provide models for future federal initiatives, while also producing immediate climate and environmental benefits.

F. *Financing Options*

The Farm Credit System is a privately owned, federally chartered network of lending institutions that focus on agricultural loans. Created by Congress in 1916 to provide a reliable source of credit for agricultural producers,[486] it now holds nearly 41% of the farm sector's total debt—a larger share than that held by commercial banks.[487] The Farm Credit System benefits from a range of publicly funded guarantees, subsidies, and exemptions. It is exempt from all taxes on profits earned from real estate transactions, gets funding capital from the Federal Farm Credit Banks Funding Corporation, and enjoys USDA guarantees on many of its loans.[488]

USDA also manages the Farm Service Agency (FSA), which, among other things, acts as a lender of last resort for farmers and ranchers. In addition to offering direct loans to farmers, the agency also issues guarantees on loans made by commercial lenders for farmers that would not otherwise qualify. While FSA's overall impact on the agricultural credit market is relatively small—it holds 2.1% of all farm debt through direct loans and guarantees another 4%-5% of loans—it has come to play an important role in supporting beginning, minority, and female farmers.[489] The Agricultural Credit Improvement Act of 1992 required FSA to reserve funds for beginning farmers and to target disadvantaged farmers,[490] a population that it had long discriminated against.[491] In recent years, it has built on this congressional mandate by expanding its services for minority, female, and beginning farmers, rebranding itself as the "lender of first opportunity" for these groups.[492]

In 2013, FSA created a microloan program aimed at smaller farmers through its existing direct operating loan program. In the first three years of the program, the agency distributed more than $350 million through almost 17,000 microloans.[493] The program caps loans at $50,000 instead of $300,000 and has a streamlined application and approval process, making it easier for small and diversified farmers to participate.[494] FSA's microloans are designed to support "non-traditional" farms, such as urban, organic, and direct-to-consumer operations.[495] The program is also well suited to help carbon farmers get off the ground or expand their operations, since many climate-friendly prac-

482. Cal. Health & Safety Code §39730 (West 2017).
483. *Id.* §39730.5 (West 2017).
484. CARB, California Environmental Protection Agency, Proposed Short-Lived Climate Pollutant Reduction Strategy 7 (2016).
485. *See generally* 2016 Minn. Sess. Law ch. 85, S.F. No. 2503 (2016) (to be codified at scattered sections of Minn. Stat. Ann. chs. 103A-114b).
486. Farm Credit Act of 1933, Pub. L. No. 73-75, 48 Stat. 257.
487. Jim Monke, Congressional Research Service, Farm Credit System 1 (2015).
488. Total farm debt is approximately $346 billion. *Id.*
489. *Id.*
490. *See generally* Agricultural Credit Improvement Act of 1992, Pub. L. No. 102-554, 106 Stat. 4142. FSA must dedicate 75% of its funding for direct farm ownership loans and 50% of its funding for direct operating loans to beginning farmers and ranchers during the first 11 months of the fiscal year. 7 U.S.C. §1994(b)(2)(A). FSA is also required to reserve 40% of its funding for guaranteed ownership and operating loans to beginning farmers during the first half of the fiscal year. *Id.* "Low-income, limited resource" farmers must receive at least 25% of FSA's guaranteed ownership and operating loans. *Id.* §1994(d).
491. A USDA task force in 1997 found low participation rates in FSA programs among minorities as well as evidence of long-running discrimination. Civil Rights Action Team, Civil Rights at the United States Department of Agriculture 21-27 (1997); *see also* Stephen Carpenter, *The USDA Discrimination Cases: Pigford, in re Black Farmers, Keepseagle, Garcia, and Love*, 17 Drake J. Agric. L. 1 (2012) (discussing credit discrimination claims against USDA).
492. FSA, USDA, Your Guide to FSA Loans 16-17 (2012).
493. *Expanded USDA Microloans Program Increases Opportunity for Small and Beginning Farmers*, NSAC, Jan. 25, 2016, http://sustainableagriculture.net/blog/expanded_usda_microloans/.
494. USDA, FSA, *Microloan Programs*, https://www.fsa.usda.gov/programs-and-services/farm-loan-programs/microloans/index (last visited Apr. 12, 2018).
495. *Id.*

tices do not require large capital expenditures, particularly those practices found in perennial and agroecological systems. With sufficient outreach to farmers and farm groups, and training for its loan officers, FSA could become the lender of first opportunity for carbon farmers.

In exchange for guarantees and other benefits, Congress should require FSA and the Farm Credit System lending institutions to offer programs providing favorable credit to farmers and ranchers using climate-friendly practices recognized by NRCS and to require minimum climate-friendly practices relating to all loans. Both FSA and the Farm Credit System are already required to offer services to young, beginning, and small farmers and ranchers.[496] Congress should extend this mandate to carbon farmers, giving FSA and the Farm Credit System reasonable, but escalating goals.

G. *Grazing Practices on Government Land*

Overgrazing by livestock increases soil erosion, water pollution, and the loss of soil carbon.[497] While grazing occurs on hundreds of millions of acres of private land, more than 40% of all grazing lands in the United States—approximately 330 million acres—are on federal public lands,[498] managed by BLM and the U.S. Forest Service (USFS).

A reduction in grazing intensity would help restore the lost carbon.[499] Although Congress has repeatedly pushed the agencies to reduce overgrazing,[500] both agencies now do little to reduce overgrazing and indeed have policies that affirmatively thwart independent efforts by ranchers to reduce grazing to more sustainable rates. (It would make economic and environmental sense to increase federal grazing fees to reflect fair market value,[501] but that is a contentious political issue and not a likely solution pathway in the near term.)

BLM and USFS lease land to ranchers on the condition that they will uphold conservation values,[502] including soil health. However, public interest groups allege that BLM and USFS have done little to enforce these lease provisions.[503] These agencies should not only enforce these provisions, but should also add new ones designed to reduce the climate impacts of grazing systems. Even small improvements in practices could have a significant impact due to the immense size of federal grazing lands. Just as on private lands, intense rotational or carefully managed grazing can have numerous ecological and climate benefits, so BLM and USFS should, through pricing or other preferences, seek to incentivize such practices.

Congress has directed that leasing consider not only production but "ecological, environmental, air and atmospheric," and other values.[504] A key term in any lease or grazing permit is the "grazing intensity"—how many animals can graze a certain allotment in a certain period. Grazing intensities should be based upon accurate assessments of forage consumption by livestock and forage availability.[505] It appears that the grazing intensity established in many leases is now outdated, in part because beef cattle live weights (and so forage consumption) have increased by about 30% over the past 30 years,[506] and decades of overgrazing and now climate change reduce forage availability in many regions.[507] This leads to overgrazing and also has important economic consequences for ranchers, who must purchase supplemental feed to sustain cattle that the land itself cannot support.[508] Both BLM and USFS should undertake a process to update the grazing intensity limit in leases to reflect current conditions.

Even if they do not update leases, the agencies should give ranchers the flexibility to graze fewer than the allotted number of animals in order to preserve the range over the longer term and increase their profitability. However, BLM regulations provide for canceling permits of ranchers who fail to make "substantial use" of allotted forage for two consecutive years.[509] The term "substantial use" is undefined and this ambiguity has prompted many ranchers to maximize their use of allotted forage to ensure compliance with BLM requirements.[510] Similarly, USFS generally requires ranchers to graze at least 90% of allotted forage or risk revocation of their leases.[511] BLM and USFS

496. 12 U.S.C. §2207; 7 U.S.C. §1994(b)(2)(A). *See generally* Farm Credit Administration, 2015 Annual Report on the Farm Credit System 26-32 (2016) (describing the Farm Credit System's efforts to serve young, beginning, and small farmers).
497. Richard T. Conant & Keith Paustian, *Potential Soil Carbon Sequestration in Overgrazed Grassland Ecosystems*, 16 Global Biogeochemical Cycles 90-1, 90-1 (2002).
498. *See* USDA, U.S. Forest Service, *About Rangeland Management*, https://www.fs.fed.us/rangeland-management/aboutus/index.shtml (last visited Apr. 12, 2018).
499. *Id.*
500. *See* Taylor Grazing Act, 43 U.S.C. §315; Federal Lands Policy and Management Act, *id.* §1751. *See also* Public Rangelands Improvement Act, *id.* §1901; National Forest Management Act, 16 U.S.C. §1600; Multiple-Use Sustained-Yield Act, *id.* §538.
501. In 2013, federal grazing fees were less than 7% of the fees charged for equivalent grazing lands on private property. Christine Glaser et al., Center for Biological Diversity, Costs and Consequences: The Real Price of Livestock Grazing on America's Public Lands 1 (2015).
502. 43 C.F.R. §4180.2 (2016).
503. Public Employees for Environmental Responsibility, *About the BLM Grazing Data*, http://www.peer.org/campaigns/public-lands/public-lands-grazing-reform/blm-grazing-data.html (last visited July 6, 2017).
504. 43 U.S.C. §1701(a)(8).
505. NRCS, USDA, Estimating Initial Stocking Rates 7-8 (2009).
506. Bryan McMurry, *Cow Size Is Growing*, Beef Mag., Feb. 1, 2009, http://www.beefmagazine.com/genetics/0201-increased-beef-cows.
507. Daniel W. McCollum et al., *Climate Change Effects on Rangelands and Rangeland Management: Affirming the Need for Monitoring*, 3 Ecosystem Health & Sustainability 1, 7 (2017).
508. M. Rebecca Shaw et al., *The Impact of Climate Change on California's Ecosystem Services*, 109 Climatic Change 465, 478 (2011).
509. 43 C.F.R. §4170.1-2 (2016).
510. Steven C. Forrest, *Creating New Opportunities for Ecosystem Restoration on Public Lands: An Analysis of the Potential for Bureau of Land Management Lands*, 23 Pub. Land & Resources L. Rev. 21, 39 (2002).
511. USFS, USDA, Range Management ch. 2230, at 18 (2005).

should revise their policies to allow ranchers to graze only at intensities they believe are optimal, allowing them to restore the range and increase soil carbon.

Finally, courts have held that, under the existing law governing grazing on land that is "chiefly valuable for grazing and raising forage crops,"[512] permits and leases cannot be used solely for conservation.[513] This has prevented even those who have paid fair market value for leases to retire the allotments from grazing. Congress should let the market work and clarify that the purchaser of a lease or permit can graze as few animals as desired in order to preserve ecological values such as soil carbon.

H. Greenhouse Gas Pricing

Carbon pricing for all greenhouse gases from agriculture would be a highly effective policy lever. (See Chapter 2, Carbon Pricing.) While economic uncertainties make it difficult to predict precise impacts, a carbon price creates a broad signal affecting the decisions of most or all actors and can spur innovation toward lower greenhouse gas technologies and practices. Its broad reach and relative ease of administration make it an attractive policy tool. Governments can impose a greenhouse gas price through a carbon tax or fee, or through a cap-and-trade program. California created a cap-and-trade program applying to carbon dioxide emitted by most economic sectors, and the Northeast states developed a cap-and-trade program for the power sector in the Regional Greenhouse Gas Initiative.[514] Policy discussions concerning carbon pricing can include the magnitude and growth rate of the price (or equivalently, the size and speed of decrease of the cap), what to do with the income generated, at what point the fee (or cap) should be applied, and what exceptions should exist.

Various carbon pricing mechanisms can refund the revenue to taxpayers, use it as general revenues, offset other less popular taxes, or support particular projects. Given the long history of using public funds to encourage change in the agricultural sector, there would be a strong argument for using carbon fee revenues to support reduction of agricultural greenhouse gas emissions and to support practices that increase soil carbon storage. Allowing agricultural producers to earn revenue by storing soil carbon or reducing methane or nitrous oxide emissions, especially if such payment were in lieu of current federal farm subsidies, could be an effective way to significantly cut emissions quickly while increasing the carbon sink. Most discussions of carbon pricing focus on fossil fuel emissions and thus assume a fee would be placed only on carbon dioxide, and not on other greenhouse gases. If this were the case, agriculture would be largely exempt, as its primary climate change contribution is through nitrous oxide and methane. There would be a strong argument to include all greenhouse gases in a pricing mechanism to ensure it does not shift practices to those with perhaps greater climate impact. For example, practices that use a bit more energy in order to rotate grazing animals or apply nitrogen fertilizer more precisely could be inappropriately discouraged if the price were not applied to all greenhouse gases.

Given the difficulty of precisely measuring emissions of nitrous oxide and methane from agricultural operations, however, it would be difficult to have a precise fee applied to such emissions. Whether as an offset or within a cap or tax regime, it would be necessary to create methodologies that can model emissions based on practices, at least until precise measurement tools become available. Thus, the baseline for any greenhouse gas pricing system should be carefully examined.

IV. Non-Public Law Approaches to Reducing Net Agricultural Emissions

There are a number of ways that the private and philanthropic sectors can boost carbon farming and help reduce net agricultural emissions. Sustained funding and support for agricultural research will be critical, especially during periods when the executive branch is indifferent or hostile to scientific research. Access to capital, already a significant issue, will continue to be a need for producers adopting new and innovative practices designed to sequester carbon or decrease emissions. Absent the involvement of the federal government, nonprofit organizations will also need to take a leading role in developing and dispersing tools for carbon farmers, whether they are practical, such as inexpensive methods for measuring soil carbon content, or legal, such as conservation easements. Finally, there is significant enthusiasm among some industry and environmental groups for agricultural carbon markets. While offset markets in agriculture have the potential to reward farmers for improving their practices, they have several important limitations, and, as discussed below, enthusiasm for such markets may be unwarranted.

A. Research

Research supporting organic agriculture in the United States was led by the private sector for many years due to USDA's general disregard of, and occasional hostility to, organic agriculture prior to the 1990s.[515] In the 1970s and 1980s, a number of private research organizations

512. Taylor Grazing Act, 43 U.S.C. §315.
513. Public Lands Council v. Babbitt, 529 U.S. 728 (2000).
514. See Guri Bang et al., *California's Cap-and-Trade System: Diffusion and Lessons*, 17 Global Envtl. Pol. 18-21 (2017), for a comparison of California's cap-and-trade system and the Regional Greenhouse Gas Initiative.

515. Niggli et al., *supra* note 281, at 55-56.

such as the Rodale Institute, the Aprovecho Institute, and the Michael Fields Agricultural Institute were created to conduct and support research into organic and ecological farming.[516] Their work to develop and proliferate new practices was instrumental in the growth of sustainable agriculture. In 1992, the Organic Farming Research Foundation was founded to conduct and disseminate research on organic farming and the organic foods market. Foundations and private donors should support the work these research organizations are conducting on climate-friendly practices, in addition to helping fund new organizations devoted to carbon farming.

B. *Financing Options*

The seasonal nature of farming makes loans particularly important for farmers. In 2015, more than 1.3 million non-real estate loans were made to farmers.[517] To put that in perspective, only about one million farmers grossed more than $10,000 in agricultural sales.[518] The vast majority of agricultural loans are to pay for operating expenses, and while many of these loans are relatively small,[519] they are nonetheless critical for farmers to stay in business. Labor, equipment, seeds, and other expenses required to produce any given product are necessarily incurred prior to harvest, and farmers may have to wait months to receive any revenue at all.

Most of these loans are granted by small banks, some of which rely on agricultural loans for a substantial part of their business. These banks, called agricultural banks, have enjoyed much higher average rates of return on assets than other smaller banks in recent years, even as farm incomes have fluctuated.[520] Agricultural lenders often hesitate to make loans to farmers using new or experimental practices, however. This can make it difficult for farmers to adopt innovative carbon farming techniques, regardless of their actual exposure to risk.

The energy efficiency financing experience provides a possible model. There, philanthropic support has often been critical for private and public financing of energy efficiency projects, which were new to lenders and thus underserved.[521] Similarly, the private philanthropic sector (either directly or through advocacy organizations) or USDA should support agricultural banks in lending for practices that are perhaps less well known and widely accepted. At a minimum, USDA and environmental organizations should ensure that agricultural banks are familiar with the benefits of carbon farming, which makes farms more resilient to weather disturbances and therefore exposes the lending institution to less risk. As is also done with energy efficiency and clean energy loans, such entities can also guarantee or support private lending to extend its reach. Finally, Congress or state legislatures should create lending institutions, or existing ones could create specialty divisions, aimed at financing farms using climate-friendly practices. These could be public-private entities, with public support or loan guarantees, as exist to foster energy efficiency, or backed in part by philanthropic support. This would allow farmers throughout the country to receive loans regardless of whether their local banks are willing to finance carbon farming. Similarly, USDA and the private philanthropic sector, either directly or through advocacy nongovernmental organizations, should support agricultural banks in lending for practices that are perhaps less well known and widely accepted.

Private financing also has a role to play. While there has been an increase in venture capital funding for "ag-tech,"[522] most of the funding has focused on precision agriculture and a narrow range of practices. Philanthropists, impact investors, and foundations should focus investment on a broader range of carbon farming practices, accelerating its development.

C. *Measuring Carbon Content in Above-Ground Biomass and Soil*

Measuring soil carbon is currently a time-intensive, expensive, and complicated exercise. There are also few established protocols for measuring precisely the greenhouse gas benefits of climate-friendly practices, making it difficult to pay farmers in offset markets for implementing such practices. These challenges have slowed the development of agricultural offset markets and research into soil sequestration. Scientists are working to develop new, more efficient methods for measuring soil carbon content,[523] but the level of resources devoted to this problem is insufficient given the urgent need for a reliable and inexpensive way to test soil. Nonprofit organizations and land-grant universities should prioritize funding to develop and distribute cost-effective monitoring, measurement, and verification tools, while the

516. *Id.*
517. Federal Reserve Bank of Kansas City, Agricultural Finance Databook tbl. A-1 (2017).
518. USDA, *supra* note 300.
519. The majority of loans were below $25,000. Federal Reserve Bank of Kansas City, *supra* note 517.
520. Nathan Kauffman & Matt Clark, *Farm Lending Remains Robust*, Fed. Res. Bank Kan. City: Ag Fin. Databook, Apr. 25, 2016, https://www.kansascityfed.org/en/research/indicatorsdata/agfinancedatabook/articles/2016/04-21-2016/ag-finance-dbk-04-25-2016.
521. See, for example, the creation of the New York City Energy Efficiency Corporation (NYCEEC). NYCEEC, https://nyceec.com/ (last visited Apr. 12, 2018). *See also, e.g.*, Carbon Trust, https://www.carbontrust.com/home/ (last visited Apr. 12, 2018); Solar and Energy Loan Fund (SELF), http://cleanenergyloanprogram.org/ (last visited Apr. 12, 2018).
522. *See* AgFunder, AgTech Investing Report: Year in Review 2015, at 3 (2016) (noting that funding for agricultural technology doubled between 2014 and 2015).
523. *See, e.g.*, Robert Pallasser et al., *A Novel Method for Measurement of Carbon on Whole Soil Cores*, *in* Soil Carbon (Alfred Hartemink & Kevin McSweeney eds., Springer 2014).

private for-profit, not-for-profit, and philanthropic sectors should work with the research community to standardize measuring techniques. In turn, extension services, those actors, and others should educate farmers about such tools to accelerate their adoption and acceptance.

D. Easements and Other Conservation Tools

In addition to federal conservation easement programs for farm owners, which are discussed above in Section III.B.4, there are a number of other local, state, and national programs that compensate farm owners for implementing agricultural easements on their land. While these programs generally rely on public funds, either directly or through tax expenditures, they are often designed and administered by nonprofits. As such, the private sector can play an important role in adapting and expanding agricultural easement programs to support climate-friendly practices. Many organizations offering agricultural easements already recognize the environmental benefits of well-managed agricultural land, which can be significant.[524] Nonetheless, few land conservation organizations include climate change mitigation as one of their goals, which would allow them to more effectively manage land for sequestration.

Agricultural easements can be drafted to give both farmers and land conservation agencies greater flexibility to monitor and reduce net emissions. Conservation easements generally articulate their purposes, giving courts, conservation organizations, and landowners guidance on how to administer the easement under evolving conditions. Land conservation agencies and agricultural land trusts should incorporate climate change mitigation into easement purposes, ensuring that farmers' efforts to mitigate climate change do not conflict with their easements.[525]

Additionally, easements should be written to allow for ecological monitoring, scientific research, and publicly accessible data sources,[526] all of which are critical for improving land management.[527] Conservation organizations and agricultural land trusts should also use other legal tools outside of easements. By leasing land instead of offering permanent easements, for example, these organizations can carefully select farmers to manage their land, allowing them to develop long-term cooperative relationships with farmers dedicated to climate-friendly practices.[528]

E. Offset Markets

Carbon offset markets allow greenhouse gas polluters to pay another party to reduce emissions or sequester carbon instead of reducing their own emissions. These purchased reductions, called offsets, can help finance the transition to carbon farming, compensating farmers for sequestering carbon or reducing emissions. Although some environmental organizations have argued that carbon markets should play a major role in decarbonizing agriculture,[529] carbon markets appear unlikely to motivate widespread behavioral change among farmers without accompanying government action and regulation,[530] including, as noted above, more reliable systems for measuring the greenhouse gas reduction impact of various practices.

The market for agricultural offsets in the United States as of 2018 is small and confined to rice production in California,[531] although agencies and others in California are also closely studying manure management at confined animal production facilities. A current limitation is the ability to measure greenhouse gas reductions from altered practices, so it would be beneficial for organizers of offset systems such as state governments to explore different payment schemes; for example, instead of paying for offsets per ton (as is generally the case), payments could be based on practices implemented per acre, with a price set by calculations of average benefits, or based on measurements of surrogate indicators.

While offset schemes hold promise for accelerating adoption of climate-friendly practices, there are significant concerns about whether current offset schemes reduce net emissions generally,[532] as well as criticisms from environmental and small-scale farmer organizations that offset markets in agriculture could be unreliable, detrimental to small and medium-scale farmers, and likely to increase volatility in food prices.[533] At present, offset markets do

524. See Section III.B.4, for a discussion of the climate benefits of conservation easements.
525. For example, conservation easements often prohibit new structures, including wind turbines and processing facilities for new agricultural products. Jessica Owley, *Conservation Easements at the Climate Change Crossroads*, 74 L. & Contemp. Probs. 199, 207-08 (2011).
526. Clauses that ensure open and easily available data should be included wherever possible.
527. Adena Rissman et al., *Adapting Conservation Easements to Climate Change*, 8 Conservation Letters 68, 73 (2015).
528. Fred Cheever et al., Private Land Conservation in the Face of Climate Change (2013).
529. Robert Parkhurst, *Carbon Markets in Agriculture Are the Next Big Thing*, Envtl. Def. Fund, Jan. 24, 2016, http://blogs.edf.org/growingreturns/2016/01/24/carbon-markets-in-agriculture-are-the-next-big-thing/.
530. Peter Alexander et al., *The Economics of Soil C Sequestration and Agricultural Emissions Abatement*, 1 Soil 331, 335 (2015) (noting weak demand for agricultural offsets absent government pressure).
531. Niina Heikkinen, *Rice Growers on the Front Lines of U.S. Carbon Markets*, E&E News, Jan. 20, 2016, https://www.eenews.net/stories/1060030839; Brian C. Murray, *Why Have Carbon Markets Not Delivered Agricultural Emission Reductions in the United States?*, Choices, 2d Quarter 2015, at 1.
532. *See, e.g.*, Tamra Gilbertson & Oscar Reyes, Dag Hammarskjöld Foundation, Carbon Trading: How It Works and Why It Fails 11-12 (Critical Currents No. 7) (2009).
533. Institute for Agriculture and Trade Policy, Five Reasons Carbon Markets Won't Work for Agriculture (2011).

prioritize year-to-year reductions such as in methane from rice production. Expansions of offset markets should continue that focus, including methane reduction from animal production, nitrous oxide emissions, or permanent (or long-term) changes in land use. On the other hand, short-term soil carbon sequestration practices, which can be quickly reversed and are poorly understood, are a less reliable strategy for offsetting fossil fuel emissions at this time.[534] Finally, given current atmospheric concentrations of greenhouse gases—resulting in part from centuries of harmful agricultural practices—we need to simultaneously decrease emissions *and* sequester carbon. Legislatures and agencies should carefully consider these factors in the design of any offset program to ensure that it reduces net emissions and spurs investment in climate-friendly practices.

V. Reducing Food System Emissions

A. *Upstream: Greenhouse Gas Emissions From Farm Inputs*

Conventional agriculture in the United States is heavily reliant on fossil fuels. Most commercial farms rely on energy-intensive equipment to perform a wide range of farm tasks, including weeding, planting, and harvesting, in order to reduce their labor needs. In addition, the manufacturing process for farm inputs such as pesticides and particularly fertilizer requires a substantial amount of energy. A detailed literature review in 2002 broke down the total energy requirements for agriculture in advanced economies using the following categories[535]:

- 36% for nitrogen fertilizer production
- 27% for on-farm fuel usage
- 15% for the manufacture of agricultural machinery
- 6.2% for irrigation
- 6% for pesticide production
- 4.7% for phosphorus and potassium fertilizer production
- 3.5% miscellaneous

Significant benefits are possible from reducing the largest two upstream emitters of greenhouse gases, the production of nitrogen fertilizer and on-farm fuel usage, which together account for almost two-thirds of upstream emissions.

534. It is easier to track the sequestration benefits of above-ground biomass, such as trees and shrubs, making agroforestry and silvopasture safer options for offsetting emissions.
535. Mario Giampietro, *Energy Use in Agriculture*, *in* Encyclopedia of Life Sciences 4 (Nature Publishing Group 2003).

1. Reduce Emissions From Fertilizer Production

Nitrogen-based fertilizers accounted for 59% of total U.S. fertilizer consumption in 2010,[536] but were responsible for approximately 90% of emissions from the fertilizer production process.[537] (Indeed, emissions from the production of nitrogen fertilizer could be about one-fourth the typical emissions from its application,[538] meaning that the climate benefits of reducing fertilizer use, if accompanied by a commensurate reduction in fertilizer production, are about 25% greater than indicated by direct emissions alone.)

New ammonia production facilities are approximately 30% more energy efficient than older ones, indicating that this sector's emissions could be significantly reduced by modernizing production processes.[539] Because carbon dioxide is required to synthesize ammonia, however, emissions cannot drop much further through efficiency measures alone.[540]

EPA has legal tools under the Clean Air Act to impose emissions limitations on both conventional pollutants, such as those that would be achieved by measures that also reduce greenhouse gas emissions, and on carbon dioxide from manufacturing. (See Chapters 12 (Industrial Sector) and 35 (Nitrous Oxide).) There is also some promise in facilities that can produce nitrogen fertilizer from biomass instead of natural gas,[541] and in facilities that produce both electricity and fertilizer accompanied by carbon capture and storage (or reuse),[542] which could produce fertilizer with very low greenhouse gas emissions. Governmental support for such projects should be explored.

536. Beckman et al., *supra* note 448, at 10.
537. In 2011, ammonia production plants in the United States accounted for roughly 14% of the chemical manufacturing sector's total carbon footprint, or about 0.1% of total emissions. Their share is expected to rise, however. Globally, ammonia production is a major contributor to greenhouse gas emissions, representing as much as 5% of greenhouse gas emissions. While the United States accounts for only 6% of global ammonia production right now, the majority of new plants are being built in the United States or Canada. *See* Celeste LeCompte, *Fertilizer Plants Spring Up to Take Advantage of U.S.'s Cheap Natural Gas*, Sci. Am., Apr. 25, 2013, http://www.scientificamerican.com/article/fertilizer-plants-grow-thanks-to-cheap-natural-gas/.
538. Griffing et al., *supra* note 23.
539. International Fertilizer Industry Association, Feeding the Earth: Energy Efficiency and CO_2 Emissions in Ammonia Production 2 (2009).
540. *Id.*
541. *See, e.g.*, Yosuke Mikami, *Ammonia Production From Amino Acid-Based Biomass-Like Sources Engineered Escherichia Coli*, 7 AMB Express 83-89 (2017).
542. *See*, *e.g.*, SCS Engineers, *Home Page*, http://www.scsengineers.com/ (last visited Apr. 12, 2018).

2. Promulgate Fuel Economy Standards for Agricultural Equipment and Reduce On-Farm Energy Use

Despite progressively tightening its fuel economy standards for light-duty vehicles, EPA has yet to promulgate any standard for off-road diesel vehicles. Fuel efficiency for on-farm vehicles has consequently lagged. EPA should promulgate fuel economy standards for off-road diesel vehicles such as tractors to reduce their carbon dioxide emissions, which remain a significant source of on-farm emissions. Since turnover among off-road vehicles is slower than turnover among light-duty vehicles, however, significant improvements in emissions reduction will be slow.

Farm programs implemented by USDA should also be designed to encourage farmers, preferably through incentives, to adopt less fuel-intensive practices. Tillage, for example, significantly increases carbon dioxide emissions from agricultural equipment, since plowing significantly increases a tractor's fuel requirements. A literature review found that tractors on no-till farms only emit one-sixth as much carbon dioxide equivalent as tractors on farms practicing complete tillage.[543] (This is, of course, in addition to the soil carbon benefits of no-till agriculture discussed above.)

B. Downstream: Emissions From Food Processing, Packaging, Marketing, and Waste

Postproduction greenhouse gas emissions, while significant, have not been comprehensively catalogued in the United States.[544] The main contributors to emissions beyond the farm gate are energy expenditures associated with food processing, packaging, marketing, and distribution. Food waste contributes to emissions indirectly, through emissions resulting from the production, distribution, and marketing of the wasted food, and directly, through methane emissions from landfills. The discussion below is limited to landfill emissions, since reductions in indirect contributions are susceptible to leakage and are difficult to track.[545] In contrast, efforts to divert food waste from landfills are relatively easy to monitor, and, as several state and local governments have shown, to implement.

1. Reducing Processing, Packaging, Distribution, and Marketing Emissions

In 2006, the food processing sector emitted approximately 117 million metric tons of carbon dioxide equivalent, making it one of only four industrial sectors in the United States responsible for more than 100 million metric tons of carbon dioxide annually.[546] (See Chapter 12 (Industrial Sector).) Mitigation within the food processing sector will largely depend on reducing energy intensity in addition to other cross-sector efforts, such as reducing reliance on fossil fuel energy sources. As a result, EPA and the U.S. Department of Energy should explore adopting energy efficiency standards that would apply to this sector.

2. Divert Food From Landfills

Diverting food and agricultural waste from landfills is an opportunity to significantly reduce greenhouse gas emissions.[547] Such a strategy could result in quick and powerful climate benefits. Although in 2016 EPA issued new rules requiring installation of systems to capture landfill gas (usually comprising half methane and half carbon dioxide) at larger municipal waste landfills constructed after July 2014, and updated landfill gas capture systems for larger

543. Rattan Lal, *Carbon Emission From Farm Operations*, 30 Env't Int'l 981, 982 (2004).

544. See Rebecca Boehm, *A Comprehensive Life Cycle Assessment of Greenhouse Gas Emissions From U.S. Household Food Choices*, 78 Food Pol'y (forthcoming June 2018), for a life-cycle assessment of greenhouse gas emissions from consumer food purchases that incorporates post-production emissions. Although it does not encompass household transportation, preparation, storage, or waste, the Boehm et al. analysis includes food production and transportation and wholesale, retail, and restaurant activity resulting from household purchases.

545. Food producers often shift their products to foreign or secondary markets in response to decreased consumer demand rather than decrease production. The dynamics of the U.S. cheese industry serve as an illustrative example. Cheese production has grown much more rapidly than domestic consumption since 2009, yet the industry has continued to expand by increasing exports, which tripled between 2007 and 2014, and through government purchasing programs that distribute surpluses to food banks and nutrition assistance programs. *See* Mark O'Keefe, *Emerging Economies Will Drive Future Cheese Demand*, U.S. Dairy Exporter Blog, Feb. 25, 2017, http://blog.usdec.org/usdairyexporter/emerging-economies-will-drive-future-cheese-demand; Mark Fahey, *Americans Have an Insatiable Demand for Pizza Cheese*, CNBC, Oct. 10, 2016, http://www.cnbc.com/2016/10/04/best-cheeses-americans-have-an-insatiable-demand-for-pizza-cheese.html; Press Release, USDA, USDA Announces Plans to Purchase Surplus Cheese, Releases New Report Showing Trans-Pacific Partnership Would Create Growth for Dairy Industry (Oct. 11, 2016), https://www.usda.gov/media/press-releases/2016/10/11/usda-announces-plans-purchase-surplus-cheese-releases-new-report. Thus, it is unlikely that any decrease in demand as the result of reductions in food waste would result in an equivalent decrease in production.

546. Sabine Brueske et al., Oak Ridge National Laboratory, U.S. Manufacturing Energy Use and Greenhouse Gas Emissions Analysis 37 tbl. 2.1-16 (2012).

547. It is sometimes argued that reducing food loss will result in reduced food production and distribution. *E.g.*, Craig Hanson et al., *What's Food Loss and Waste Got to Do With Climate Change? A Lot, Actually.*, World Resources Inst., Dec. 11, 2015, http://www.wri.org/blog/2015/12/whats-food-loss-and-waste-got-do-climate-change-lot-actually. While intuitively this makes sense, there are a number of variables that make it impossible to predict what impact reduced domestic demand would have on land use, including funding for farm programs, support for biofuels, and fluctuations in global consumer demand and international commodity markets. Additionally, the amount of cropland and grazing land in the United States has stayed more or less constant since 1945, despite a radically higher supply of agricultural commodities gained through higher yields. If agriculture's land footprint remains unchanged in the face of such significant increases in supply, it appears unlikely to be affected by relatively low fluctuations in demand stemming from lower rates of food loss. *See also supra* note 545 (discussing how food producers often develop new markets in response to decreased demand rather than decrease production).

existing landfills constructed after 1987,[548] there is still great climate benefit to reducing organic waste in landfills. Older and smaller landfills are not covered; there is a long time lag before full compliance will be required; and the landfill gas capture is not complete.

Organic matter, which includes food, wood, yard waste, and paper products, is the single largest component of landfills, constituting the majority of waste discarded in municipal waste systems.[549] Food waste alone makes up more than 20% of the materials discarded.[550] Once in a landfill, organic matter decomposes without the presence of oxygen, releasing large amounts of methane as a result.[551] EPA estimates that organic matter in landfills was responsible for 16% of U.S. methane emissions in 2016.[552] A 2016 study, however, found that EPA underestimates the amount of municipal waste disposed of by a factor of two, indicating that the methane emissions from organic matter might actually be much higher.[553]

Food waste decays more rapidly than other organics due to its high moisture content, making it an especially heavy emitter of methane soon after disposal. As a result, food waste is responsible for as much as 90% of methane emissions from landfills during their initial years when they are less likely to be capped.[554] While reliable data are lacking on the sources of food waste, one industry-funded report estimates that residential food waste is responsible for 44% of post-farm food waste.[555] The commercial sector, which includes restaurants and grocery stores, is estimated to dispose of 44% of post-farm food waste, while waste from institutions and industry operations make up the remaining 12%.[556]

European countries have demonstrated that organics can be diverted from landfills in a cost-effective and environmentally beneficial way. The European Landfill Directive, passed in 1999, required Members of the European Union to reduce biodegradable waste to 35% of 1995 levels by 2016.[557] Many Member States have gone beyond this requirement. A 2010 survey found that the majority of German households have access to an organic waste bin and many of them are required to use them.[558] Germany revised its national waste management law, the Circular Economy Act, in 2012 to require residents to sort organic waste for collection by 2015.[559] In 2016, a new law wento into effect in France banning supermarkets larger than 4,305 square feet in size from throwing away or destroying food.[560]

States and municipalities have also taken action to divert organic waste from landfills. In 2012, Vermont passed the Universal Recycling Law, which, among other things, enacted a complete ban on food waste in landfills.[561] The ban goes into effect in 2020 and applies to all households and businesses. Shifting waste to composting facilities converts the waste into useful material and results in negative net emissions.[562] San Francisco passed an ordinance in 2009 requiring all businesses and households to sort organics for collection and composting.[563] San Francisco now collects more than 220,000 tons of organic waste each year, and it is considered the country's most successful composting program.[564] In 2014, the Seattle City Council also passed a mandatory composting ordinance.[565] Even though the ordinance limits fines for noncompliance to $1 for residents and $50 for commercial businesses,[566] composting collection rates went up significantly after the law went into effect in 2015.[567]

Vermont's Universal Recycling Law provides an ideal model for Congress to follow when designing legislation banning food waste in landfills. Failing national action, states and municipal governments should adopt such a

548. News Release, EPA, EPA Issues Final Actions to Cut Methane Emissions From Municipal Solid Waste Landfills (July 15, 2016), https://19january2017snapshot.epa.gov/newsreleases/epa-issues-final-actions-cut-methane-emissions-municipal-solid-waste-landfills-0_.html; Standards of Performance for Municipal Solid Waste Landfills, 81 Fed. Reg. 59332 (Aug. 29, 2016) (regulating new and modified landfills under the New Source Performance Standards program of the Clean Air Act); Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills, 81 Fed. Reg. 59276 (Aug. 29, 2016) (regulating existing landfills under Clean Air Act §111(d)).
549. *See* EPA, *supra* note 9, at 7-18 tbl. 7-6.
550. *Id*.
551. *Id*. at 7-3.
552. EPA, *supra* note 11.
553. Jon Powell et al., Letter, *Estimates of Solid Waste Disposal Rates and Reduction Targets for Landfill Gas Emissions*, 6 Nature Climate Change 162, 162 (2016) (finding that the total amount of municipal waste disposed of in the United States was 115% higher than EPA's estimate in 2012).
554. Dana Gunders, Natural Resources Defense Council, Wasted: How America Is Losing Up to 40 Percent of Its Food From Farm to Fork to Landfill 14 (2012).
555. Business for Social Responsibility, Food Waste: Tier 1 Assessment 12 (2012).
556. *Id*.
557. *See generally* Council Directive 1999/31/EC, 1999 (EU).
558. Peter Krause et al., Umwelt Bundesamt, Compulsory Implementation of Separate Collection of Biowaste 3-4 (2015).
559. Kreislaufwirtschaftsgesetz, v. 24.2.2012 (BGBl. I S.212) art. 11.
560. Angelique Chrisafis, *French Law Forbids Waste by Supermarkets*, The Guardian, Feb. 4, 2016, https://www.theguardian.com/world/2016/feb/04/french-law-forbids-food-waste-by-supermarkets. *See* Proposition de Loi 632 du 9 décembre 2015 relative à la lutte contre le gaspillage alimentaire [Proposal of Law 632 of December 9, 2015, on the fight against food waste], Assemblée Nationale [French National Assembly], Dec. 9, 2015.
561. Vt. Stat. Ann. tit. 10, §6602(29) (West 2017). California, Connecticut, and Massachusetts have also passed legislation or promulgated regulations requiring commercial businesses to divert food waste from landfills under certain circumstances. Cal. Pub. Res. Code §42649.81 (West 2017) (applies to businesses generating eight cubic yards of organic waste or more per week); Conn. Gen. Stat. Ann. §22a-226e (West 2017) (limits entities to no more than 52 tons of organic waste by 2020); Mass. Regs. Code tit. 310, §§19.006, 19.017(3) (2017) (bans entities from disposing of more than one ton of food waste per week).
562. EPA, Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM)—Organic Materials chs. 1-29 to 1-30 (2016).
563. S.F., Cal., Ordinance 100-09 (June 9, 2009).
564. This includes yard waste in addition to food waste.
565. Sean Kennedy, *In Seattle, Compost Your Food Scraps—Or Else*, CNN, Oct. 3, 2014, http://www.cnn.com/2014/09/24/politics/seattle-composting-law/.
566. Seattle, Wash., Mun. Code §§21.36.082(C), 21.36.083(B) (2016).
567. Sara Bernard, *Why Seattle Still Has a Huge Garbage Problem*, Grist, June 15, 2015, http://grist.org/cities/why-seattle-still-has-a-huge-garbage-problem/.

law. Given that waste from retail establishments is estimated to make up almost half of the total waste, laws that address only this portion of the waste could still have a significant impact.

VI. Changing Consumption Patterns

Just as the federal government influences what farmers grow through its farm programs, it also influences what people consume through its dietary recommendations, labeling systems, and procurement policies. The private sector also plays an important role in influencing consumption patterns through advertising, labels, and menu options. Below we build on Chapter 3 (Behavior), by providing a brief overview of how the government and the private sector can encourage positive behavioral change in the food system.

A. Integrate Greenhouse Gas Emissions Into Dietary Guidelines

The dietary guidelines, updated every five years by USDA and the U.S. Department of Health and Human Services (HHS), are much more than the federal government's recommendations regarding nutrition and diet. They also dictate how government agencies teach nutrition; determine what students, seniors, and other recipients of government-funded meals are fed; and guide government-funded research and nutrition projects.[568] Due to the guidelines' tremendous impact, environmentalists and sustainable food advocates have sought to include sustainability in them. The "guiding principles" of the 2010 dietary guidelines encouraged the development and expansion of "sustainable agriculture and aquaculture practices" for the first time.[569] In 2015, the Dietary Guidelines Advisory Committee[570] tried to build on this brief nod to sustainability by recommending that the guidelines incorporate sustainability in their dietary recommendations.[571] Secretary of Agriculture Tom Vilsack and Secretary of Health and Human Services Sylvia Burwell, who shared joint responsibility over the guidelines, responded with a letter stating that the inclusion of sustainability as a goal in the guidelines was beyond their statutory authority.[572]

Advocates have persuasively argued that this is an incorrect interpretation of the enabling legislation.[573] The term "nutrition monitoring and related research" is broadly defined in the statute, listing "food supply and demand determinations" as one of the factors to be considered.[574] Since sustainability is crucial to the long-term viability of the country's food supply, advocates argue, the statute gives USDA and HHS the authority to consider it as a factor in the guidelines. Such a move would not be without precedent. The dietary guidelines of several countries, including Brazil, Denmark, the Netherlands, and Sweden, explicitly acknowledge the interdependence of healthy diets and environmental sustainability.[575]

The Dietary Guidelines Advisory Committee's 2015 report also emphasized the connection between environmental sustainability and healthy diets, defining "sustainable diets" as a "pattern of eating that promotes health and well-being and provides food security for the present population while sustaining human and natural resources for future generations."[576] Among the issues the committee recommended integrating into the guidelines were land and water use, soil fertility, biodiversity loss, and greenhouse gas emissions.[577] The advisory committee's review of the literature on population-level dietary patterns and long-term food sustainability found "a moderate to strong evidence base" that increasing the consumption of healthy plant-based foods would reduce the environmental impact of the average U.S. diet. It is likely that the updated dietary guidelines would have recommended the reduced consumption of carbon-intensive meat as a result of these finding had sustainability been included as a factor. Brazil's dietary guidelines, for example, encourage the use of minimally processed plant-based foods over animal products to reduce greenhouse gas emissions and deforestation.[578]

Both agencies should acknowledge their legal ability to include sustainability as a factor in the guidelines and work to encourage healthy, climate-friendly diets. By incorporating sustainability into the guidelines, USDA and HHS could quickly and effectively decrease the carbon intensity of the American diet. An industry-funded food and health survey conducted in 2017 found that more than half of American consumers claim that food sustainability

568. *See* 7 U.S.C. §5341(a)(1) ("Each such report . . . shall be promoted by each Federal agency in carrying out any Federal food, nutrition, or health program").
569. USDA & HHS, Dietary Guidelines for Americans: 2010, at 57 (2010).
570. The Dietary Guidelines Advisory Committee is a group of medical and scientific experts that issues a detailed report to HHS and USDA on the latest scientific evidence regarding health and nutrition prior to each iteration of the dietary guidelines.
571. USDA & HHS, Scientific Report of the 2015 Dietary Guidelines Advisory Committee pt. D ch. 5 (2015).
572. Tom Vilsack & Sylvia Matthews Burwell, *2015 Dietary Guidelines: Giving You the Tools You Need to Make Healthy Choices*, USDA Blog, Oct. 6, 2015, https://www.usda.gov/media/blog/2015/10/6/2015-dietary-guidelines-giving-you-tools-you-need-make-healthy-choices.
573. *E.g.*, Michele Simon, My Plate, My Planet: Food for a Sustainable Nation—Statutory Authority for Sustainability in the Dietary Guidelines for Americans: Legal Analysis (2015).
574. 7 U.S.C. §5302.
575. Ministry of Health of Brazil, Dietary Guidelines for the Brazilian Population 18-19, 31-32 (2d ed. 2014); Megha Cherian, *Sustainability: A Growing Factor in Dietary Guidelines?*, Global Citizen, May 11, 2016, https://www.globalcitizen.org/en/content/sustainability-growingfactor-in-dietary-guidelines/.
576. USDA, *supra* note 571.
577. *Id.* at 1-2.
578. Ministry of Health of Brazil, *supra* note 575, at 31-32.

is important and almost 80% are seeking to eat more fruits and vegetables, which generally have a much lower climate impact than animal products. The same share of consumers are familiar with the "MyPlate" graphic that embodies the U.S. dietary guidelines.[579] Thus, further revision to the dietary guidelines would help Americans learn about the environmental consequences of their food choices, while immediately affecting what millions of Americans eat each day. It would also help secure the long-term viability of the United States' food supply.

B. *Prioritize Climate Change Mitigation in Procurement Contracts*

The 2008 Farm Bill directed USDA to pass regulations encouraging institutions participating in child nutrition programs to purchase local agricultural products.[580] Three years later, USDA issued a rule allowing these institutions to apply a geographic preference in the procurement of unprocessed, local agricultural products.[581] Congress should pass similar legislation explicitly allowing schools participating in child nutrition programs to give a preference to low-carbon agricultural products. Additionally, Congress could pass legislation prioritizing low-carbon agricultural products for all government bodies, including large-scale purchasers such as the U.S. Department of Defense. Modeled on Massachusetts' local preference law, which requires state agencies to give preference to food products grown or produced in Massachusetts, such a law would provide carbon farmers with an enormous new market.[582]

States and local governments, of course, should pass similar laws. Large institutions and corporations seeking to improve their sustainability can also look to food purchasing as an important opportunity.

C. *Private-Sector Strategy*

1. Create a Certification System

Certification is another method that may help encourage the growth of carbon farming. Organic certification has helped create a price premium for organic products, leading to increased investment and innovation in the field.[583] As a result, organic food has grown from 1% of the market in 1997 to almost 5% of the market in 2014.[584] It is not clear whether the certification program has driven more sustainable practices in conventional agriculture, although some argue that it has helped spur increased interest in "natural" and other weaker indications of sustainability. More importantly, perhaps, this certification system and the growth of this approach demonstrate the feasibility of such farming, laying the groundwork for stronger government programs.

Several private organizations,[585] such as the Rainforest Alliance and Fairtrade Netherlands, already have, or are in the process of developing, certifications for carbon-neutral coffee.[586] Environmental groups and other nonprofit organizations should expand on these initiatives by developing certification programs for other carbon-neutral food products, which could have the same impact over time as the organic certification and could help boost interest and investment in climate-friendly practices.[587]

2. Expand Restaurant Menu Options

Almost a third of all calories consumed in the United States are from foods prepared away from home.[588] Studies also show that people tend to consume more calories and meat when eating out.[589] In this environment, climate-friendly diets are unlikely to catch on unless consumers have easy and inexpensive access to prepared foods that are climate friendly. Currently, the average restaurant menu, whether fast-food or sit-down, principally offers carbon-intensive meat options for entrées.[590] Restaurants should offer an expanded range of low-carbon options, helping to make climate-friendly diets more convenient and

579. International Food Information Council Foundation, 2017 Food and Health Survey (2017).
580. Food, Conservation, and Energy Act of 2008, Pub. L. No. 110-234, §1102, 122 Stat. 923, 1125-26.
581. Geographic Preference Option for the Procurement of Unprocessed Agricultural Products in Child Nutrition Programs, 76 Fed. Reg. 22603 (Apr. 22, 2011) (codified at 7 C.F.R. pts. 210, 215, 220, 225-226).
582. Mass. Gen. Laws Ann. ch. 7, §23B (West 2012).
583. *See* Toensmeier, *supra* note 1, at 369.
584. USDA, ERS, *Organic Market Overview*, https://www.ers.usda.gov/topics/natural-resources-environment/organic-agriculture/organic-market-overview/ (last updated Apr. 4, 2017).
585. A publicly administered national certification system would have several advantages; however, the federal government is unlikely to develop one without prior successful private initiatives. The first organic certification agency in the United States, California Certified Organic Farmers, was created in 1973, 17 years before Congress established a national organic certification system with the passage of the Organic Foods Production Act of 1990.
586. *Project Profile: Sustainable Climate-Friendly Coffee (CO_2 Coffee)*, Rainforest Alliance, July 31, 2016, http://www.rainforest-alliance.org/work/climate/projects/oaxaca-carbon-coffee; Fairtrade Max Havelaar, *Klimaatneutrale Koffie [Climate-Neutral Coffee]*, http://www.fiks-maxhavelaar.nl/klimaat-neutrale-koffie/ (last visited Apr. 12, 2018).
587. It remains to be seen whether environmental concerns will motivate consumers to purchase certified products. Research indicates that organic food consumers are largely motivated by health and taste. Renée Hughner et al., *Who Are Organic Consumers? A Compilation and Review of Why People Purchase Organic Food*, 6 J. Consumer Behav. 94, 101-03 (2007).
588. USDA, ERS, *Food-Away-From-Home*, https://www.ers.usda.gov/topics/food-choices-health/food-consumption-demand/food-away-from-home.aspx (last updated Feb. 8, 2018).
589. Jessica E. Todd et al., USDA, The Impact of Food Away From Home on Adult Diet Quality 7-8 (2010) (ERRN-90), https://www.ers.usda.gov/webdocs/publications/46352/8170_err90_1_.pdf?v=41056.
590. In fact, "entrée" was generally used to refer to a "substantial meat course" in the United States until the Second World War. Dan Jurafsky, The Language of Food: A Linguist Reads the Menu 30 (2014).

affordable.[591] In response to the significant health impact of "commodity-based diets" high in corn, wheat, soy, and animal products,[592] local governments, through their own purchasing, advertising, or public support, could also encourage a wider range of whole or minimally processed plant-based options at restaurants. Doing so would support restaurants that market more vegetarian options, as well as low-carbon options such as meat and dairy products from integrated crop-livestock systems with demonstrated climate benefits.

VII. Conclusion

Carbon neutrality in agriculture is achievable and should be a priority for the United States. As of 2016, agriculture was responsible for almost 10% of U.S. greenhouse gas emissions, while the nation's food system as a whole contributed approximately double that amount. This is avoidable. The climate-friendly agricultural practices included in this chapter are proven to significantly reduce greenhouse gas emissions from farming, ranching, and livestock production. In addition, agriculture is unique among major sectors of the economy in possessing the potential not only to reduce emissions, but also to remove carbon from the atmosphere and sequester it in the soil. By both reducing emissions and increasing soil carbon sequestration, U.S. agriculture can become carbon neutral.

Curbing climate change is not the only reason that policymakers and producers should support agricultural practices that reduce emissions or increase soil carbon. Virtually all of these practices—including, for example, more precise fertilizer application, cover crops, managed rotational grazing, agroforestry, silvopasture, and improved manure management—also provide other environmental benefits such as clean water or wildlife habitat. In addition, these practices make agricultural operations more resilient to changes in weather patterns that will come with climate change. Finally, many of these practices are cost effective, especially over the longer term.

U.S. policymakers should support the widespread adoption of climate-friendly agricultural practices. For instance, USDA should fund additional research and the extension service should expand farmer training. Congress and USDA should reform the major farm support programs, including crop insurance, commodity payments, and conservation programs, to incentivize or even to require adoption of climate-friendly practices. Congress, USDA, and other federal agencies should also use the farm bill and trade, tax, regulatory, and financing tools to encourage these practices. State legislatures and agencies should employ similar tools. The private sector also has a significant role to play in encouraging and leveraging governmental action.

Climate change presents perhaps the most significant threat to agriculture and human well-being. However, it remains politically divisive. The many benefits of climate-friendly agricultural practices should make them attractive to all, regardless of one's views on climate change. Thus, while change has often been slow in the agricultural sector, there is a real opportunity to realize climate neutrality in agriculture, while improving other environmental attributes, rural communities, and producer income. Policymakers and others should take up this challenge with energy.

591. Such a development would likely require significant consumer demand and pressure. *See* Karen Ganz et al., *How Major Restaurant Chains Plan Their Menus: The Role of Profit, Demand, and Health*, 32 Am. J. Preventative Med. 383 (2007).

592. *See* Ludwig, *supra* note 168.