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Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass

Claudia Hitaj and Shellye Suttles

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Abstract

This report examines recent trends in energy use in the agricultural sector and the extent to which farm businesses engage in on-farm energy production. A 2013 ERS report on energy consumption and production in agriculture focused on corn and soybean production for the biofuel market and farmer responses to rising energy prices. However, since then, increasing volume mandates for cellulosic biofuel in the Renewable Fuel Standard, as well as the shale energy revolution and the promulgation of the Clean Power Plan (CPP), have changed (or could change, in the case of CPP) agriculture's energy use and production patterns. The study finds that a small but growing number of farms harvest cellulosic biomass. Also, while the shale revolution contributed to lowering natural gas and fuel prices, domestic fertilizer prices have not substantially diverged from global prices–even though natural gas remains the major production cost for fertilizer. Shale energy production has impacted enrollment in the Conservation Reserve Program (CRP); the study finds that between 2006 and 2013, CRP acreage in counties overlaying shale plays declined, on average, at a greater rate (32 percent) than in non-shale counties (22 percent). The impact of the CPP on farm electricity use is expected to be minor for most farm businesses, as electricity represents, on average, only 1 to 6 percent of their total production expenses.

Keywords: Energy; agriculture; renewable energy; shale; biofuel; biomass; Renewable Fuel Standard; Clean Power Plan

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Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass

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What Is the Issue?

Since the early 2000s, energy policy and market conditions have affected the agriculture sector as both a consumer and producer of energy. Farms consume energy directly in the form of gasoline, diesel, electricity, and natural gas, and indirectly in energy-intensive inputs such as fertilizer and pesticides. In addition, some farms produce renewable energy or lease out land for wind turbine, oil, or gas development.

In 2005, the Renewable Fuel Standard (RFS) was enacted, requiring transportation fuel sold in the United States to contain a minimum volume of biofuels, directly impacting agriculture as a producer of biofuel feedstocks. Technological advances in hydraulic fracturing and horizontal drilling have made the extraction of natural gas and oil from shale plays economically feasible, contributing to a decline in U.S. natural gas and oil prices. Farms in drilling regions benefit from lease and royalty payments, but they also experience environmental costs and strained infrastructure. In August 2015, the Environmental Protection Agency finalized the Clean Power Plan (CPP) to reduce carbon emissions from the power sector (although the Supreme Court issued a stay on implementation of the regulation in February 2016). The CPP's emission reductions are expected to be achieved by shifting from coal toward natural gas and renewables, with implications for energy production and consumption in agriculture.

In this report, the authors analyze consumption and production of energy across farms, as well as how changes in the energy sector affect the agricultural sector. The report focuses mainly on impacts on farm businesses, defined as farms where the primary operator spends the majority of time on agricultural production, or, when the operator is largely employed off-farm, where the farm operation has over $350,000 in annual gross-cash income.

What Did the Study Find?

Although farm businesses account for only 41 percent of all U.S. farms, they account for 93 percent of the value of agricultural production and 90 percent of fuel and electricity consumption.

- Energy consumption by farm businesses varies significantly by principal commodity. In 2014, fuel and electricity constituted 12-16 percent of total cash expenses for rice, cotton, peanut, and poultry producers compared with 7-10 percent for other crop and livestock producers. In addition, the share of indirect energy expenses, in the form of fertilizers and pesticides, ranged from 16-36 percent of total cash expenses for crop producers.

- Farmers' energy consumption also varies by tillage practice. Tillage reduced through conservation or no tillage is associated with lower fuel but greater fertilizer and pesticide expenditures for corn and wheat producers. In contrast, reduced tillage is associated with greater fuel but lower fertilizer expenditures for cotton producers.

Changes in energy markets and regulations are affecting agriculture in different ways. Farmers have become energy suppliers by growing biomass and installing renewable energy systems and by leasing land to energy companies. Changing energy prices thus affect farmers' input costs, as well as revenue from supplying energy products.

- Over 57,000 farm businesses and other farms (2.7 percent of U.S. farms) were engaged in producing renewable energy such as solar, wind, and geothermal in 2012, more than twice as many as in 2007. In 2012, another 10,000 farm businesses and other farms leased their wind rights to others.
- A small but growing number of farms (nearly 12,000, or 0.5 percent of farms in 2012) is harvesting cellulosic biomass to help meet the Renewable Fuel Standard volume mandates for cellulosic biofuel.
- In 2012, 35 percent of active farm and ranch land was in counties overlaying a shale play (shale counties). In 2014, about 6 percent of U.S. farm businesses averaged $56,000 in lease and royalty payments from energy production.
- Acreage in USDA's Conservation Reserve Program declined by about 32 percent in shale counties, on average, from 2006 to 2013, compared with a 22-percent decline in non-shale counties.
- The shale revolution has resulted in declining natural gas and oil prices, which benefit farms with the greatest diesel, gasoline, and natural gas shares of total expenses, such as rice, cotton, and wheat farms. However, domestic fertilizer prices have not substantially fallen despite the large decrease in the U.S. natural gas price (natural gas accounts for about 75-85 percent of fertilizer production costs). This is due to the relatively high cost of shipping natural gas, which has resulted in regionalized natural gas markets, as compared with the more globalized fertilizer market.
- The CPP may result in greater electricity rate increases for agricultural and other rural customers than for the average retail customer, due to rural electric cooperatives' greater share of electricity generation from coal. However, direct-use electricity expenses of farm businesses represent only about 1-6 percent of total production expenses, suggesting relatively small impacts of the CPP for most farm businesses.

How Was the Study Conducted?

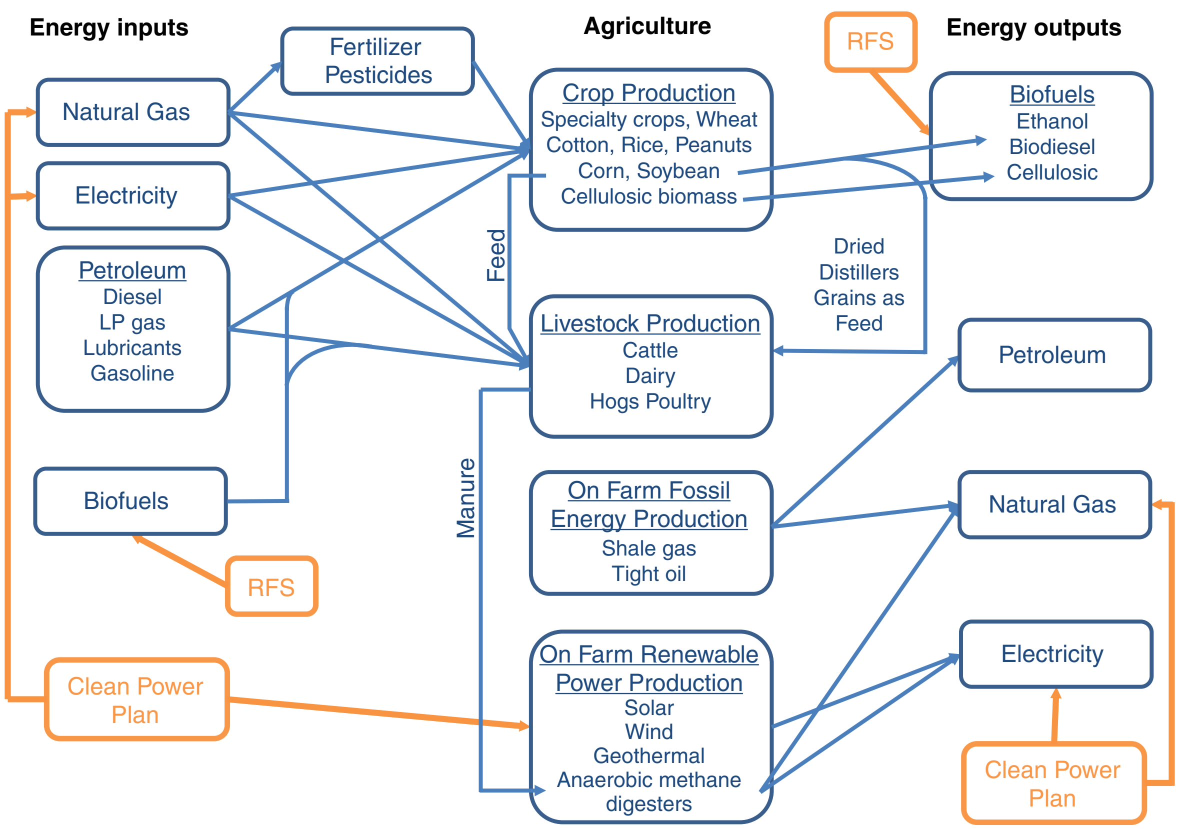
This study uses the most recent USDA data sources on agricultural energy consumption, production, and energy-related lease and royalty income from the 2012 Census of Agriculture, the 2013 Farm and Ranch Irrigation Survey, the 2013 Agricultural Resource Management Survey, and the 2014 Tenure, Ownership, and Transition of Agricultural Land Survey. The report also updates and expands on a previous ERS report by Beckman et al. (2013) that presented information through 2010-11. Beckman's report focused on how expanding biofuel policies increased the demand for agricultural products such as renewable fuel feedstocks, as well as on how farmers adjusted production in response to high energy prices. The current report limits the discussion on biofuels to the cellulosic feedstock volume mandate of the RFS. The authors update and expand Beckman's overview of energy consumption by distinguishing between the different forms of consumption (electricity, natural gas, and diesel, among others) to investigate the impact of the shale energy revolution and the CPP. Finally, the current report provides updated numbers on renewable energy production on farms and discusses new trends in the energy sector, such as industrial energy generation through oil and gas drilling and farmers' leasing of wind rights.

Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass

Introduction

Agriculture has long been a consumer of energy, directly in the form of gasoline and diesel fuels, electricity, and natural gas and indirectly in energy-intensive inputs such as fertilizer and pesticides. In recent decades, agriculture has started producing energy, such as biofuels and renewable electricity, and farmers have allowed their land to be used for oil and gas drilling. As the agriculture and energy markets have become increasingly linked, farmers are impacted by changes in the energy sector through both expenditures and revenue (fig.1).

Figure 1
Relationship between agriculture and energy



RFS = Renewable Fuel Standard.
Source: USDA, Economic Research Service.

Arguably, the two most important drivers of the changing relationship between agriculture and energy are Government mandates for renewable energy (ethanol and other forms) and the shale revolution. Government support for biofuels through the 2005 Renewable Fuel Standard (RFS) spurred a fourfold increase in the consumption of feedstock (primarily corn) for ethanol from 2004 to 2015 (U.S. EIA, 2016a). Corn acreage increased 9 percent during the same period (USDA, NASS, 2016). In addition to the RFS, the U.S. Department of Agriculture (USDA) and Environmental Protection Agency (EPA) have a variety of voluntary programs to support agricultural production of biomass feedstocks (such as corn and soybeans) and renewable energy.

Extraction of the deposits of natural gas in shale formations became profitable with the advent of hydraulic fracturing and horizontal drilling technology. Since large-scale shale gas production began in the Barnett Shale in Texas in the early 2000s, hydraulic fracturing for gas and oil trapped in shale formations has transformed the energy industry, and agriculture has benefited from the resulting drop in energy prices. Other impacts on agriculture from hydraulic fracturing include the clearing of land for drill pads and access roads, increased competition for labor, water, and transportation infrastructure such as rail and trucking, and lease and royalty payments to landowners who also own the mineral rights (Hitaj et al., 2014).

A possible future change in energy markets that could affect agriculture is regulation of carbon emissions. In August 2015, the Environmental Protection Agency (EPA) finalized the Clean Power Plan to reduce carbon emissions from the power sector 32 percent by 2030 (though the Supreme Court stayed implementation of the rule in February 2016). As electricity costs average about 1-6 percent of total expenses for farm businesses, impacts are expected to be minor and to affect mainly the livestock sector, irrigated farms, and peanuts, cotton, rice, and specialty crops. The greatest impact of the Clean Power Plan on agriculture, should it be implemented, would be the increased demand for renewable energy, as a growing number of farms are engaged in renewable energy production.

Most recently, the USDA announced its own Climate Change Mitigation Strategy to reduce greenhouse gas emissions from agriculture, which includes Building Blocks for Climate-Smart Agriculture and Forestry. One building block focuses on increasing on-farm energy generation and improving agricultural energy efficiency through incentives rather than regulations. All the building blocks together aim to reduce agricultural greenhouse gas emissions by 120 million metric tons of carbon dioxide equivalent per year (about 20 percent from current levels) by 2025 (USDA, 2015).

The relationship between the agriculture and energy sectors and the pathways by which the Renewable Fuel Standard and the Clean Power Plan could affect agriculture are highlighted in figure 1. Petroleum, electricity, natural gas, and biofuels are linked to agriculture as both energy inputs and outputs. The increase in energy outputs is the result of policy and market changes such as the Renewable Fuel Standard, the shale energy revolution, and Government incentives for renewable power.

This report builds partly on a previous ERS report: *Agriculture's Supply and Demand for Energy and Energy Products* by Beckman, Borchers, and Jones (2013). Beckman et al. focused on how record-high energy prices and expanding biofuel policies had increased the demand for agricultural products such as renewable fuel feedstocks, as well as on how farmers adjusted production in response to higher agricultural commodity prices and increased costs of production. In the present study, the authors limit discussion of biofuels to the cellulosic-feedstock-volume mandate of the

Renewable Fuel Standard, since Beckman et al. analyze in detail corn for ethanol and soybean for biodiesel production and the impact on the livestock feed sector. The previous report also provides an overview of energy consumption, which this report updates and expands, in particular by distinguishing the different forms of energy consumption (electricity, natural gas, diesel, and gasoline, among others) to investigate the impact on agriculture of the shale energy revolution and the Clean Power Plan. Finally, this report provides updated numbers on renewable energy production on farms and discusses industrial energy generation on farms through oil and gas drilling or leasing wind rights.

The analysis is based on several data sources. The Census of Agriculture, which is conducted every 5 years by USDA's National Agricultural Statistics Service (NASS), provides a detailed picture of U.S. farms and ranches and the people who operate them. We use data from the most recent Census of 2012. The Agriculture and Resource Management Survey (ARMS), which is conducted annually by NASS and USDA's Economic Research Service (ERS), targets about 30,000 farms and collects financial information for farm businesses and a variety of financial and demographic information for farm operators and their households. Dubman (2000) provides an overview of survey estimators, sample design, disclosure rules, and reliability measures for ARMS, as well as a description of how the coefficient of variation (CV) is estimated with the delete-a-group jackknife method. The Tenure, Ownership, and Transition of Agricultural Land (TOTAL) Survey, which was conducted by NASS and ERS in 2014, is a study of all landlord owners of agricultural land, including nonoperators (who rent out the land they own). One version of the TOTAL survey was designed for these nonoperator landlords, while the other version surveyed farm operators and is similar to the ARMS of previous years (in fact, replacing ARMS in 2014). The present report uses the operator version of TOTAL.

On-Farm Energy Consumption

Agricultural operations consume energy in a variety of forms: directly as gasoline, diesel, electricity, or natural gas, and indirectly as fertilizer or pesticide. Large amounts of natural gas are required in the manufacturing of fertilizer and pesticide, so these inputs are categorized as indirect energy consumption on farms. In this section, we explore how energy consumption on farms has changed over time and how it differs across farms by principal commodity, farm size, and production practices.

We estimate energy consumption by the agricultural sector using data on energy prices and farm expenses for energy inputs from the National Agricultural Statistics Service (USDA, NASS, 2016). For example, diesel consumption in the agricultural sector is estimated as the total amount paid by farms for diesel divided by the annual average price of diesel, which yields diesel consumption in gallons and is converted to British thermal units (Btu) using energy content factors from the U.S. Energy Information Administration (EIA, 2015e). Miranowski (2005) estimated the implied energy use associated with fertilizer and pesticide consumption, and we base our estimates on the energy content ratios he determined. Since we use average yearly prices—which mask within-year variation—to calculate energy consumption, the results should be viewed with caution, in particular for periods with high energy price volatility such as 2006-09.

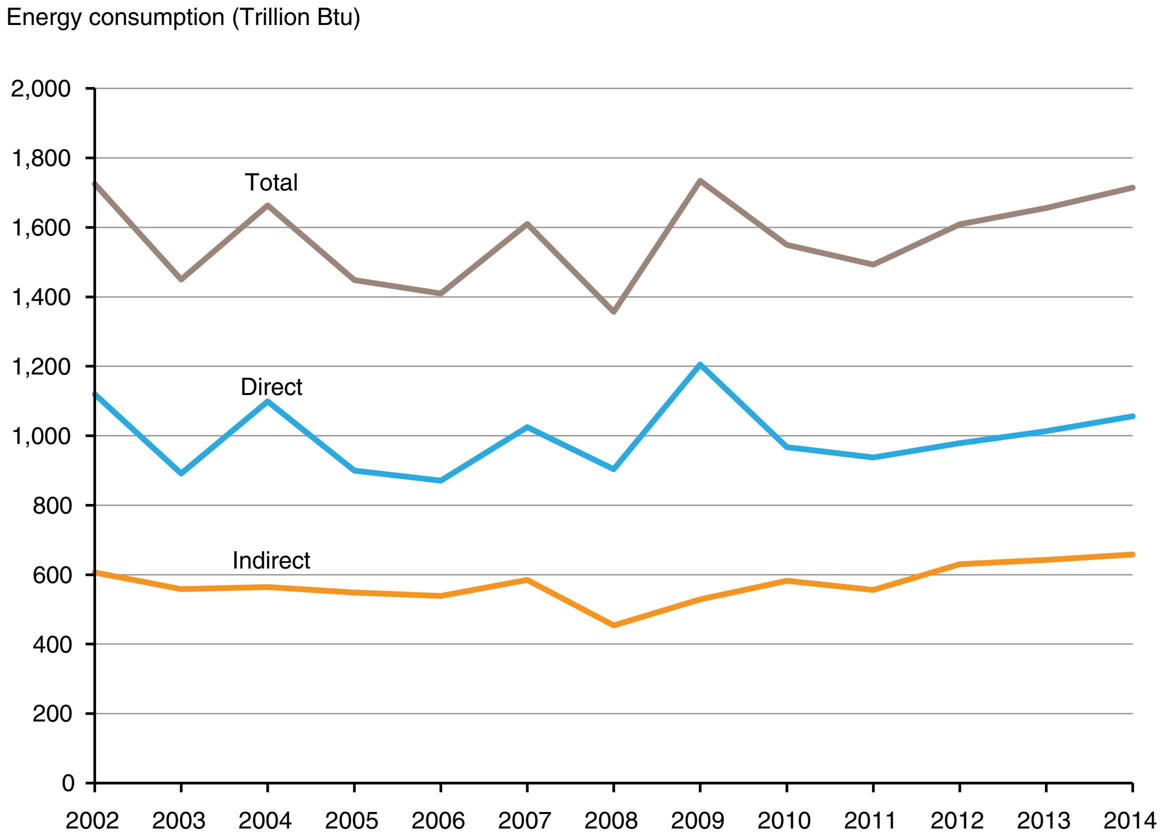
In 2014, the agricultural sector consumed 1,714 trillion Btu of energy, accounting for about 1.74 percent of total U.S. primary energy consumption, and about 60 percent of this energy was consumed directly (fig. 2). Total agricultural energy consumption peaked at 1,700 trillion Btu in 2009, dropped to 1,500 trillion Btu in 2012, and has been increasing since then. Diesel, gasoline, and liquefied petroleum (LP) gas consumption declined from 2009 to 2012 but has increased since then, while electricity and natural gas consumption has increased steadily since 2005 (fig. 3).

The total amount and form of energy consumed varies based on a farm's principal commodity, that is, a production specialty that accounts for more than half of an operation's value of production. For example, cotton production requires large amounts of electricity to operate irrigation pumps; dryland wheat production does not. Previous research has shown that the production of certain crops results in significantly different energy expenditures (Beckman et al., 2013). In the next section, we explore these differences in detail.

Agricultural producers adjust their energy consumption according to the practices they choose, given prices in the input markets. As energy prices increase, agricultural producers can reduce their energy expenditures by purchasing fewer energy-based inputs, improving their energy efficiency, and switching to less-energy-intensive crops. Differences in energy consumption across production practices imply that there is opportunity to reduce energy consumption within each commodity category by changing production practices. However, the changes would not be without tradeoffs. For example, an analysis of ARMS 2013 data reveals that adopting conservation till and no-till practices to reduce soil erosion and fuel expenses (due to fewer machine passes in the field) are accompanied by increased pesticide and fertilizer expenditures for corn and wheat producers.

Sands et al. (2011) find that the agricultural sector is sensitive to changes in energy prices both directly and indirectly. The authors find that higher energy-related production costs would decrease agricultural output, increase agricultural prices, and decrease farm income. Indeed, farm operators report they have adjusted their production in response to higher fuel and fertilizer prices (Beckman,

Figure 2
Total, direct, and indirect energy consumption in the agricultural sector

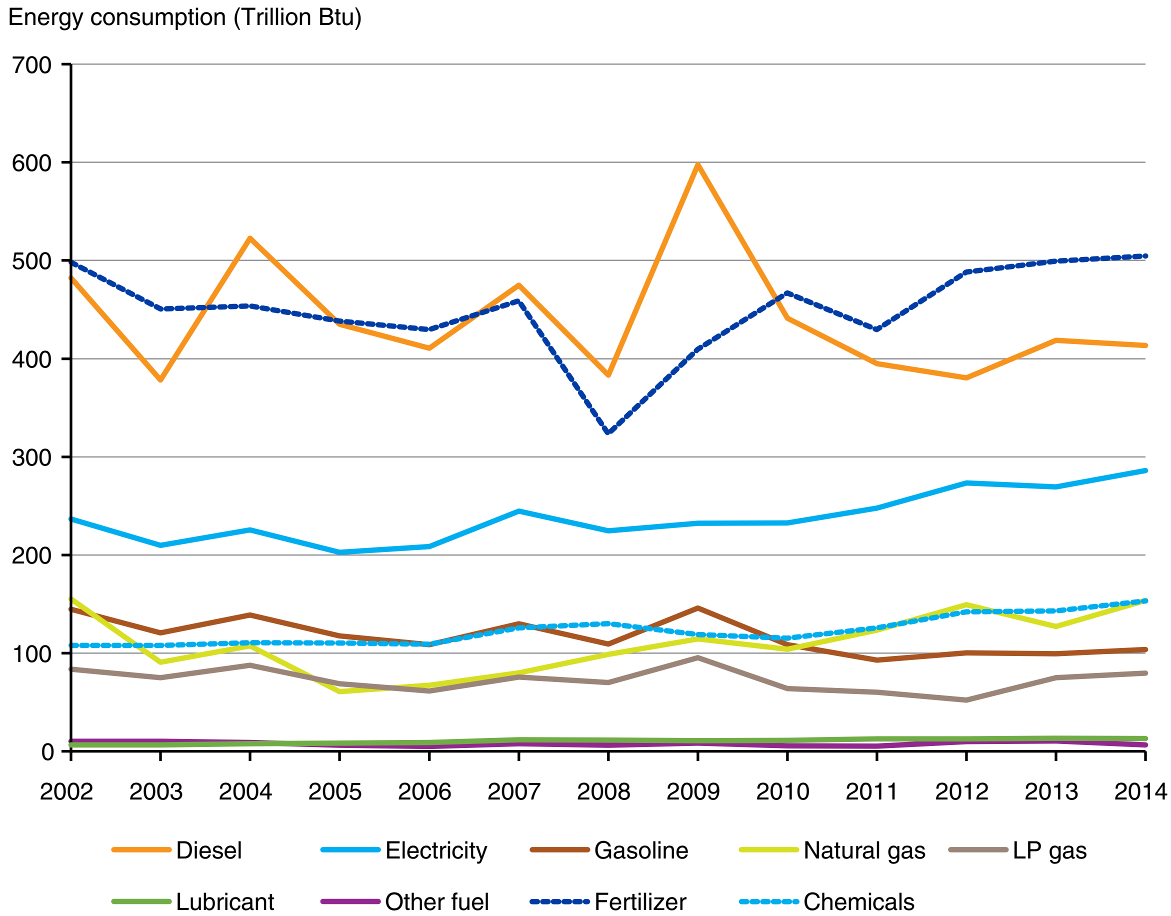


Source: USDA, Economic Research Service calculations using data from National Agricultural Statistics Service (NASS) Quick Stats 2.0 (USDA, NASS, 2016), U.S. Energy Information Administration (EIA, 2015e), and Miranowski (2005). Energy consumption is computed by dividing expense statistics (USDA, NASS, 2016) for the different categories by prices (EIA, 2015e) and then converting the consumption unit (gallons of diesel or cubic feet of natural gas, for example) into British thermal unit (Btu) using data from EIA (2015e). The energy associated with the consumption of fertilizer and agricultural chemicals was estimated by using the energy content ratios determined by Miranowski (2005). Since we use average yearly prices, which mask within-year variation, to calculate energy consumption, the results should be viewed with caution, in particular for periods with high energy-price volatility such as 2006-09.

et al., 2013). Nationally, 20 percent of farms reported reduced fuel use in response to higher prices, and 32 percent reported less fertilizer use due to higher fertilizer prices.

The USDA defines a farm as any place that produced and sold—or normally would have produced and sold—at least $1,000 of agricultural products during a given year. USDA uses acres of crops and head of livestock to determine if a place with sales of less than $1,000 could normally produce and sell that amount. Given this relatively broad definition of a farm, we focus primarily on *farm businesses* in our analysis of energy consumption and production in U.S. agriculture. According to the farm typology developed by the USDA Economic Research Service, *farm businesses* are classified as farms where the principal operator is currently employed and spends the majority of work time on agricultural production (the primary occupation is farming), or, if the principal operator is largely employed off-farm, the operation has over $350,000 in annual gross cash farm income (GCFI). In the USDA 2014 Agricultural Resource Management Survey (ARMS), although farm businesses only account for 41 percent of all U.S. farms, they account for 93 percent of the value of agricultural production and 90 percent of U.S. farm fuel and electricity consumption.

Figure 3
Direct and indirect energy consumption by fuel in the agricultural sector



LP = Liquefied petroleum.
Source: USDA, Economic Research Service calculations using data from National Agricultural Statistics Service (NASS) Quick Stats 2.0 (USDA, NASS, 2016), U.S. Energy Information Administration (EIA, 2015e), and Miranowski (2005). Energy consumption is computed by dividing expense statistics (USDA, NASS, 2016) for the different categories by prices (EIA, 2015e) and then converting the consumption unit (gallons of diesel or cubic feet of natural gas, for example) into British thermal unit (Btu) using data from EIA (2015e). The energy associated with the consumption of fertilizer and agricultural chemicals was estimated by using the energy content ratios determined by Miranowski (2005). Since we use average yearly prices, which mask within-year variation, to calculate energy consumption, the results should be viewed with caution, in particular for periods with high energy-price volatility such as 2006-09.

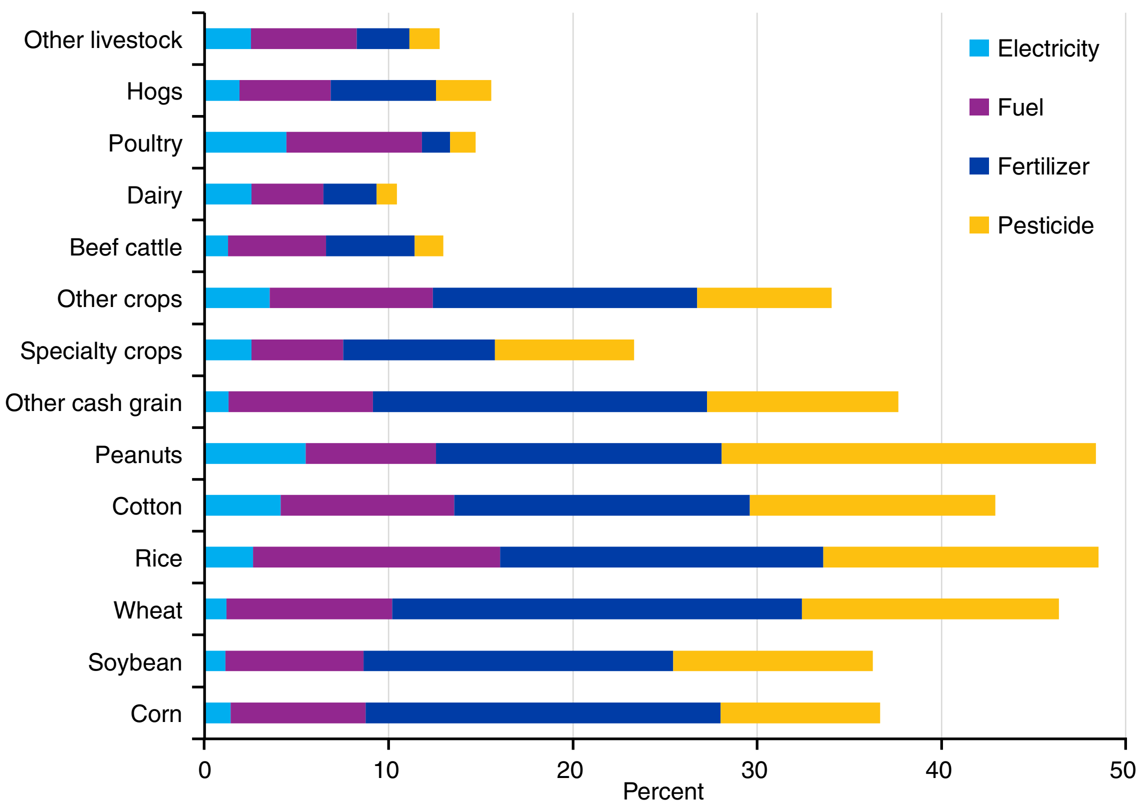
Energy Consumption by Principal Commodity

We compare energy consumption across farm businesses by their principal commodity–a production specialty that accounts for more than half of an operation's value of production. Farm businesses often produce multiple commodities, so the energy consumption statistics should not be interpreted as related solely to the commodity highlighted as the principal commodity. For example, a farm may produce corn and soybeans, but apply fertilizer only to cornfields, as fertilizer is rarely applied in soybean production. If soybeans account for just over half of that farm's value of production, the fertilizer expenses incurred for the production of corn are attributed to soybeans instead. Other examples include livestock farms that also grow crops, so that fertilizer and pesticides applied to the crop appear as expenses for the livestock. However, comparisons across farm businesses by principal commodity still reveal general trends in energy consumption across commodities, because the principal commodity accounts for the majority of the farm's value of production.

In recent years, farms producing wheat, corn, and sorghum, along with cotton and rice, had the highest shares of energy-based inputs (Beckman et al., 2013; Suttles, 2014). To compare energy consumption across farm businesses that produce different principal commodities, we measure energy-based expenses as a percentage of total cash expenses, which includes both variable costs, such as feed, seed, and labor, and fixed costs, such as insurance, taxes, and land rental. In 2014, farm businesses producing rice, peanuts, wheat, and cotton had the highest share of energy-based expenses, as shown in figure 4 (USDA, NASS, 2015d). Fertilizer and pesticides have the greatest share of energy expenses among crop producers. Fertilizer expenses are 22 percent of total cash expenses for wheat producers, 19 percent for corn producers, and 18 percent for other cash-grain producers. Cotton and rice production have high shares of direct energy inputs: fuel is used to apply

Figure 4

Share of 2014 farm business energy-based expenses as a percentage of total cash expenses, by principal commodity



Note: Fuel includes diesel, gasoline, natural gas, liquefied petroleum (LP) gas, lubricants, and other fuel. Other livestock includes horses, goats, and other livestock. Specialty crops include fruits, nuts, vegetables, and nursery/greenhouse production. Other crops include tobacco, edible beans, edible peas, and other legumes. Other cash grain includes sorghum, barley, and oats. Farm businesses may produce more than one commodity, so the energy-based expenses should not be attributed solely to the principal commodity, which is the production specialty that accounts for more than half of an operation's value of production.

The coefficient of variation (CV) is 50-75 percent for the share of electricity expenses for peanuts, and less than 50 percent otherwise. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

Source: USDA, National Agricultural Statistics Service and USDA, Economic Research Service, 2014 Tenure, Ownership, and Transition of Agricultural Land Survey.

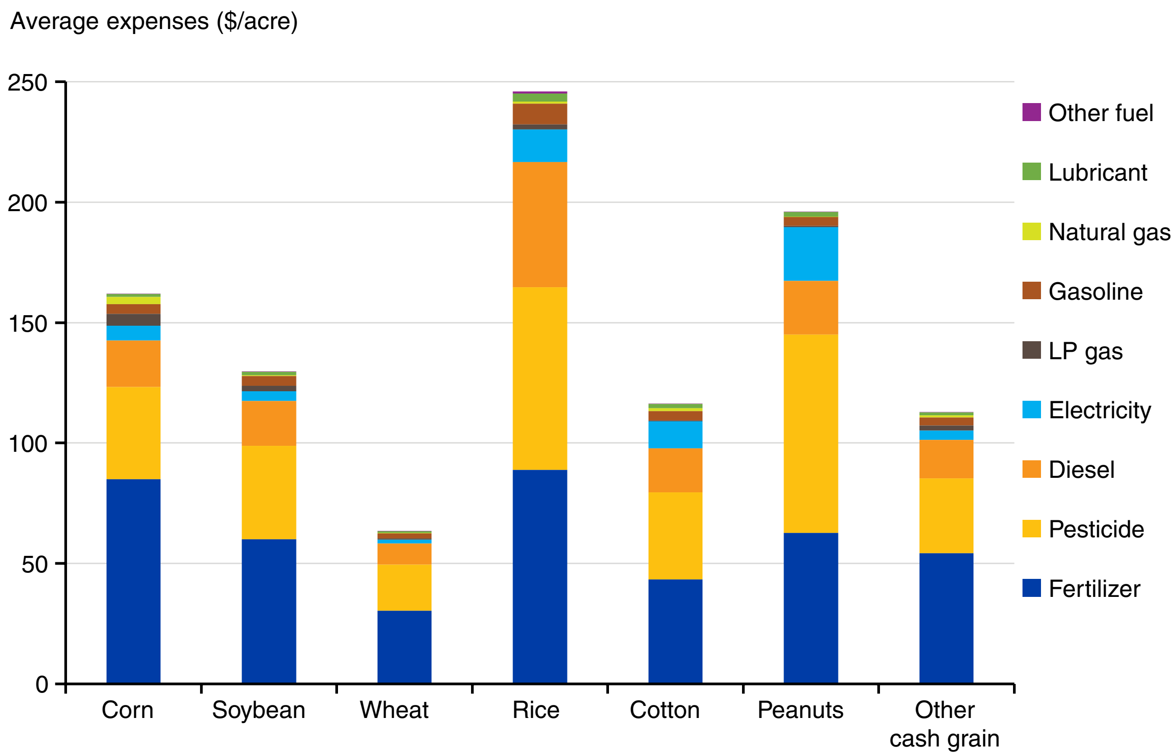
chemicals and electricity powers irrigation equipment. Peanut producers had the highest shares of electricity use at 6 percent, followed by poultry and cotton producers at 4 percent.

In 2014, rice producers spent on average almost $250 per acre on energy-related inputs compared with about $60 per acre for wheat producers. Figure 5 shows that fertilizer expenses per acre were highest for rice ($89) and corn ($85) producers, while peanut and rice producers spent almost twice as much on pesticides per acre, $82 and $76 respectively, than any of the other crop producers. Direct energy expenses per acre for fuels and electricity were greatest for rice ($82) and peanut ($51) producers.

Among livestock producers, hog and dairy operations had the highest average energy-related expenses per farm in 2014 at $91,000 and $85,000, respectively (fig. 6). Hog and dairy farmers had higher expenses for fertilizer and pesticide compared to beef cattle ranchers and other livestock producers, as they often engage in crop production as well. Dairy operations had the highest expenses for direct energy, mostly diesel and electricity. Poultry operations had the highest average

Figure 5

Average energy-based expenses per acre for crop farm businesses, by principal commodity, 2014



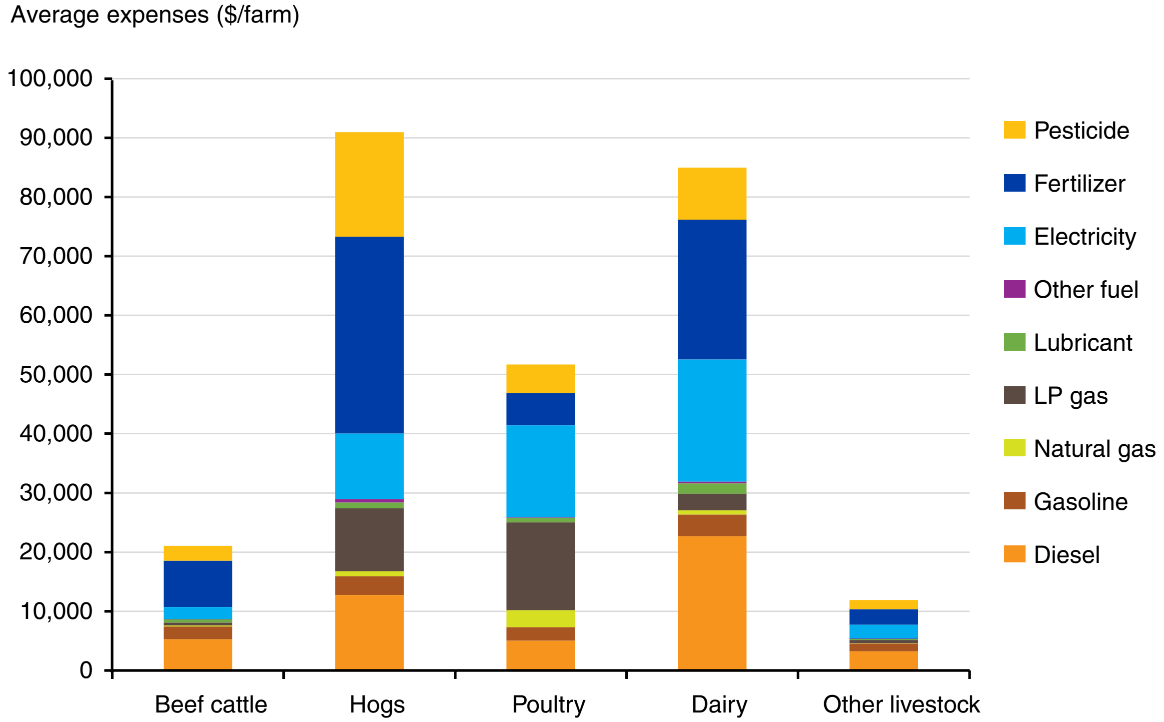
LP = Liquefied petroleum.

Note: Other cash grain includes sorghum, barley, and oats. Other crops include tobacco, edible beans, edible peas, and other legumes. Farm businesses may produce more than one commodity, so the energy-based expenses should not be attributed solely to the principal commodity, which is the production specialty that accounts for more than half of an operation's value of production.

Natural gas and other fuel expenses per acre for peanuts are not included because there are too few observations to disclose the statistic. The coefficient of variation (CV) is greater than 50 percent for electricity (peanuts), natural gas (corn, rice, cotton, and other cash grain), LP gas (peanuts), lubricant (peanuts), and other fuel (rice, cotton). The CV is less than 50 percent otherwise. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

Source: USDA, National Agricultural Statistics Service and USDA, Economic Research Service, 2014 Tenure, Ownership, and Transition of Agricultural Land Survey.

Figure 6
Average energy-based expenses per farm for livestock farm businesses, by principal commodity, 2014



LP = Liquefied petroleum.

Note: Farm businesses may produce more than one commodity, so the energy-based expenses should not be attributed solely to the principal commodity, which is the production specialty that accounts for more than half of an operation's value of production.

The coefficient of variation (CV) is 25-50 percent for natural gas expenses (hogs, poultry, dairy), lubricant (poultry), and other fuel (hogs, poultry). The CV is less than 25 percent otherwise. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

Source: USDA, National Agricultural Statistics Service and USDA, Economic Research Service, 2014 Tenure, Ownership, and Transition of Agricultural Land Survey.

expenses for liquid propane gas ($14,847, about 30 percent of their energy expenditures), as many poultry farms use propane to heat their poultry houses.

Direct Energy Use

The use of energy-related inputs involves direct and indirect inputs, as noted. Direct energy inputs include electricity and diesel, gasoline, natural gas, propane, and other fuels. Indirect energy implies that the energy consumption takes place off-farm; in agriculture, these indirect energy inputs are typically fertilizer and pesticide, which require energy for their manufacture.

Electricity

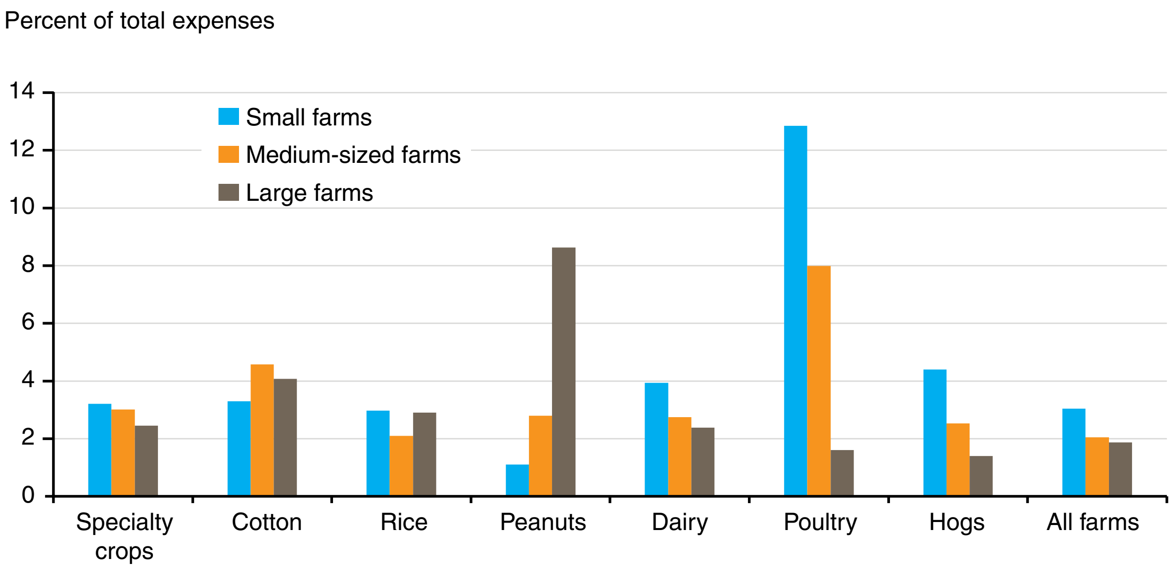
Electricity is used in a variety of ways in on-farm agricultural production. For example, field crop producers use it in pumping water for irrigation, grain drying, and storage ventilation. Greenhouse crop producers use electricity for irrigation, heating, air circulation and ventilation fans, and supplemental lighting. Dairy and livestock producers use electricity in vacuum pumping and cooling milk, feeding equipment, ventilation, water heating, animal-house heating and cooling, and lighting. Agricultural extension agencies offer professional guidance and energy audits for improving energy efficiency across fuel sources in agricultural production (DATCP, 2006; Runkle and Both, 2011; Shouse et al., 2012).

The U.S. Energy Information Administration (Tyson, Brown, and Harnish, 2014) finds that farmers account for a significant share of industrial electricity consumers in States where there is high demand from farm irrigation systems. In these States, farmers pay a high cost to connect irrigation systems to the grid, and due to seasonal demand, they sometimes pay high prices for electricity. Rural utilities may consider farmers as industrial users or separately as agricultural irrigation service customers.

In 2014, peanut, poultry, and cotton producers had the highest share of electricity expenses (5.5 percent, 4.4 percent, and 4.1 percent, respectively) as a percentage of total expenses. When we examine farm businesses based on farm size (fig. 7), we find that small poultry producers had the highest share of electricity expenses (12.8 percent) in 2014, about 8 times greater than large poultry producers. Large operations among all farm types often had the lowest shares of electricity expenditure, with the exception of peanut producers. The higher share of electricity expenses for large

Figure 7

Farm business shares of electricity expenses (as a percentage of total expenses) in 2014, by principal commodity and farm size



Note: Small, medium, and large farms are categorized as gross cash farm income under $350,000, between $350,000 and $999,999, and $1 million and over, respectively. Farms with gross cash farm income less than $350,000 are considered farm businesses only if the principal operator spends the majority of time working for the farm. Farm businesses may produce more than one commodity, so the electricity expenses should not be attributed solely to the principal commodity, which is the production specialty that accounts for more than half of an operation's value of production.

The coefficient of variation (CV) is 50-75 percent for the share of electricity expenses for large farm businesses (poultry), 25-50 percent for large farm businesses (rice, cotton), and less than 25 percent otherwise. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

Source: USDA, National Agricultural Statistics Service and USDA, Economic Research Service, 2014 Tenure, Ownership, and Transition of Agricultural Land Survey.

peanut producers compared with small peanut producers likely reflects that irrigation and on-farm drying of harvested peanuts are more economical on large farms.

Diesel and Gasoline

Diesel fuels and fuel oils, or distillates, are the dominant fuels consumed in both crop and livestock operations (Hicks, 2014). Distillates and gasoline are used in trucks, tractors, and heavy machinery for tilling, spraying, fertilizing, harvesting, and other agricultural activities. By principal commodity, rice producers had the highest average diesel and gasoline expenses at $61 per acre, compared with $26 per acre for peanuts, $22-$23 per acre for corn, soybeans, and cotton, and $11 per acre for wheat (USDA, NASS, 2015d). The large decline in oil prices since 2014 has reduced fuel costs on farms, particularly those that rely on heavy machinery for their operations. Fuel and oil expenses are forecast to decrease by over 14 percent in 2016, following a similar decline in 2015 (USDA, ERS, 2016).

Diesel fuel has 14 percent higher energy content (Btu) than gasoline and is more energy efficient, but it emits nearly 3 percent more carbon dioxide (pounds of CO_2 per million Btu) (U.S. EIA, 2014b). EPA's National Clean Diesel Campaign (NCDC) sets standards for newly manufactured diesel engines to reduce ozone-forming nitrogen oxides and particulate matter (U.S. EPA, 2014b). The NCDC includes Clean Agriculture USA. This incentive-based program is designed to reduce diesel emissions from older, existing diesel engines and non-road agricultural equipment often found on farms (U.S. EPA, 2010a). Thus far, few agricultural vehicles have used the funds available under these programs.

The Environmental Quality Incentives Program (EQIP) includes an Air Quality Initiative, which provides financial assistance to implement conservation practices that address air resource issues (USDA, NRCS, 2016). In California, where several counties are in nonattainment of the National Ambient Air Quality Standards by the EPA, the typical conservation treatment is the replacement of diesel-powered internal combustion engines that power agricultural vehicles or equipment (such as irrigation pumps) with new diesel-powered engines meeting current California emission standards (USDA, NRCS-CA, 2016).

Natural Gas and Liquefied Petroleum (LP) Gas

On-farm agricultural production uses a relatively low amount of natural gas directly, compared to the amount of indirect natural gas used in ammonia-based nitrogen fertilizer production. Farms may use compressed or liquefied natural gas (LNG) to replace diesel fuel (Filipic, 2013). Natural gas is used in greenhouse heating and grain drying, as well as for operating trucks, tractors, machinery, and irrigation water pumps (U.S. DOE, 2013). Producers of specialty crops, corn, poultry, and cotton had the largest average expenditures per farm for natural gas at $3,105, $2,906, $2,866, and $2,575, respectively.[1] These producers benefit from the decline in natural gas prices due to the production of natural gas through horizontal drilling and hydraulic fracturing.

Liquefied petroleum (LP) gas, which includes propane and butane, is a byproduct of natural gas processing and crude oil refining (U.S. DOE, 2015). Propane is used for a variety of farm operations, such as for powering irrigation systems, high-temperature dryers, building and water heating, flame

[1] The coefficient of variation (CV) is less than 50 percent for specialty crops and poultry and greater than 50 percent for corn and cotton. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

weed control, tractors, and standby generators. In 2005, more than half of U.S. farms used propane for many of these purposes. Winter heating in greenhouse and livestock operations was the most common use (Comis, 2005). In 2014, about 29 percent of energy-related expenses on poultry farms were for LP gas (4 percent of total expenses) (USDA, NASS, 2015d).

Indirect Energy Use

Energy is also needed for the production of agricultural chemicals such as fertilizer and pesticide. Two types of energy are used in chemical production: process energy and inherent energy (Audsley et al., 2009). Process energy is used for heating, cooling, and pressurizing in the manufacturing process. Inherent energy is the primary energy feedstock used in the manufacturing process that is retained in the chemical's structure. Energy is also used in the transport, packaging, and application of agricultural chemicals. Agricultural operations consume energy in other indirect forms, such as the energy required to make seeds or machinery, but we do not account for these forms of indirect energy use in this report.

Fertilizer and Pesticide

In 2014, fertilizer expenses amounted to 20-22 percent of total expenses for wheat and corn producers, the greatest share among all crop producers (USDA, NASS, 2015d). The fertilizers that are most used in the United States contain nitrogen (N), phosphorus (P), and potassium (K). According to Worrell, Phylipsen, Einstein, and Martin (2000), nitrogenous fertilizer production is an energy-intensive industry that consumes approximately 1 percent of global energy supply. Ammonia is the key component of nitrogen fertilizers (85 percent), and natural gas is the primary feedstock (inherent energy) and energy source (process energy) in the production of anhydrous ammonia (Gellings and Parmenter, 2004).

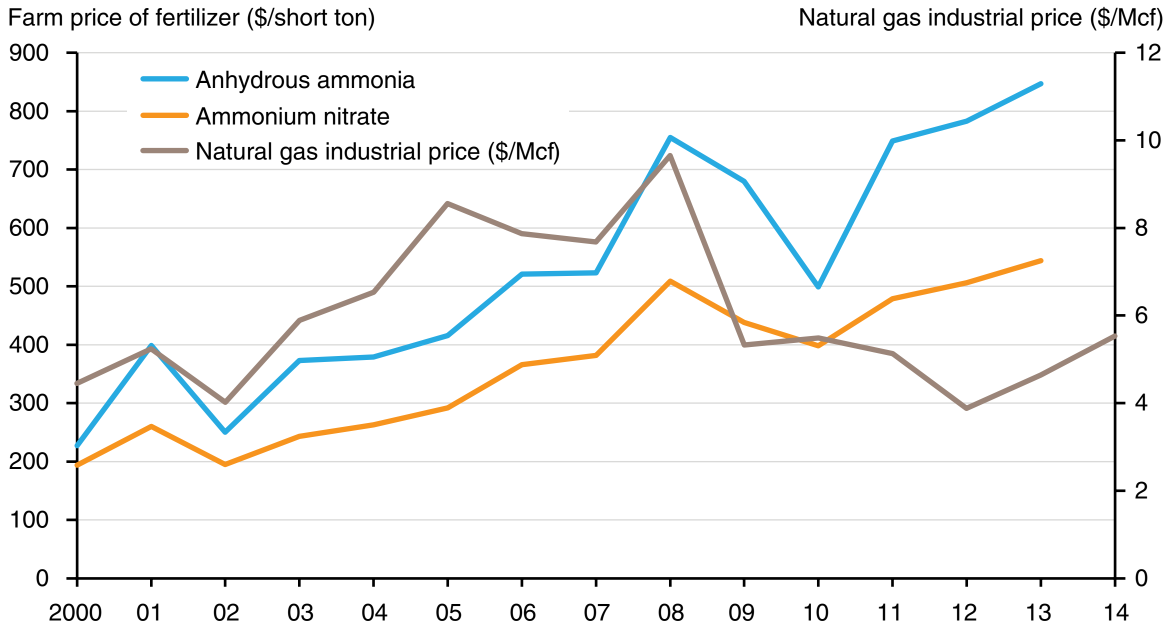
Unlike nitrogen fertilizers, phosphate and potassium fertilizers are derived from minerals and thus do not require natural gas as an inherent energy source. Potash, for example, is a water-soluble fertilizer, composed of a mixture of potassium minerals. However, phosphate and potassium fertilizers still require process energy for their manufacture.

While fertilizer prices declined alongside natural gas prices from 2008 to 2010, they have increased since then despite declining domestic natural gas prices, as shown in figure 8. Domestic fertilizer plants are operating at capacity due to rising fertilizer demand, so the price of fertilizer is determined by the higher import price.[2] Hausman and Kellogg (2015) find that the U.S. ammonia price does not substantially diverge from global prices after 2007, despite the large decrease in the U.S. natural gas price. Farmers have not yet experienced any effect of declining natural gas prices on fertilizer prices.

Fertilizer production in the United States has increased in response to the decline in natural gas prices. Hausman and Kellogg determined that the number of establishments engaged in fertilizer manufacturing increased by 8 percent from 2007 to 2012 during the shale gas boom, while capital expenditures at those establishments more than doubled. Domestic fertilizer production is expected

[2] Other countries that produce fertilizer have not been able to take advantage of low natural gas prices in the United States, as shipping in the form of liquefied natural gas is expensive. In contrast, fertilizer can be shipped much more easily, so prices are determined at a global level.

Figure 8
Fertilizer and natural gas prices, 2000-2014



Mcf = 1,000 cubic feet.

Note: This figure shows the national average industrial natural gas price, which is lower than the spot price of natural gas at Henry Hub, a pricing point and distribution hub in the natural gas pipeline system in Louisiana, which is depicted in Box 1, Box figure 1-1.

Source: USDA, National Agricultural Statistics Service (USDA, NASS, 2015b) and U.S. Energy Information Administration (U.S. EIA, 2014c).

to increase in the near future to meet demand, with 14 plants in the proposal stage (LeCompte, 2013). In 2013, a nitrogen plant began ammonium sulfate production in Texas, and a fertilizer plant is expected to begin anhydrous ammonia production in Iowa during the fall of 2016 (Boesen, 2016).

Pesticides include insecticides, herbicides, and fungicides and are used to control diseases, fungi, weeds, insects, birds, rodents, and other pests. Defoliants are used to remove foliage from plants, such as cotton, prior to harvest. In 2014, pesticides accounted for 20 percent of total expenses for peanut producers, followed by pesticide expenses for producers of rice (15 percent), wheat (14 percent), and cotton (13 percent) (USDA, NASS, 2015d).

Pesticides are primarily composed of ethylene and propylene, both derived from crude petroleum or natural gas as inherent energy. Helsel (2012) finds that although pesticides are energy-intensive in their production on a per weight basis, they represent less than 15 percent, usually around 5 percent, of the total energy used in the production of many field crops. In addition, several newer pesticides, which require greater manufacturing energy input, are labeled for use at very low rates, with the result that energy use on a per acre basis is two to three times less than for their predecessors with higher use rates.

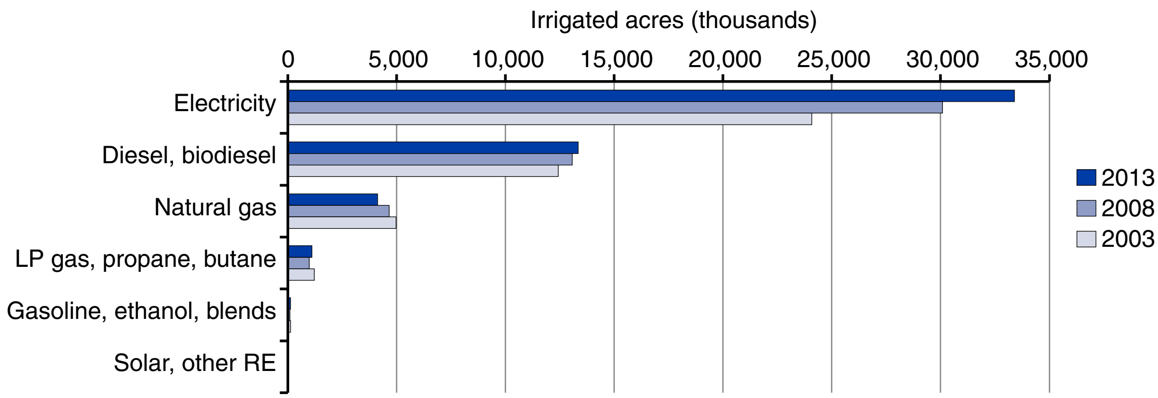
Energy Consumption by Production Practice

Farmers' and ranchers' choices of production practices have implications for their energy consumption. Often tradeoffs are involved, such as between reducing labor and energy costs or between reducing soil erosion and chemical use. Farmers' decisions to invest in energy-efficient technology depend on their expectations of future energy prices and the availability of financing. (As described in Box 4, several USDA and EPA programs exist that provide financing for energy-efficiency improvements on-farm.) In this section, we analyze energy expenditures for irrigation, conservation, and no-till practices, as well as organic production practices.

Irrigation

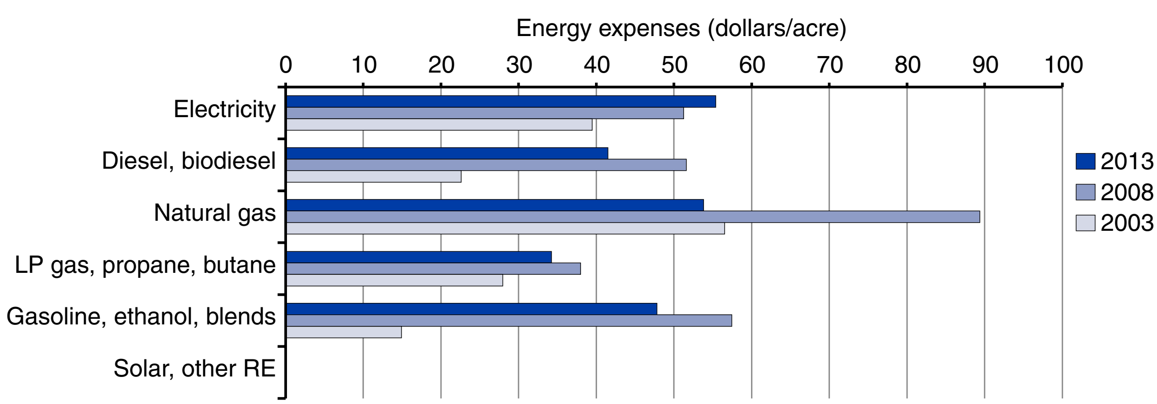
Although farmers use different types of irrigation systems, energy use associated with most irrigation involves the pumping plant: the pump, power unit, and possibly the gearhead (Plant & Soil Sciences eLibrary). In 2012, about 6.1 percent of U.S. farmland was irrigated—mainly land that produced rice, cotton, alfalfa hay, peanuts, and specialty crops (USDA, NASS, 2014a). Energy sources for irrigation include diesel, natural gas, propane, electricity, and gasoline, and to a much lesser extent, gasoline and ethanol blends and solar power (fig. 9). Operations using natural gas or petroleum fuels saw their costs per irrigated acre decline from 2008 to 2013 as natural gas and oil prices decreased. Those using electricity had increasing costs for irrigation equipment (fig. 10). The

Figure 9
Energy source for pumping irrigation water



LP = Liquefied petroleum; RE = Renewable energy.
Source: USDA, National Agricultural Statistics Service 2003, 2008, and 2013 Farm and Ranch Irrigation Survey.

Figure 10
Energy expenses by fuel type for pumping irrigation water



LP = Liquefied petroleum; RE = Renewable energy.
Source: USDA, National Agricultural Statistics Service 2003, 2008, and 2013 Farm and Ranch Irrigation Survey.

number of farms using natural gas for irrigation declined 17 percent from 2003 to 2013, despite the drop in costs from 2008-2013, while farms using electricity for irrigation increased 37 percent. Beyond the volatility in natural gas prices, electric motors offer certain benefits for irrigation compared to gas engines. An electric motor is typically easier to operate, requires less maintenance and repair, maintains its power-output level over time, and does not violate local air quality restrictions (Curley and Knutson, 1992).

In the United States, irrigated agriculture accounts for 80-90 percent of consumptive water use (Schaible and Aillery, 2012). Based on the 2013 Farm and Ranch Irrigation Survey, more than 5 percent of farms listed reducing energy costs as the primary purpose of improving their irrigation equipment. Reducing energy costs by investing in new irrigation equipment is reported as a co-benefit by 46 percent of operations (Schaible and Aillery 2012).[3]

Tillage Practices

Crop production involves a number of operations, including primary tillage, secondary tillage, fertilizer application, chemical application, planting, cultivation, irrigation, and harvesting. Each of these field operations consumes fuel through the use of heavy machinery.

Conservation tillage is defined as a system that leaves at least 30 percent of residue on the soil surface after planting, while conventional tillage leaves less than 30 percent. In a no-till system, farmers plant directly into the undisturbed residue of the previous crop without tillage. Conservation tillage has historically been shown to lower fuel cost by reducing the number of passes over the field. In a wheat study by New Mexico State University, conservation tillage was found to save nearly $30 per acre in irrigation fuel and oil expenses (Baker and Rouppet, 1996). The Conservation Technology Information Center finds that conservation tillage reduces fuel use by 3.5 gallons per acre on average (CTIC, 2015). The present study yields similar findings using ARMS 2013 data (fig. 11). Conservation and no-till practices are associated with reduced fuel use for corn, soybean, and wheat producers, but increased fuel use for cotton producers.

However, increased pesticide application is often required to manage pests and weeds on operations that reduce tillage. Manure is not a fertilizer option for no-till systems, since it needs to be worked into the soil, while manufactured fertilizer can be injected into the soil without tillage. Fertilizer expenses may therefore change on operations that substitute manufactured fertilizer for manure in keeping with reduced tillage. Farm businesses producing corn and wheat and using no-till or conservation tillage had higher average pesticide and fertilizer expenses than businesses using conventional tillage (fig. 11). In contrast, cotton and soybean operations were able to reduce or maintain their pesticide costs per acre with conservation and no-tillage practices, and cotton operations also experienced greatly reduced fertilizer costs per acre.

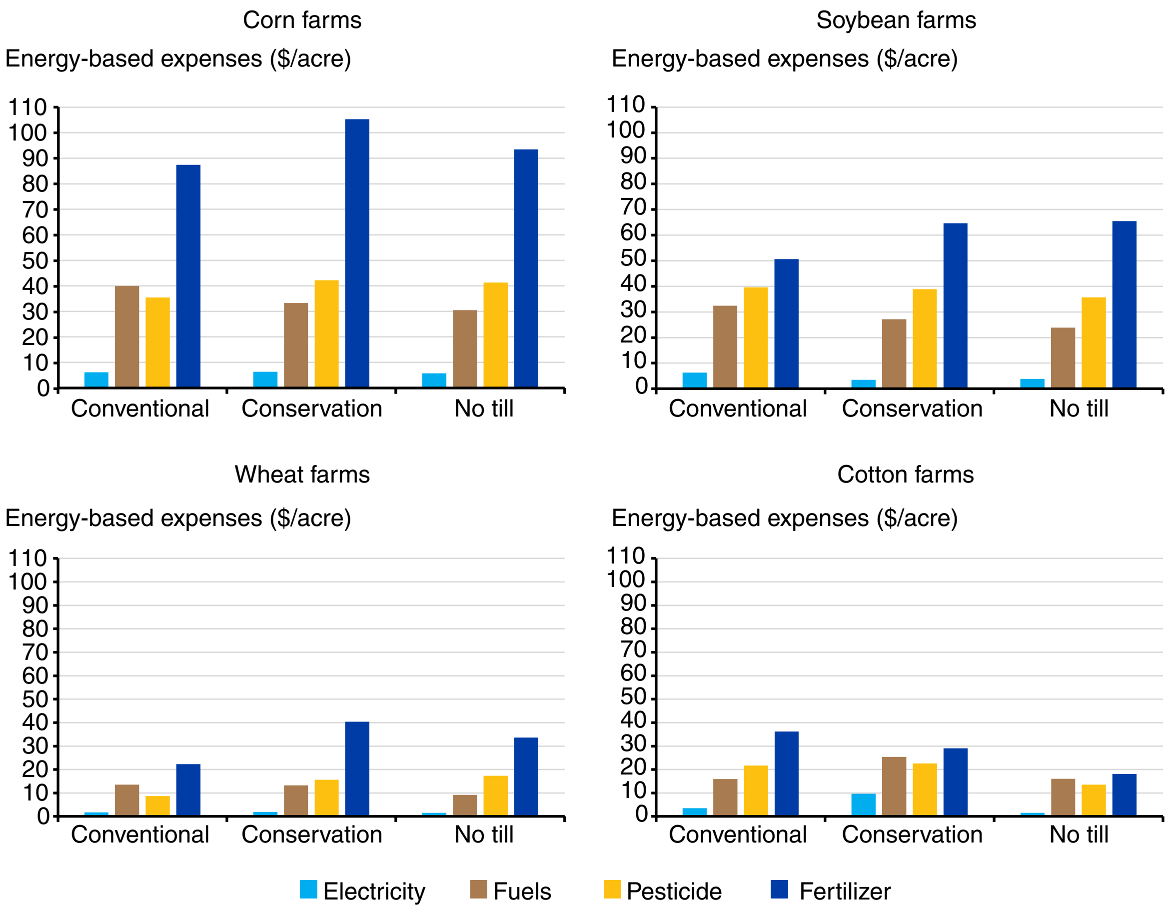
Organic Production Practices

The market for organically grown food is relatively small but continues to expand. As of 2011, 5.4 million acres were managed under certified organic farming systems (Greene et al., 2016). Energy consumption differs between organic and conventional crop farming, primarily due to fertilizer and

[3] Respondents also mentioned reducing water use and improving crop quality as reasons for investing in new irrigation equipment.

Figure 11

Average 2013 energy-based expenses in dollars per acre, by tillage practice and principal commodity



Conservation tillage is defined as a system that leaves at least 30 percent of residue on the soil surface after planting, while conventional tillage leaves less than 30 percent. In a no-till system, farmers plant directly into the undisturbed residue of the previous crop without tillage. Farm businesses may produce more than one commodity, so the energy-based expenses should not be attributed solely to the principal commodity, which is the production specialty that accounts for more than half of an operation's value of production. For example, fertilizer is rarely applied to soybeans, so these expenses are likely incurred when a farm business produces another crop in addition to soybeans.

The coefficient of variation (CV) is greater than 50% for cotton, and less than 50% for corn, soybeans, and wheat. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

Source: USDA, National Agricultural Statistics Service and USDA, Economic Research Service 2013 Agricultural Resource Management Survey.

pesticide use. Organic farming uses crop rotation, compost, and manure as substitutes for manufactured fertilizer; mechanical weeding as a substitute for herbicides; and biological pest control as a substitute for pesticides, though organic pesticides are allowed.[4] While mechanical weeding increases fuel use on organic farms, the reduction in nitrogen-based fertilizer and agricultural chemicals decreases the indirect consumption of energy.

In 2012, organic wheat, soybean, and cotton farmers spent significantly less on fertilizer and pesticide per bushel or bale than nonorganic farmers (table 1). However, organic operations typically

[4] Certified organic operations may use organic pesticides and a limited number of synthetic pesticides, detailed in the National List of Allowed and Prohibited Substances (AMS, 2015). Many conventional producers use these practices as well.

had greater fuel, oil, and utility expenses than nonorganic operations of the same type: organic corn farmers spent more than twice as much on fuel and oil as nonorganic corn farmers. This is to be expected with the use of mechanical weeding, which requires fuel as opposed to herbicides (Fennimore et al., 2014). Producers of organic fruits, nuts, and vegetables spent more on fertilizers, fuel and oil, and utilities than their nonorganic counterparts. Organic beef cattle operations had higher energy expenses per head than nonorganic beef cattle, while the reverse was true for dairy operations.[5]

Table 1

Average energy expenses per unit of production for organic and nonorganic farm businesses in 2012, by principal commodity

	Fertilizer		Pesticide		Fuels & oils		Utilities	
Farms specializing in:	Organic	Non-organic	Organic	Non-organic	Organic	Non-organic	Organic	Non-organic
Corn ($/bu)	3.41	1.81	1.13	0.75	1.68	0.68	1.35	0.23
Soybean ($/bu)	3.42	4.01	1.66	1.98	2.49	1.83	0.97	0.55
Wheat ($/bu)	0.79	1.83	0.79	1.11	1.63	1.20	0.42	0.38
Vegetables ($/acre)	229.71	183.85	114.79	122.55	225.70	183.05	184.18	129.25
Fruit & nuts ($/acre)	192.72	152.63	222.07	214.35	163.75	135.80	257.47	184.23
Cotton ($/bale)	32.29	79.18	42.60	67.19	93.41	61.78	53.23	32.29
Rice ($/lb)	3.26	2.78	2.00	2.25	2.47	1.68	1.05	0.70
Beef cattle ($/head)	178.69	140.96	78.55	49.79	288.30	188.57	135.76	86.43
Dairy ($/head)	108.63	199.46	23.88	75.53	215.67	222.05	105.01	127.31
Poultry and eggs ($/head)	6.39	2.39	0.45	0.85	9.84	8.99	4.70	7.33
Hogs ($/head)	48.43	30.85	10.05	15.11	36.01	53.75	81.91	33.10

Source: 2012 Census of Agriculture (USDA, NASS 2014a).

Note: Fertilizers include lime, soil conditioners, manure, and other growing materials. Pesticides include insecticides, herbicides, fungicides, and other pesticides. Differences in expenditures on fertilizers and pesticides between organic and nonorganic operations do not directly translate into differences in energy content. Organic operations use compost and biological pest control that may not be reported under the predefined categories of the survey but require indirect energy use in their production.

[5] Livestock farms often grow crops for feed or for marketing and use fertilizer and pesticides.

Nexus: Emerging Energy Markets and Policies

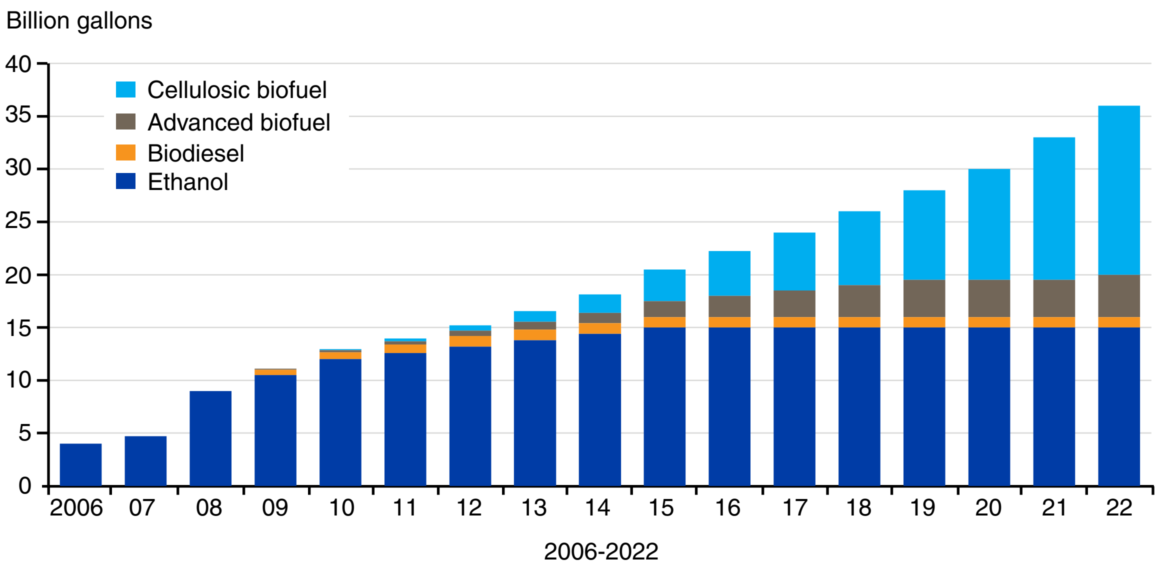
Energy consumption and production patterns in agriculture are affected by policy and technology changes in the energy sector. In the early 2000s, the RFS mandated a specified use of transportation biofuels. Simultaneously, technological advances in hydraulic fracturing and horizontal drilling made the extraction of shale gas and tight oil economically feasible. Profound changes in the power sector may occur if the EPA begins regulating carbon emissions from new and existing power plants. Volatile oil and natural gas prices, along with increasing electricity prices, have impacted both the expenditure and revenue side of agricultural operations, as agriculture is increasingly engaged in the production of energy along with energy consumption. An overview follows of the RFS, the shale revolution, and the Clean Power Plan, along with a summary of USDA programs supporting energy efficiency improvements and renewable energy investments on farms.

Renewable Fuel Standard (RFS)

The 2005 Energy Policy Act created the original RFS by establishing the first national renewable fuel volume mandate (U.S. EPA, 2007). The 2007 Energy Independence and Security Act (EISA) updated the RFS to include biodiesel, increase the volume of renewable fuels to 36 billion gallons of ethanol equivalent by 2022, establish new categories of renewable fuels (i.e., cellulosic biofuel, biomass-based diesel, and advanced renewable fuels), and require renewable fuels to emit fewer lifecycle greenhouse gases than petroleum-based fuels. Figure 12 shows the volume mandate from the updated RFS (as updated by EISA in 2007) by renewable fuel category.

Figure 12

Renewable volume mandate of the Renewable Fuel Standard according to the 2007 Energy Independence and Security Act



Note: Cellulosic biofuel is fuel derived from nonfood-based feedstocks that include crop, wood, and industrial residues or wastes. Advanced biofuel includes any renewable fuel that is not conventional corn-based ethanol. Biodiesel is diesel derived from vegetable oils or animal fats. Ethanol is conventional corn-based ethanol.

Source: U.S. Environmental Protection Agency (U.S. EPA, 2010b).

Agriculture plays an important role in achieving RFS goals—corn is the primary feedstock for conventional ethanol, as are soybeans for biodiesel and sugarcane for advanced biofuel.

EPA economic modeling predicted that the RFS would increase farm income by expanding the market for corn and soybeans for biofuel production (U.S. EPA, 2010b). This was corroborated by ERS analyses showing an increase in national corn and soybean acreage beginning in 2006 (Malcolm et al., 2009; Wallander et al., 2011). The new demand for the biofuel feedstocks corn and soybean has impacted the livestock feed market as well, as discussed in more detail in Beckman et al., 2013.

It was a pivotal moment for the RFS in 2015 when conventional biofuels reached the volume specified by the RFS of 15 billion gallons and the mandate for cellulosic biofuel production (from agricultural residues and dedicated energy crops) expanded to 123 million gallons in accordance with the EPA's most recent requirements.[6] In anticipation of changing RFS requirements, commercial-scale cellulosic ethanol plants have been increasing capacity since 2008, and two new cellulosic plants began operations in the fall of 2014. In late 2014, these two producers generated over 700,000 gallons of cellulosic biofuel from agricultural waste, energy crops, and wood waste. Also in that year, over 32.6 million gallons of renewable natural gas (biogas) contributed to the cellulosic biofuel mandate (U.S. EPA, 2015a).

In 2013, EPA finalized the RFS to mandate only 810,185 gallons of the original 1 billion gallons of cellulosic biofuel required (U.S. EPA, 2014a). In addition, obligated parties (fuel refiners or importers required by EPA to meet renewable volume obligations) are able to offset the remainder of their cellulosic biofuel obligation by purchasing cellulosic waiver credits from EPA when it reduces the required volume. EPA has continually reduced the cellulosic biofuel requirements from the original mandate since 2010. These changes to the RFS create uncertainty for the development of agricultural residue supplies and of dedicated energy-crop markets that may allow agricultural producers to profitably harvest biomass.[7]

Nevertheless, over 2,500 farm businesses harvested cellulosic biomass in 2012. If the uncertainty regarding the cellulosic mandate of the RFS is mitigated and a strong market for cellulosic biofuel materializes, almost 125 million dry tons of cellulosic biomass could potentially be produced by 2022 at $50 per dry ton (U.S. DOE, 2011). However, biomass production may use energy, fertilizer, and pesticide as inputs into the production process, and the price of such energy-related inputs can alter the profitability of supplying biomass.

The Shale Gas and Tight Oil Revolution

Hydraulic fracturing for natural gas began in the Barnett shale (Texas) in the early 2000s and spread to the Haynesville (Texas and Louisiana) and the Marcellus (Pennsylvania) shales in 2007. Horizontal drilling and hydraulic fracturing technology are used in tandem to extract natural gas

[6] It is important to note that the RFS-mandated conventional ethanol volume is not a limit on nationwide production; it is simply a limit on what can be applicable to the RFS program. In addition, due to the nested structure of the RFS, all advanced biofuel-volume mandates can be considered minimum requirements.

[7] A technical analysis of domestic biomass production in the Billion Ton Update (2011) simulated a variety of agricultural residues and wastes that could be used to produce cellulosic biomass in the United States. The analysis found that the largest quantities will be from crop residues. If all crops are considered, the analysis predicted that there may be more than 400-million dry tons of crop residues available for cellulosic biofuel production.

or oil from shale formations. Currently, the majority of tight oil is produced in the Bakken shale in North Dakota and Montana and the Eagle Ford shale in Texas.[8] Figure 13 depicts the growth in production across different shale plays over time.[9] Shale gas wells overtook conventional gas wells in 2013 to become the largest source of natural gas production (Tran, 2014). In 2015, production of oil and natural gas from shale plays started to decline following the drop in oil and natural gas prices.

Agriculture is affected by the shale revolution through the placement of drill pads, access roads, and pipelines on farmland; the drop in natural gas and oil prices (Box 1); competition with energy companies for labor, water, and transportation infrastructure; increased risk of soil or water contamination; and income from leases and royalties for mineral owners. Hitaj et al. (2014) discuss these impacts of the shale revolution on agriculture in more detail. Most are local in nature, but some, such as competition for freight rail, affect larger regions. For example, freight trains carrying oil from the Bakken shale and a record crop year in 2014 caused a backlog in grain shipments, depressing local crop prices in Montana and North Dakota by $0.11 to $0.18 per bushel and reducing cash receipts of grain and oilseed producers by an estimated 3 percent (USDA, 2015).

Farmers who own their mineral rights have the opportunity to receive lease and royalty payments from energy companies. Not all landowners also own the mineral associated with their land. Landowners in new drilling regions are more likely to own their mineral rights than those in regions with historical energy production, since mineral rights in those areas may have been sold in the past. Some shale formations, such as portions of the Marcellus shale in northeastern Pennsylvania, occur in regions with no history of drilling, while others, such the Bakken shale in Texas, overlap with traditional oil and natural gas fields. In an analysis of agricultural land values, Weber and Hitaj (2015) find evidence indicative of greater mineral rights ownership in the Marcellus than in the Bakken shale region. We discuss income from lease and royalty payments in the section "On-Farm Energy Production" in this report.

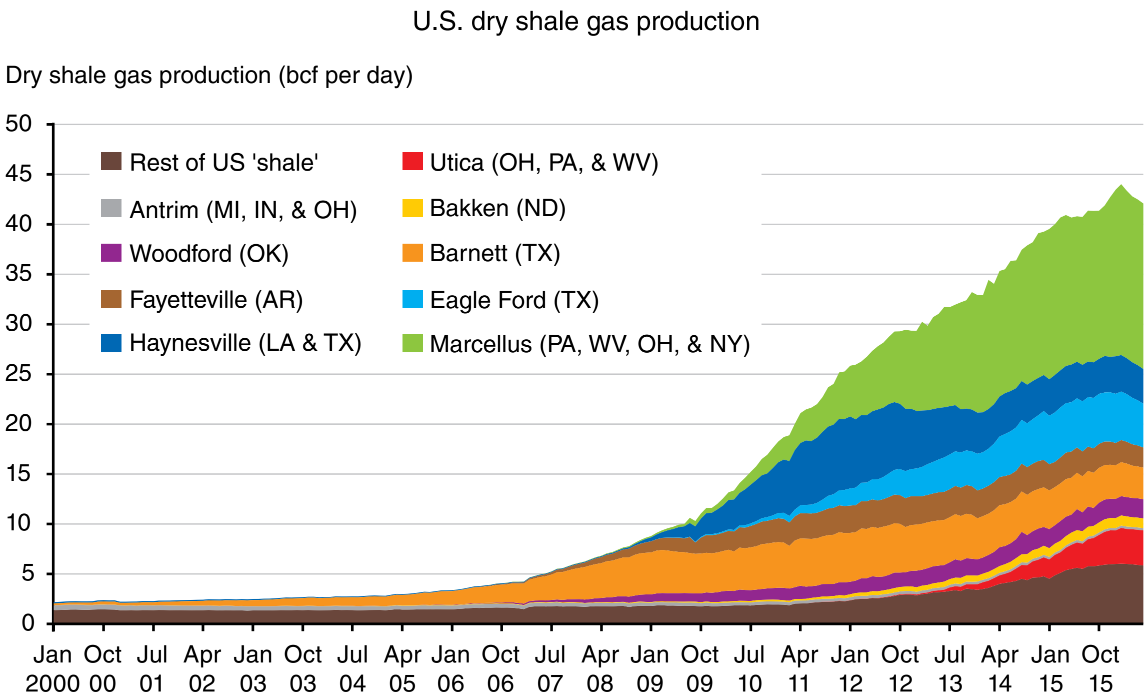
In contrast to conventional natural gas, shale gas production declines rapidly after the well is drilled, on average by 70 percent by the end of the first year (King, 2014). Increasing and even maintaining a certain level of shale gas production requires constantly drilling new wells or refracturing existing ones due to the current high extraction rates. With 35 percent of farm and ranch land in operation in 2012 located in shale counties (USDA, NASS, 2014a), many agricultural operations are likely hosting a drill pad, access road, or pipeline.

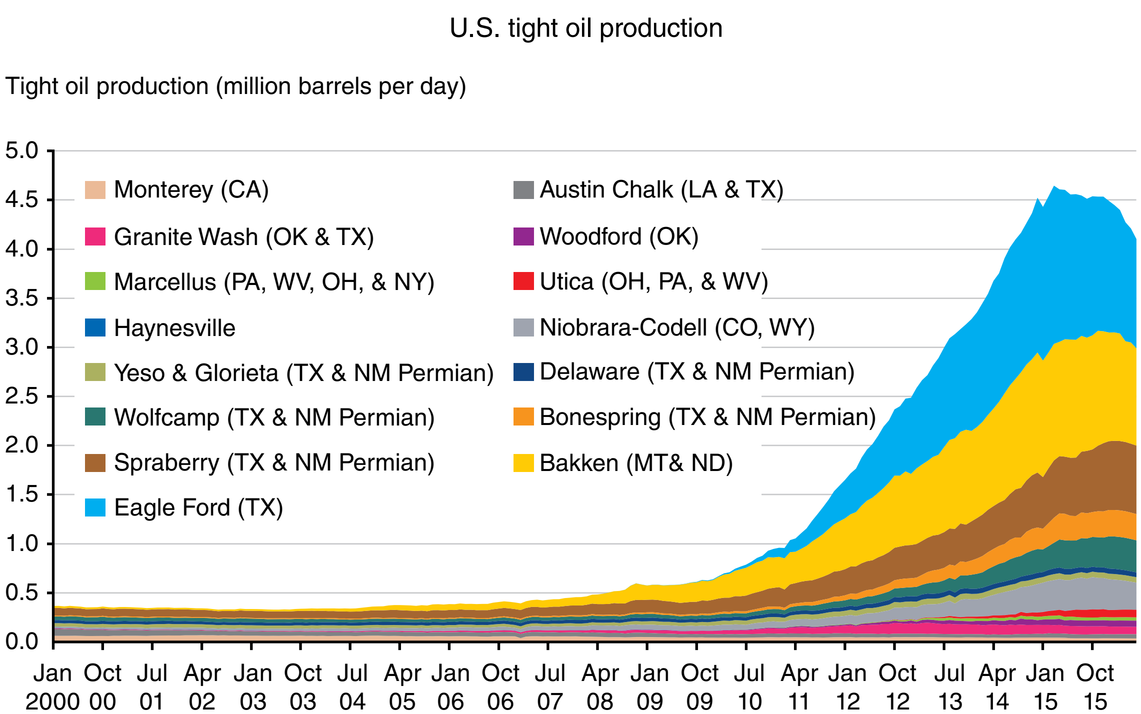
Vegetation removal due to oil and gas development between 2000 and 2012 affected about 7.4 million acres of land, of which about 47 percent is rangeland, 37 cropland, and 13 forestland (Allred et al., 2015). This amounts to 0.7 percent of cropland and 0.8 percent of rangeland, given that in 2012 cropland and rangeland in the United States amounted to 390 and 415 million acres, respectively (USDA, NASS, 2014a). Allred et al. (2015) conclude that vegetation removal to construct oil pads and roads is likely long-lasting and potentially permanent, as recovery or reclamation of previously drilled land has not kept pace with accelerated drilling. They find that the amount of vegetation cover (biomass) lost in croplands from 2000 to 2012 equals about 6 percent of wheat produced in 2013 within the region, while the amount of vegetation cover (biomass) lost in rangelands is the

[8] The oil extracted is referred to as tight oil, since the term shale oil was already in use to describe a different type of oil (kerogen) that can also be found in shale formations.

[9] Shale plays are shale formations that contain significant amounts of natural gas and share similar geologic and geographic properties.

Figure 13
Gas and oil production from shale formations





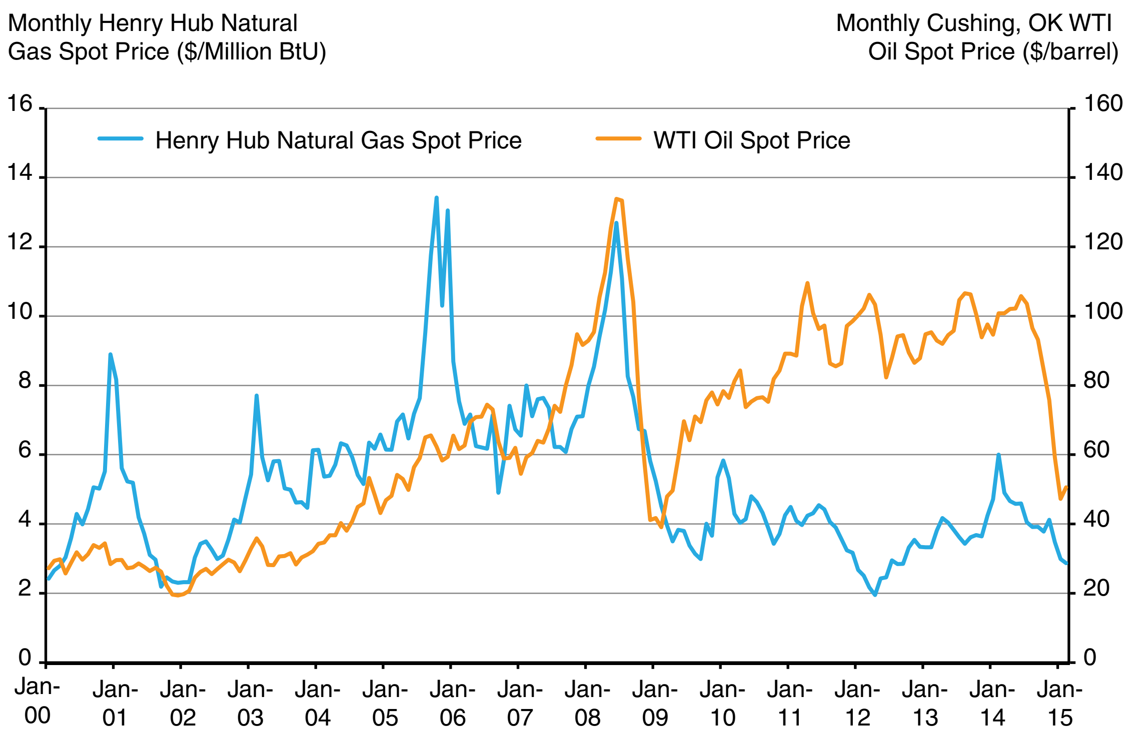
Source: U.S. Energy Information Administration (EIA) (2016b).

Box 1. Energy Production From Shale Plays Affects Oil and Natural Gas Prices

The large increase in domestic oil and natural gas production from shale plays since the early 2000s has contributed to a decrease in natural gas prices since 2008 and in oil prices since 2014. Natural gas prices never fully recovered after the recession due to the growth in domestic production from shale, as seen in Box figure 1-1, and the difficulty of exporting natural gas (which can be shipped overseas only in the form of liquefied natural gas). In early 2011, the United States became a net exporter of noncrude petroleum liquids and refined petroleum products (U.S. EIA, 2015f). Oil prices have declined since 2014 due to the increase in production from tight oil plays and the reduced demand from the slowing economies in Europe and China. However, any disruption to oil supply could result in an increase in price in the short term. In the medium term, domestic production from shale wells would respond quickly to price changes, smoothing out any large price swings, at least domestically. This is perhaps one of the biggest changes the shale revolution has brought, with U.S. shale assuming a swing-producer role (Krane and Agerton 2015).

Box figure 1-1

Natural gas and oil prices, January 2000–February 2015



OK WTI = Oklahoma West Texas Intermediate (grade of crude oil).
Source: U.S. Energy Information Administration (U.S. EIA 2015d; U.S. EIA 2015g).
Prices are nominal.

The drop in natural gas and oil prices has slowed the pace of drilling in shale regions. In the Bakken shale, the number of drilling rigs in operation declined from a high of 218 in June 2012 to 63 in October 2015 (U.S. EIA, 2015a). Oil production only began declining in June 2015, since drilling productivity, as measured by oil production per drilling rig, increased by more than a factor of 6 between 2007 and 2015. This increase in drilling productivity means that drilling in many shale regions remains profitable even at lower oil prices.

equivalent of approximately 5 million animal unit months (AUM; the amount of forage required for one animal for 1 month).

Clean Power Plan (CPP)

The Environmental Protection Agency (EPA) first announced proposed standards to limit carbon pollution from *new, modified, and reconstructed* power plants under the Clean Air Act Section 111(b) in 2013 and from *existing* power plants under Section 111(d) in 2014. In August 2015, the EPA finalized the two rules for both new and existing power plants, but in February 2016 the Supreme Court issued a stay on the regulation until the rule is reviewed by the U.S. Court of Appeals of the District of Columbia Circuit. As the rule is written, the compliance period for the Clean Power Plan would begin in the summer of 2020. The goal is to reduce carbon emissions in the power sector in 2030 by 32 percent compared to 2005 levels.

Under the CPP, each State is given a specific goal for reducing the carbon intensity of the power sector (see box 2, "State-Specific Goals Under Clean Power Plan (CPP)"). The choice of policy instruments to achieve the carbon emissions reduction goal is left to the States.

The precise role that biomass will play in shifting away from fossil-fueled power generation is still uncertain. The EPA is expected to issue a carbon-accounting framework for different biomass feedstocks, such as agricultural residues, woody biomass, and municipal solid waste. This accounting affects incentives and thus would impact the extent to which biomass is used to substitute for fossil fuel in the power-generation sector.

The EPA estimates that electricity rates would increase by 3 percent in 2020, 1-2 percent in 2025, and 0-1 percent in 2030, compared to base-case price estimates modeled for these same years (U.S. EPA, 2015c). Monthly electricity bills are anticipated to increase by 2.4 to 2.7 percent in 2020. Because increased energy efficiency would lead to reduced usage, bills are expected to decline by 7 to 7.7 percent in 2030.

The anticipated national average electricity rate increase of 3 percent masks differences across regions, related mostly to the current reliance on coal power in the generation mix. Based on the EPA estimates, electricity customers in the Northeast could expect electricity rate increases of 5 to 6 percent in 2020 due to the CPP, compared to a rate increase of 1 percent in the Southeast and in Kansas and Missouri. Most irrigation areas, including California, the Mississippi Portal, Colorado, and Idaho, could expect electricity rate increases of around 3 percent in 2020.

In our analysis of energy consumption on farms, we find that direct-use electricity expenses as a share of total expenses are 1 to 6 percent, on average, for various farm types. This indicates that the CPP would lead to relatively small increases in the share of electricity expenses for most farms, based on the rate increases estimated by the EPA.

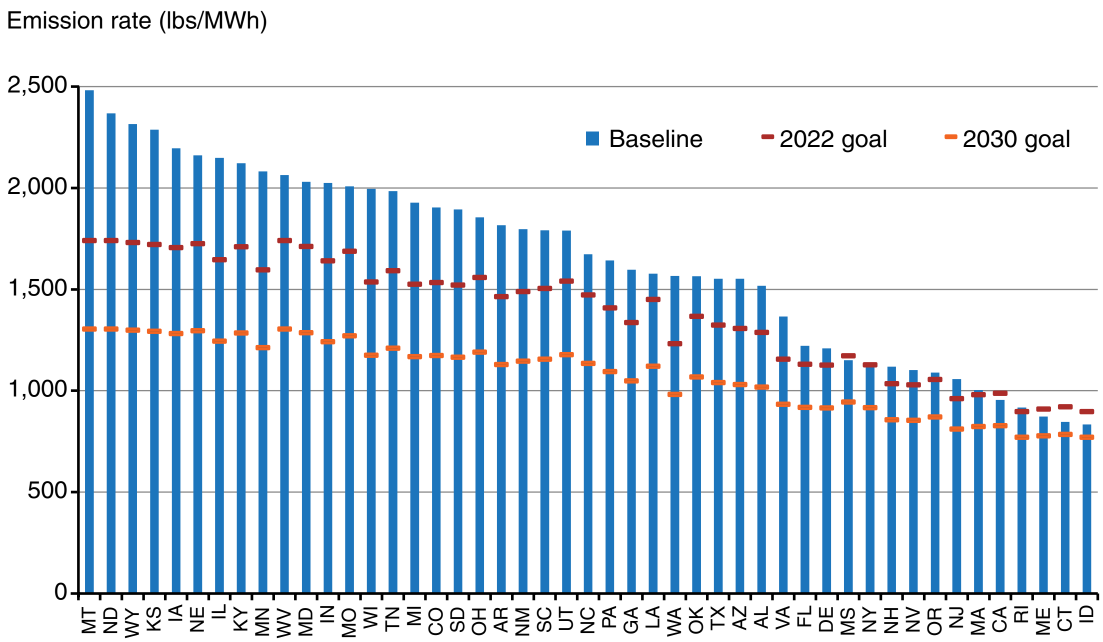
However, agricultural electricity customers may experience greater rate increases than the average retail customer as a result of the CPP. Farm and ranch operations are likely to receive their electricity from a rural electric cooperative rather than another type of utility. Rural electric cooperatives serve 12 percent of the population but over 75 percent of the land area in the United States, and they have more than double the share of industrial customers (who include agricultural customers) than investor- and publicly owned utilities (U.S. EIA, 2014a). The rural electric cooperatives generate 70 percent of their electricity from coal compared with 37 percent for other utilities (NRECA,

Box 2. State-Specific Goals Under Clean Power Plan (CPP)

The EPA calculated each State's emissions standard based on three "building blocks": Improving the heat rate at existing power plants, redispatching from high-emitting power sources towards low-emitting sources (such as switching from coal to natural gas combined-cycle power plants), and increasing power generation from zero-emitting renewable power plants. Box figure 2-1 shows for each State the baseline carbon emission rate, along with the goal in 2022 and 2030. The figure shows the wide variation in the standard for each State (from 1,305 lb/MWh in Montana, North Dakota, and West Virginia to 771 lb/MWh in Rhode Island and Idaho) and in the required percentage reduction (from 47 percent in Montana to 7 percent in Connecticut).

Box figure 2-1

State-specific reductions in CO2 emission rates under the Clean Power Plan



Source: Data are reported in the U.S. Environmental Protection Agency Emission Performance Rate and Goal Computation Technical Support Document – Appendixes 3 and 5.

2014). The greater reliance on coal-fired generation means that rural electric cooperatives and their customers are likely to experience larger price hikes from the CPP. The National Rural Electric Cooperative Association (NRECA) expects electricity rates at the cooperatives to increase by 17 percent over the 2020-2030 period (NRECA, 2014).

Agricultural operations that irrigate face above-average electricity rates because their seasonal demand for electricity occurs during peak hours in irrigation regions. Based on data from the USDA Rural Utilities Service, for 65 percent of rural electric cooperatives in operation, irrigation customers paid on average 14 cents/kilowatt hour (kWh) for electricity compared with 12 cents/kWh for residential customers and 9-11 cents/kWh for small-to-large commercial and industrial customers. Given the expected closure of coal-fired facilities, combined with the peak nature of electricity demand for irrigation, agricultural customers who irrigate may experience rate increases closer to the 17 percent predicted by NRECA than to the 3 percent estimated by the EPA.

The CPP would affect natural gas prices as well, with the electricity-generation mix shifting away from coal, initially toward natural gas and increasingly toward renewables. The EPA estimates that the CPP would increase natural gas prices by 4-5 percent in 2020 and decrease natural gas prices by 3-7 percent in 2025, compared with the reference-case prices in these same years (U.S. EPA, 2015c). The shifting natural gas price would most affect corn, cotton, poultry, and special crop producers, who had the highest average natural gas expenditures among all crop and livestock producers.

Increasing prices raise agriculture's costs of production. However, farms producing electricity may benefit as prices rise. As States look to diversify their renewable power portfolios with solar power, wind power, and biopower, on-farm electricity generation may become more profitable.

Federal and State Incentives for Renewable Power and Energy Efficiency

In addition to the Federal production and investment tax credits for renewable energy, many States have a Renewable Portfolio Standard (RPS), production incentives, or sales and property tax credits that encourage renewable electricity generation. The RPS sets a minimum requirement for the share of electricity supplied from designated renewable energy resources within a certain timeline. Currently, 29 States and the District of Columbia have mandatory standards and 8 States have voluntary goals (DSIRE, 2015).

Net metering policies also encourage onsite renewable power generation, and they are available in 41 States (DSIRE, 2015). Net metering, along with the impact of related policies on the economics of distributed generation (onsite generation), is defined and discussed in Box 3, "Net Metering and Distributed Generation."

Agricultural operations can take advantage of these State and Federal incentives for renewable energy generation available to businesses and residences, in addition to grants and loan guarantees targeted specifically at agricultural operations. Farmers and ranchers can apply to receive loans and grants for energy efficiency improvements, renewable energy systems, and the production of biomass feedstocks, as detailed in Box 4, "Energy Efficiency and Renewable Energy Programs Targeted at Farms and Rural Communities."

Box 3. Net Metering and Distributed Generation

The growth in distributed generation—electricity generated onsite on the properties of utility customers—is due in large part to net metering State and Federal policy incentives. Net metering allows customers to sell any unused electricity generated by their solar panels or wind turbines, for example, back to the utility at the *retail* rate. This is an implicit subsidy for distributed generation, since independent power producers operating utility-scale generators receive the lower *wholesale* rate for any electricity they sell to the utility. The difference between the retail and wholesale rate is what allows utilities to cover their fixed costs and past sunk costs. As more and more customers choose to generate power on their properties, utilities raise rates to make up the loss in net revenue, which makes small-scale renewable power even more economical. This effect is called the "utility death spiral" (Borenstein 2013). Customers with onsite renewable power systems shift the burden of paying for the utility's fixed costs to other customers.

Agricultural electricity customers are spread out over a larger area than residential customers in cities, so fixed costs make up a larger proportion of overall costs for delivering electricity, making the potential for "utility death spiral" more pronounced. In response to this issue in the third quarter of 2015, regulators and legislators in 27 States were reviewing or changing net metering policies. In addition, 26 utilities in 18 States had ongoing or decided rate cases in which the utility proposed to increase fixed charges, by 70 percent, on average (NC Clean Energy Technology Center, 2015).

The economics of generating renewable power on farms may thus be changing. Agricultural customers may face a higher fixed charge in the future, but changes to the rates customers receive for any electricity they sell back to the grid would only impact those farms that produce more electricity than they consume. This would not apply to farms with small solar devices that are not grid connected but that are used, for example, to power electric fences or water pumps.

Box 4. Energy Efficiency and Renewable Energy Programs Targeted at Farms and Rural Communities

The Rural Energy for America Program (REAP) offers loan guarantees and grants to agricultural producers and rural small businesses to install renewable energy systems or make energy efficiency improvements (USDA, Rural Development, 2016). The funds may be used to construct renewable energy systems such as biomass production, anaerobic digesters, geothermal electricity systems, small-scale hydropower, wind generation, solar generation, and ocean generation, as well as hydrogen derived from biomass or water using wind, solar, or geothermal energy sources. In 2015, a record number of solar projects were funded. The vast majority of grants and loans over the 2003-14 period went towards energy efficiency improvements in heating, ventilation, and air conditioning systems, insulation, lighting, refrigeration, doors and windows, and irrigation pumps (Box table 4-1). REAP projects saved or generated 1.1 million megawatt ho—urs in 2015, eno—ugh to meet the annual electricity consumption of over 100,000 homes.[1]

In addition to REAP, other USDA programs exist to reduce carbon pollution or increase energy efficiency in agriculture. The Energy Efficiency and Conservation Loan Program (EECLP) is an existing USDA program that provides loans to finance energy efficiency and conservation projects for commercial, industrial, and residential consumers (USDA, 2015). The Electric Program of USDA's Rural Utility Service provides eligible borrowers with financing for the construction or improvement of electric generation, transmission, and distribution facilities in rural areas to ensure that rural consumers' power supply needs are met (USDA, Rural Utilities Service, 2013). The National On-Farm Energy Initiative is a USDA Environmental Quality Incentives Program (EQIP) initiative to help agricultural producers identify ways to conserve energy on their farms and ranches through the development of energy audits, as well as to provide financial assistance for implementing various efficiency measures and conservation practices (USDA, NRCS, 2015).

Box table 4-1
Projects supported by Rural Energy for America Program 2015 and 2003-2014

	Number of projects		Total development cost (millions)		Energy saved/ generated (megawatt hours)		Gallons of advanced biofuel (millions)	
Technology	2015	2003-2014	2015	2003-2014	2015	2003-2014	2015	2003-2014
Energy efficiency	731	6,985	$98	$663	290,223	6,641,015		
Solar	1,064	1,943	$639	$685	512,976	526,402		
Biomass	54	515	$133	$1,416	266,479	858,627	19	785
Geothermal	32	291	$9	$36	2,762	106,454		
Wind	24	656	$7	$743	8,685	850,228		
Hydroelectric/ Hydropower	8	31	$26	$66	16,038	32,301		

Source: USDA, Rural Development (2016).
Note: The numbers for 2003-14 are totals for the period.

—continued

[1]In 2013, the average annual electricity consumption for a U.S. residential utility customer was 10,908 kWh (U.S. EIA, 2015).

Box 4. Energy Efficiency and Renewable Energy Programs Targeted at Farms and Rural Communities—continued

The Biomass Crop Assistance Program (BCAP) provides financial assistance to agricultural and private forest landowners to establish, produce, store, and transport biomass feedstocks, particularly feedstocks to meet the advanced biofuel mandate in the Renewable Fuel Standard (USDA, FSA, 2011; USDA, FSA, 2015). BCAP provides matching payments for the transportation of the feedstock to conversion facilities, as well as initial establishment and annual payments to producers who enter contracts to produce biomass on acreage in BCAP project areas. Between fiscal years 2009-12, over $290 million was used to fund BCAP projects in 31 States (McMinimy, 2015).

The AgSTAR program, established in 1993, is a voluntary program sponsored by EPA, USDA, and the U.S. Department of Energy to advance the implementation of anaerobic digester systems in livestock facilities in the United States (U.S. EPA, 2004). The goals of the program are to increase farm-based renewable energy generation and enhance rural economic growth, as well as to improve air, land, and water resources. The AgSTAR program assists interested farm operators in identifying costs, benefits, risks, and financing. The program also guides operators toward Federal and State funding opportunities such as grants and cost-sharing programs.

On-Farm Energy Production

In response to the RFS requirements, the shale revolution, and Government incentives for renewable energy, farms have increased energy production since the early 2000s, either directly by producing bioenergy and renewable energy or indirectly by growing biomass feedstocks or serving as a location for oil or gas drilling rigs or large wind turbines. On-farm energy generation technologies include wind power, solar power, small hydropower, methane digesters, geothermal exchange, and biofuel production.

In 2007, according to the Census of Agriculture, 23,451 U.S. farm businesses and other farms[10] (1.1 percent of all U.S. farms) produced energy or electricity on-farm with solar panels, geo-exchange, wind turbines, small hydro, or methane digesters. By 2012, the number of farm businesses and other farms producing on-farm renewable energy had more than doubled to 57,891 (2.7 percent of farms). This does not include the 6,463 farm businesses and other farms that produced ethanol and biodiesel on the operation or the 10,181 farm businesses and other farms that leased wind rights to others.

Several surveys regarding on-farm renewable energy generation have been conducted in recent years. In 2008, the Agricultural Resource Management Survey (ARMS) was supplemented with a bioenergy survey from ERS and NASS, and in 2009, the 2007 Census of Agriculture was supplemented with an on-farm renewable energy production survey (U.S. Department of Agriculture, 2011). The 2012 Census of Agriculture asked farmers and ranchers about their use of various types of renewable energy-producing systems, whether they leased wind rights to others, and whether they harvested cellulosic biomass for renewable energy production. Figure 14 presents the results of this latest Census of Agriculture for farm businesses and all other farms and ranches (USDA, NASS, 2014a). In 2012, 74,535 farm businesses and other farms (3.5 percent of all farms) had renewable energy-producing systems (solar panels, geoexchange, wind turbines, small hydro, or methane digesters), produced biodiesel or ethanol, or leased their wind rights to others.

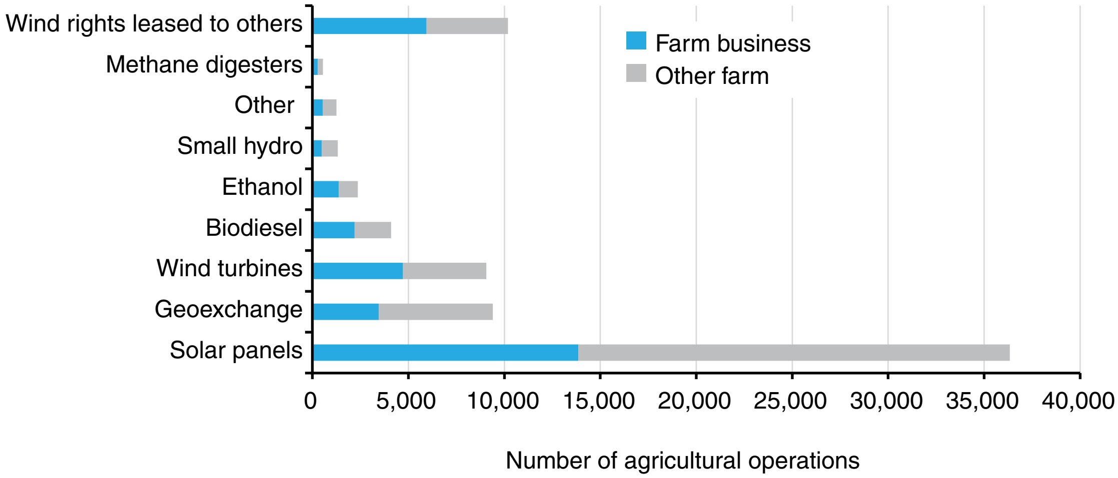
Capacity installed on-farm is generally small, on average less than 100 kW for wind and 4.4 kW for solar (Xiarchos and Vick, 2011). A small wind system of 100 kW could generate enough electricity to meet the demand for most farms, as detailed in the section on small wind and hydro. A large technical growth potential remains for renewable energy systems on farms, as farms generally have the space to accommodate such systems.

Figure 15 shows the share of farm businesses with on-farm renewable energy systems, including solar panels, small hydro, wind turbines, and methane digesters. Adoption of on-farm renewable energy systems is concentrated in the Western United States, Illinois, and New England. Low adoption rates prevail in the Southeastern States, which are also the least likely to have State RPS programs (mandates for renewable electricity) and the associated programs targeted toward agriculture. Xiarchos and Lazarus (2013) found that distributed solar and wind adoption rates on farms are positively affected by specific set-asides for solar or distributed generation, while distributed wind can also be affected by RPS requirements. The following sections discuss several types of on-farm renewable energy-producing systems in more detail.

[10] See page 5 for the USDA definition of a farm and farm business.

Figure 14

Number of agricultural operations with on-farm renewable energy producing systems, by type of system, 2012



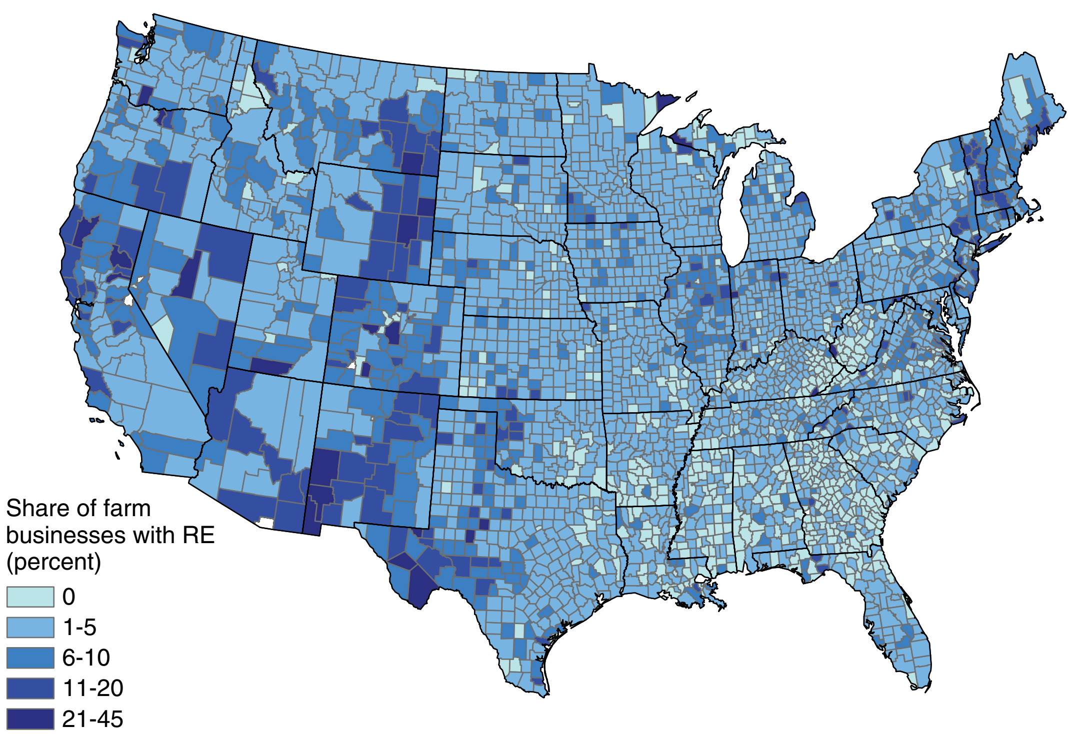
Note: Ethanol and biodiesel refer to farms producing these biofuels directly on the operation and do not refer to farms growing feedstocks, such as corn and soybeans used to produce biofuels.

This figure includes farm businesses as well as other farms. USDA defines a farm as any place that produced and sold—or normally would have produced and sold—at least $1,000 of agricultural products during a given year. USDA uses acres of crops and head of livestock to determine if a place with sales of less than $1,000 could normally produce and sell that amount. Farm businesses, as mentioned on page 5, include only farms where the primary operator is currently employed and spends the majority of work time on agricultural production, or, if the primary operator is largely employed off-farm, the operation has over $350,000 in annual gross cash farm income.

Source: 2012 Census of Agriculture (USDA, NASS 2014a).

Figure 15

Share of farm businesses with on-farm renewable energy (RE) systems by county, 2012



Source: 2012 Census of Agriculture (USDA, NASS 2014a).

Industrial Energy Generation: Utility-Scale Wind Power and Fossil Fuel Extraction

Agricultural landowners can lease land for utility-scale wind power plants (see “Wind rights leased to others” in figure 14) and fossil fuel extraction. In most cases, the landowner is compensated in at least two of three ways in the lease agreement: from royalty payments, rental payments, or bonus payments (Fitzgerald, 2012). Royalty payments are based on a fraction of the value of any mineral produced on the leased land. Rental payments are based on the use of the land rights during a specified period. A bonus payment is typically paid when the lease agreement is signed.

In the case of agricultural land leased for oil and gas exploration and drilling, the mineral rights are typically leased, but occasionally both surface and mineral rights are leased. For a well that produces two million cubic feet of natural gas per day in the first month and an assumed natural gas price of $4 per thousand cubic feet, annual royalties would start at $200,000, drop to $80,000 in the first and second years, and decline to $23,000 in the sixth year (King, 2014).

Income from royalties or leases associated with energy production (e.g., natural gas, oil, and wind turbines) is not uncommon, particularly in Oklahoma, Utah, Kansas, West Virginia, Colorado, and Texas, where 15-24 percent of farm businesses received such income in 2014 (table 2). In States with active shale development, about 12 percent of farm businesses received, on average, $65,781 in income from royalties or leases associated with energy production, compared with 6 percent and $56,162 for the United States as a whole. Average lease and royalty payments were highest in North Dakota ($157,000) and Pennsylvania ($154,000), mainly due to oil and gas drilling in the Bakken and Marcellus shales, respectively. Nationally, 70 to 80 percent of energy production income can be attributed directly to the selling or leasing of oil and gas rights. The remainder is due to selling or leasing “other rights,” which would include land for wind turbines or drilling access roads and pipelines but can also include hunting rights. Iowa, Illinois, and Minnesota had the most farm businesses with leases for industrial wind rights, according to the 2012 Census of Agriculture.

Income from royalties or leases associated with energy production can form an important part of farm-related income, often exceeding the average payment received through various agricultural Government programs.[11] Energy-related income is equal to 4-6 percent of gross cash farm income in Oklahoma, Pennsylvania, and Texas. Total payments to farm businesses from energy companies increased from $2.3 billion in 2011 (Weber, Brown, and Pender, 2015) to $2.9 billion in 2014. Declining oil and natural gas prices will likely be reflected in royalties associated with existing leases as well as in future lease and purchase agreements for oil and gas rights.

Farm size matters both to the probability of participation in energy production and to the average payment. In 2014, approximately 5.5 percent of small farm businesses received payments from industrial energy production, while 8.6 percent of medium-sized farm businesses and 6.9 percent of large farm businesses received these payments. Small farm businesses selling or leasing industrial energy rights received, on average, $21,838 ($45.72 per acre with sold or leased energy rights) in income for these operations, while medium-sized received $99,327 ($98.57 per acre with sold or leased rights), and large farm businesses received $198,647 ($110.76 per acre with sold or leased rights).

[11] Government payment programs include the Direct Counter-cyclical Payment Program, the Average Crop Revenue Election Program, upland cotton transition payments, Loan Deficiency Payments, Marketing Loan Gains, agricultural disaster payments, and the Conservation Reserve Program, Conservation Reserve Enhancement Program, Environmental Quality Incentives Program, Conservation Security Program, and Conservation Stewardship Program, among others.

Table 2

Income from royalties and leases associated with energy production for farm businesses, by State, 2014

	Farms receiving income from energy royalties or leases (%)	Average energy payment ($, if receiving)	Average government payment ($, if receiving)	Energy payment as share of gross cash farm income (%)
Oklahoma	23.6	58,993	48,303	6.0
Utah	19.0	L	50,885	L
Kansas	18.4	24,261	19,731	0.8
West Virginia	17.6	L	L	L
Colorado	16.6	29,847	21,956	2.2
Texas	15.5	93,413	30,785	4.6
Louisiana	13.0	25,118*	15,021	1.1*
Ohio	10.3	16,412	1,994	0.6
New York	10.2	1,356	3,015*	0.0
Pennsylvania	9.6	154,070*	3,056*	6.0*
North Dakota	9.2	157,409	8,785	2.2
Arkansas	9.0	27,846*	16,645	0.8*
New Mexico	8.6	L	87,808	L
Wyoming	7.3	L	41,996	L
Michigan	5.4	8,080#	4,195#	0.1#
Rest of United States	1.9	25,676	12,210	0.1
United States	6.1	56,162	16,088	0.8

L = too few observations to disclose the statistic. * = coefficient of variation (CV) is 50-75 percent. # = CV is greater than 75 percent. The CV is the ratio of the standard error to the estimate and is sometimes referred to as the "relative standard error" (see Dubman (2000) for more information).

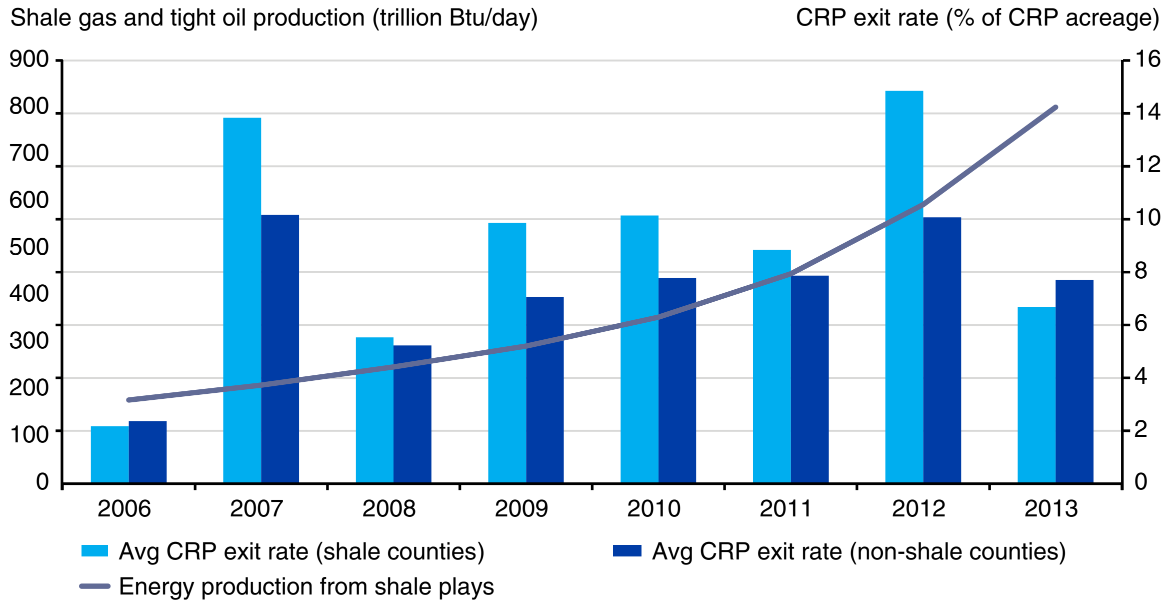
Source: USDA, National Agricultural Statistics Service and USDA, Economic Research Service, 2014 Tenure, Ownership, and Transition of Agricultural Land Survey.

Oil and Gas Production From Shale and the Conservation Reserve Program

Industrial energy leases may affect participation of farm businesses in certain USDA programs, such as the Conservation Reserve Program (CRP), Wetland Reserve Program, and Farm and Ranch Lands Protection Program (Aakre and Haugen, 2009).

About 28 percent of CRP land is located in counties that overlay shale formations (shale counties). Figure 16 shows that the average percentage of CRP acres that either exit the program before contract expiration or are not re-enrolled is much higher in shale than nonshale counties. Early exits and decisions not to re-enroll could be due to a number of factors, one of which is the placement of oil or natural gas wells, pipelines, and access roads through CRP land. Landowners exiting CRP early must remove the affected acres from the program and pay the early-exit penalty, which is the sum of all CRP payments received since enrollment plus interest. CRP acreage in shale counties declined by about 32 percent, on average, from 2006 to 2013 compared with a 22-percent decline in nonshale counties.

Figure 16
Average exit rate from the Conservation Reserve Program and oil and gas production in shale and nonshale counties



Note: Shale counties are defined as counties that partially or completely overlay shale formations. The average CRP exit rate for any given year is defined as the percentage of CRP acreage that either exits the program early (paying an exit penalty) or that is not re-enrolled.

Source: USDA, Economic Research Service (2014a) and Farm Service Agency (2014).

Solar Power

In agriculture, solar energy can be used in a photovoltaic (PV) system to convert solar radiation to electricity or, more simply, to thermal heating. Xiarchos and Vick (2011) show that agriculture and solar energy have a long history, with remote ranches and farms previously off the grid adopting solar PV energy for electricity. Solar energy generated on farms is used to power electric fencing, lighting, water pumps, pond aeration, and ventilation. Farmers can take advantage of the Federal investment tax credit, which amounts to 30 percent of the expenditures to install a solar system after the exclusion of any subsidized portion of the project.

As of 2012, a total of 36,331 U.S. farm businesses and other farms (1.7 percent of U.S. farms) had on-farm solar panels in the United States. States with the most on-farm solar energy were California (15 percent of farms with solar), Texas (10 percent), and Colorado (5 percent), according to the Census of Agriculture (USDA, NASS, 2014a). However, in 2011 the average capacity of solar energy systems installed in Texas (0.7 kW) and Colorado (1.6 kW) was much smaller than in California (11 kW) (Xiarchos and Vick, 2011).

Small Wind and Hydropower

In 2009, 1,420 U.S. farms (0.06 percent of operations) owned 1,845 wind turbines. The majority of these turbines had a capacity of less than 100 kW (small-scale). Only Iowa, Kansas, Minnesota, and Montana had turbines with a capacity greater than 100 kW, and the majority (9 of 14) were located in Iowa (U.S. Department of Agriculture, 2011). As of the 2012 Census of Agriculture, the States with the most on-farm small-scale wind systems among 9,054 U.S. farms (0.4 percent), owned by the farm or outside companies, were Texas (13 percent), Iowa (10 percent), and Illinois (7 percent) (USDA, NASS, 2014a).[12]

If a farm or ranch has water flowing through its property, it may be able to take advantage of generating electricity with a small hydropower system. According to the Department of Energy (U.S. DOE, 2012), these systems are able to generate up to 100 kW of electricity, depending on the amount of water flow and vertical incline of the property. In 2012, California (14 percent), Tennessee (8 percent), and Virginia (7 percent) had the most farms and ranches with small hydropower systems among 1,323 U.S. agricultural operations (0.06 percent of farms) with similar systems, according to the Census of Agriculture (USDA, NASS, 2014a).

A 100 kW small-wind or hydro system can generate up to 100 kWh of electricity in an hour and 2,400 kWh in a day (assuming a 100-percent capacity factor), meeting a substantial share of electricity consumption on most operations. In 2014, electricity consumption on farms ranged from about 1,110 kWh per day for peanut farms to 806 kWh per day for dairy farms, 250 kWh per day for corn farms, and 150 kWh per day for wheat farms.[13]

Biofuel and Cellulosic Feedstock Production

As a result of the RFS and its supporting programs, there is a significant market for renewable transportation fuels. Beckman et al. (2013) provide an overview of biofuel production, noting that in 2012 more than 42 percent of corn production was used as a feedstock for ethanol production, while only about 1 percent of soybean production was allocated to biodiesel production. The biodiesel market is smaller than the ethanol market, and soybeans provide about half of biodiesel feedstocks. In 2013, biodiesel was produced from soybeans (54 percent), animal fats (11 percent), corn oil (10 percent), canola oil (6 percent), and palm oil (6 percent), among other sources (EIA 2015c). Biofuels are generally produced in ethanol and biodiesel plants, though some farms (less than 0.3 percent of farms in 2012) produce biofuels directly on the operation: 4,099 farms produced biodiesel and 2,364 farms produced ethanol in 2012. The biodiesel and ethanol produced directly on farms can be for farm use or for outside sale.

However, unlike ethanol and biodiesel, cellulosic biofuels are derived from nonfood biomass feedstocks, including crop residues, wood wastes, energy crops, and municipal solid wastes. It is believed that cellulosic biomass has an advantage over conventional biofuels because its feedstocks are either wastes or dedicated energy crops harvested from marginal lands (U.S. DOE, 2016).[14] Although it is often challenging to produce biofuel from cellulosic feedstocks, the conversion technology is constantly improving. As a result of an increasing cellulosic biofuel mandate in the RFS, there have also been advances in producing, harvesting, collecting, and transporting cellulosic biomass feed-

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[12] The methodological difference between the 2009 survey and 2012 survey regarding renewable energy is that the 2009 survey limited the response to wind turbines owned by the operation (excluding turbines under wind rights lease agreements) and the 2012 survey opened responses to all wind turbines on the operations, regardless of ownership.

[13] These calculations are based on the average expenses for electricity for farms by principal commodity from the ERS/NASS 2014 Agricultural Resource Management Survey, as well as the industrial retail rate of electricity of 7 cents per kWh from EIA's Electric Power Monthly February 2015 report.

[14] Collecting crop waste could have some detrimental impacts on soil health by removing soil cover, increasing soil erosion, and reducing soil organic matter.

stocks. In 2012, nearly 12,000 farms (0.5 percent) harvested cellulosic biomass (excluding grains, oilseeds, and wood) (USDA, NASS, 2014a).

Anaerobic Methane Digesters

Anaerobic methane digestion uses bacteria to break down biodegradable material (agricultural waste, such as manure or crop residues) into a biogas that is composed primarily of methane. In energy production, the methane generated is burned in an engine generator to produce electricity, and the waste heat is used for space or water heating (Lazarus, 2008). Cogeneration projects, which capture waste heat from electricity generation, are the most often-adopted electricity projects among on-farm methane digesters (U.S. EPA, 2010c). Other biogas technologies include electricity generation without heat, boiler fuel, pipeline gas, vehicle fuel, or methanol.

Manure management on farms, which includes treatment, storage, and transport, emits methane and nitrous oxide. In 2014, emissions from this source totaled 78.7 million metric tons of carbon dioxide equivalent, accounting for 14 percent of greenhouse gas (GHG) emissions from the agricultural sector (U.S. EPA, 2016). Anaerobic methane digesters offer multiple benefits: Digesters turn manure or crop residues into renewable energy that can be sold or used on farm, improve air quality by reducing odors and GHG emissions, and reduce the potential for pathogens to enter surface or ground water (MNDA, 2016). The AgSTAR program, established in 1993 and discussed in Box 4, is a voluntary program sponsored by EPA, USDA, and the U.S. Department of Energy to advance the implementation of anaerobic digester systems in livestock facilities in the United States (U.S. EPA, 2004). Technical and financial assistance for anaerobic digesters is also available through the Air Quality Initiative of the Environmental Quality Incentives Program (EQIP) (USDA, NRCS, 2016).

Adoption of anaerobic methane digesters on farms is a small but growing trend. In 2009, 121 farms reported having 140 methane digesters (U.S. Department of Agriculture, 2011). These on-farm methane digesters produced approximately 385 million kWh equivalent of energy. By July 2010, there were 145 farm-scale methane digester projects and 12 commercial-scale projects in the United States, which produced an estimated 404 million kWh of energy (U.S. EPA, 2010c). The majority of these digester projects were located on dairy farms; there were also some on hog farms, poultry facilities, and beef operations. As of 2012, 537 farms (0.04 percent of livestock farms) had methane digesters across the United States (USDA, NASS, 2014a).

Methane digesters have not been widely adopted in the United States mainly because the costs of constructing and maintaining these systems have exceeded the value of the benefits provided to the operators (Key and Sneeringer, 2011). Policies such as the Clean Power Plan that could increase the price of electricity or provide for a carbon-offset market would make methane digesters more valuable. Key and Sneeringer estimate the number and type of hog and dairy operations that would find it profitable to adopt a digester at a range of carbon prices.

Conclusions

Agriculture has always been a considerable consumer of energy, directly and indirectly, and in recent years it has become a producer of energy as well. This report analyzes farm energy consumption and production, as well as markets and policies that drive the nexus between agriculture and energy.

The majority of energy consumed in agriculture is in the indirect form used to manufacture fertilizer, followed by diesel, electricity, and natural gas. Energy inputs form a substantial share of many farm business expenses—about 40 to 50 percent for rice, peanut, wheat, and cotton producers, 35 percent for corn and soybean producers, and 10 to 15 percent for livestock operations.

Farmers' decisions about production practices affect energy-use patterns. For example, conservation practices, such as no-till and conservation tillage, are associated with lower fuel costs per acre across almost all crops but with higher fertilizer and pesticide expenses per acre for corn and wheat producers.

Though still few in number, the proportion of U.S. farms generating renewable energy has more than doubled between 2007 and 2012 from 1.1 to 2.7 percent, including farms producing solar, wind, and geothermal, but not farms that harvest biomass feedstocks such as corn, soybeans, and cellulosic materials or that lease their wind rights to others. Aside from producing bioenergy feedstocks, farms also serve as a location for other energy-generating activities, such as oil and gas wells and industrial wind farms. In 2012, 35 percent of farm and ranch land in operation was located in shale counties, and in 2014, about 12 percent of farm businesses in States with active shale development averaged $66,000 in income from royalties and leases associated with energy production.

Agriculture is now linked to energy markets in two ways, on the supply side and the demand side. Farms are exposed to volatility in energy prices as energy consumers, and for agricultural operations that produce energy and sell their electricity, renewable fuel, or biomass feedstock, the price volatility extends to the farm revenue side as well. For example, oil, natural gas, and electricity prices affect input costs, but oil and natural gas prices can also affect royalty or lease income associated with energy production on farms, while electricity prices can affect the value of renewable power generated on-farm.

Agricultural operations are or would be affected by a number of national policies, such as the Renewable Fuel Standard program and the Clean Power Plan, as well as changing market conditions from the shale energy revolution. Since its inception in 2005, the RFS has affected the markets for corn, soybean, sugarcane, and cellulosic material, which form the feedstock for ethanol, biodiesel, advanced biofuel, and cellulosic biofuel production. In 2012, nearly 12,000 farms harvested cellulosic biomass, while 4,100 farms produced biodiesel and 2,400 farms produced ethanol directly on the operation (USDA, NASS, 2014a).

The shale revolution that began around the start of the new millennium has lowered domestic natural gas and oil prices, reducing farm expenditures on diesel, gasoline, and natural gas. Fuel and oil expenses are forecast to decrease by over 14 percent in 2016, following a similar decline in 2015 (USDA, ERS, 2016). To date, lower domestic natural gas prices have resulted in capacity expansion at fertilizer manufacturing establishments, but domestic fertilizer prices still closely track global fertilizer prices and thus have not fallen along with natural gas prices (Hausman and Kellogg, 2015).

Farms in shale regions are also impacted by increased competition for water, labor, and transportation infrastructure while potentially benefiting from energy lease and royalty payments.

The Clean Power Plan is expected to increase U.S. average retail electricity and natural gas prices by 3 and 5 percent, respectively, in 2020 (EPA, 2015). However, agricultural customers served by rural utilities would likely face greater electricity price increases, perhaps nearly 17 percent, since rural utilities generate twice as much electricity from coal power plants than other utilities do (NRECA, 2014). Nevertheless, as electricity expenses form, on average, about 1-6 percent of total expenses, impacts are expected to be minor and concentrated mainly on the livestock sector and irrigated farms. The greatest impact of the Clean Power Plan on farmers, should it be implemented, would be the increase in demand for renewable energy, as a growing portion of farms are engaged in renewable energy production.

The agricultural sector has adapted—and continues to adapt—in the transition to a low-carbon economy by growing the feedstocks required for renewable fuels or by serving as a location for utility-scale wind-power plants. Farms can reduce their GHG emissions by reducing energy consumption, for example, by adopting conservation tillage practices, substituting renewable power generated on-farm for electricity generated from fossil fuels, or turning manure, a source of GHG emissions, into biogas with anaerobic methane digesters. Regulation of carbon emissions in the power sector and voluntary Government programs would further support these types of actions.

References

Aakre, D., and R. Haugen. 2009. *Wind Turbine Lease Considerations for Landowners*. North Dakota State University Extension, Fargo, ND.

Allred, B.W., W.K. Smith, D. Twidwell, J.H. Haggerty, S.W. Running, D.E. Naugle, S.D. Fuhlendorf. 2015. "Ecosystem services lost to oil and gas in North America," *Science* 24:401-02.

Audsley, E., K. Stacey, D.J. Parson, and A.G. Williams. 2009. *Estimations of the Greenhouse Gas Emissions from Agricultural Pesticide Manufacture and Use*. Crop Protection Association, Cranfield, Bedford, UK.

Babcock, B.A., and J.F. Fabiosa. 2011. *The Impact of Ethanol and Ethanol Subsidies on Corn Prices: Revisiting History*. CARD Policy Brief. Center for Agricultural and Rural Development, Iowa State University.

Baker, R.D., and B. Rouppet. 1996. *Conservation Farming in New Mexico*. New Mexico State University, Agricultural Science Center at Clovis, Las Cruces, NM.

Beckman, J., A. Borchers, and C.A. Jones. 2013. *Agriculture's Supply and Demand for Energy and Energy Products*, EIB-112, USDA Economic Research Service, May 2013. http://www.ers.usda.gov/media/1104145/eib112.pdf.

Boesen, B. 2016. Iowa fertilizer plant to begin production this fall. KWQC.com, May 17, 2016. http://kwqc.com/2016/05/17/iowa-fertilizer-plant-to-begin-production-this-fall/.

Borenstein, S. 2013. Rate design wars are the sound of utilities taking residential PV seriously. Blog post from November 12, 2013, of the Energy Institute at Haas, Haas School of Business, University of California, Berkeley. https://energyathaas.wordpress.com/.

Bracmort, K. 2015. *The Renewable Fuel Standard (RFS): Cellulosic Biofuels*, R41106, Congressional Research Service, January 2015. http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R41106.pdf.

Comis, D. 2005. *Farming on Propane*. News. USDA Agricultural Research Service, Washington, DC.

CTIC. 2015. Top 10 Benefits of Conservation Tillage. Conservation Technology Information Center. http://www.ctic.purdue.edu/resourcedisplay/293/.

Curley, R.G., and G.D. Knutson. 1992. "Cost Comparison: Engines vs. Electric Motors for Irrigation Pumping," *California Agriculture* 46(5).

Database of State Incentives for Renewables & Efficiency. 2015. *Renewable Portfolio Standard Policies*. North Carolina Solar Center, Raleigh, NC.

DATCP. 2006. *Dairy Farm Energy Management Handbook*. Wisconsin Department of Agriculture, Trade and Consumer Protection, Madison, WI.

Dubman, R. 2000. Variance Estimation with USDA's Farm Costs and Returns Surveys and Agricultural Resource Management Study Surveys. USDA, Economic Research Service, Staff Paper.

Fennimore, S.A., B.D. Hanson, L.M. Sosnoskie, J.B. Samtani, A. Datta, S.Z. Knezevic, and M.C. Siemens. 2014. "Field Applications of Automated Weed Control." in *Automation: The Future of Weed Control in Cropping Systems*, edited by S.L. Young and F.J. Pierce. New York: Springer.

Filipic, M. 2013. *News: Farmers, Greenhouse Operators Invited to Natural Gas Workshop Jan. 14*. News Releases. Agricultural College of Food, and Environmental Sciences. The Ohio State University, Columbus, OH.

Fitzgerald, T. 2012. *Oil and Gas Leasing*. Montana State University Extension. Montana State University, Bozeman, MT.

Gellings, C.W., and K.E. Parmenter. 2004. "Energy Efficiency in Fertilizer Production and Use." In *Efficient Use and Conservation of Energy*, edited by Clark W. Gellings and Kornelis Blok. Paris, France: UNESCO Encyclopedia of Life Support Systems.

Greene, C., S. Wechsler, A. Adalja, and J. Hanson. 2016. Economic Issues in the Coexistence of Organic, Genetically Engineered (GE), and Non-GE Crops. Economic Information Bulletin EIB-149, Economic Research Service, U.S. Department of Agriculture.

Hausman, C., and R. Kellogg (2015). Welfare and Distributional Implications of Shale Gas. Brookings Papers on Economic Activity, Brookings Institution, Washington, DC.

Helsel, Z.R. 2012. *Energy Use and Efficiency in Pest Control, Including Pesticide Production, Use, and Management Options*. Farm Energy. eXtension, Centreville, AL.

Hicks, S. 2014. *Energy for Growing and Harvesting Crops Is a Large Component for Farm Operating Costs*. EIA Today in Energy, October 17, 2014. U.S. Energy Information Agency, Washington, DC.

Hitaj, C., A. Boslett, and J.G. Weber. 2014. *Shale Development and Agriculture*. CHOICES. Agricultural & Applied Economics Association, Milwaukee, WI.

Hoffman, L., and A. Baker. 2011. *Estimating the Substitution of Distillers' Grains for Corn and Soybean Meal in the U.S. Feed Complex*, FDS-11-I-01, USDA Economic Research Service, October 2011.

IRS. 2011. "Cotton." In *Farmers Audit Techniques Guide*. Washington, DC: U.S. Internal Revenue Service.

Irwin, S. 2013. *Ethanol Prices Drive Corn Prices, Right?* farmdocDAILY. University of Illinois at Urbana-Champaign, Champaign, IL.

Jacobson, L.D. 2014. *Energy Use in Swine Buildings*. 2014 Minnkota Meeting, Granite Falls, MN.

Key, N., and S. Sneeringer. 2011. Climate Change Policy and the Adoption of Methane Digesters on Livestock Operations. Economic Research Report ERR-111, USDA Economic Research Service.

King, H. 2014. *Production and Royalty Declines in a Natural Gas Well Over Time*. Decline of Natural Gas Well Production and Royalties Over Time. Geology.com.

Krane, J., and M. Agerton. 2015. OPEC Imposes 'Swing Producer' Role upon U.S. Shale: Evidence and Implications. IAEE Energy Forum, 3rd Quarter.

Lawrence, J.D., J. Mintert, J.D. Anderson, and D.P. Anderson. 2008. *Feed Grains and Livestock: Impacts on Meat Supplies and Prices*. CHOICES. Agricultural & Applied Economics, Milwaukee, WI.

Lazarus, W.F. 2008. *Farm-Based Anaerobic Digesters as an Energy and Odor Control Technology: Background and Policy Issues*, AER-843, USDA Office of the Chief Economist, Office of Energy Policy and New Uses, February 2008. http://www.usda.gov/oce/reports/energy/AnerobicDigesters0308.pdf.

LeCompte, C. 2013. "Fertilizer Plants Spring Up to Take Advantage of U.S.'s Cheap Natural Gas," *Scientific American*. Nature Publishing Group, New York City, NY.

Malcolm, S.A., M. Aillery, and M. Weinberg. 2009. *Ethanol and a Changing Agricultural Landscape*, ERR-86, USDA Economic Research Service, November 2009. http://www.ers.usda.gov/media/153816/err86.pdf.

Matlock, M., L. Nalley, and Z. Clayton-Niederman. 2009. *Carbon Life Cycle Assessment of United States Cotton: A View of Cotton Production Practices and Their Associated Carbon Emissions for Counties in 16 Cotton Producing States*. University of Arkansas, Center for Agricultural and Rural Sustainability, Fayetteville, AR.

McMinimy, M.A. 2015. *Biomass Crop Assistance Program (BCAP): Status and Issues*, R41296, Congressional Research Service, January 2015. http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R41296.pdf.

Miranowski, J. 2005. "Energy Consumption in US Agriculture." In *Agriculture as a Producer and Consumer of Energy*, edited by J. Outlaw, K. Collins, and J. Duffield. Cambridge, MA, CAB International.

MNDA. 2016. *Manure/Methane Digester. Minnesota Conservation Funding Guide*, Minnesota Department of Agriculture.

NC Clean Energy Technology Center. 2015. The 50 States of Solar: A Quarterly Look at America's Fast-Evolving Distributed Solar Policy Conservation. NC Clean Energy Technology Center, North Carolina State University. https://nccleantech.ncsu.edu/10793/.

NRECA. 2014. *Comments on Proposed Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units and Notice of Data Availability*. R.E. Cronmiller. National Rural Electric Cooperative Association, Arlington, VA.

Plant & Soil Sciences eLibrary. (No date.) *Chapter 13: Energy Costs for Irrigation Pumping*. Irrigation Management. University of Nebraska, Lincoln, NE.

Rascoe, A. 2013. *US Ethanol Producers Brace for Biofuel Mandate Fight in Congress*. Reuters.

Runkle, E., and A.J. Both. 2011. *Greenhouse: Energy Conservation Strategies*. Extension Bulletin. Michigan State University Extension, East Lansing, MI.

Sands, R., P. Westcott, J.M. Price, J. Beckman, E. Leibtag, G. Lucier, W. McBride, D. McGranahan, M. Morehart, E. Roeger, G. Schaible, and T.R. Wojan. 2011. *Impacts of Higher Energy Prices on Agriculture and Rural Economies*, ERR-123, USDA Economic Research Service, August 2011. http://www.ers.usda.gov/media/118256/err123_1_.pdf.

Schaible, G.D., and M.P. Aillery. 2012. *Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands*, EIB-99, USDA Economic Research Service, September. http://www.ers.usda.gov/media/884158/eib99.pdf.

Schnepf, R., and B.D. Yacobucci. 2013. *Renewable Fuel Standard (RFS): Overview and Issues*, R40155, Congressional Research Service, March 14, 2013. https://www.fas.org/sgp/crs/misc/R40155.pdf.

Shouse, S., M. Hanna, and D. Petersen. 2012. *Energy Considerations for Low-Temperature Grain Drying*. Farm Energy. Iowa State University Extension and Outreach, Ames, IA.

Sieminski, A. (2015). Oil and Gas Outlook. Presentation by Adam Sieminski, Administrator of the U.S. Energy Information Administration at the National Capital Area Chapter of the U.S. Association for Energy Economics, October 16, 2015, in Washington, DC.

Suttles, S. "Agricultural Energy Use and the Proposed Clean Power Plan," *Amber Waves,* USDA Economic Research Service, September 8, 2014. http://www.ers.usda.gov/amber-waves/2014-september/agricultural-energy-use-and-the-proposed-clean-power-plan.aspx#.VOTo2LEo6Ul.

Svejkovsky, C., and D. Ryan. 2012. *Small-Scale Wind Energy on the Farm*. Tracy Mumma. National Sustainable Agriculture Information Service, National Center for Appropriate Technology, Butte, MT.

Tran, T. 2014. *Shale Gas Provides Largest Share of U.S. Natural Gas Production in 2013*. EIA Today in Energy. U.S. Energy Information Administration, Washington, DC.

Tyson Brown, M., and M. Harnish. 2014. *Many Industrial Electricity Users are Farmers*. EIA Today in Energy. U.S. Energy Information Administration, Washington, DC.

UC IPM. 2013. Cotton: Harvest Aid Chemicals. UC Pest Management Guidelines, UC Integrated Pest Management Program, University of California, Davis. http://www.ipm.ucdavis.edu/PMG/r114800111.html#REFERENCE.

U.S. Department of Agriculture. 2015. *Agriculture Secretary Tom Vilsack and Senior White House Advisor Brian Deese Announce Partnerships with Farmers and Ranchers to Address Climate Change*. Washington, DC.

U.S. Department of Agriculture. 2011. *On-Farm Renewable Energy Production Survey (2009)*, AC-07-SS-6, U.S. Department of Agriculture, February 2011. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/On-Farm_Energy_Production/energy09.pdf.

U.S. Department of Agriculture. 2015. Rail Service Challenges in the Upper Midwest: Implications for Agricultural Sectors. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC.

US U.S. Department of Agriculture, Agricultural Marketing Service (AMS). 2015. *The National List of Allowed and Prohibited Substances*. Washington, DC.

U.S. Department of Agriculture, ERS. 2000. *Farm Resource Regions*, AIB-760, USDA Economic Research Service, September 2000. http://www.ers.usda.gov/media/926929/aib-760_002.pdf.

—. 2014a. "County-Level Oil and Gas Production in the United States." USDA Economic Research Service. http://www.ers.usda.gov/data-products/county-level-oil-and-gas-production-in-the-us.aspx.

—. 2014b. *Findings*. Bioenergy. USDA Economic Research Service, Washington, DC.

—. 2015. "Commodity Cost and Returns." USDA Economic Research Service. http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx.

—. 2016. "Farm Sector Income Forecast: February 2016." USDA Economic Research Service, Washington, DC.

U.S. Department of Agriculture, Farm Service Agency (FSA). 2011. *Biomass Crop Assistance Program (BCAP)*. USDA, Washington, DC.

—. 2014. "Conservation Reserve Program." USDA Farm Service Agency.

—. 2015. *Biomass Crop Assistance Program*. Energy Programs. USDA Farm Service Agency, Washington, DC.

U.S. Department of Agriculture, National Agricultural Statistics Service (NASS). 2014a. 2012 Census of Agriculture.

—. 2014b. 2013 Agricultural Resource Managament Survey. USDA National Agricultural Statistics Service..

—. 2015a. 2013 Farm and Ranch Irrigation Survey. USDA National Agricultural Statistics Service.

—. 2015b. Agricultural Prices. USDA National Agricultural Statistics Service. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do;jsessionid=F154BA78C7C50C021C8CA924EDB72FD5?documentID=1002.

—. 2015c. *Livestock and Animals*. 2012 Census Ag Atlas Maps. USDA National Agricultural Statistics Service..

—. 2015d. Tenure, Ownership, and Transition of Agricultural Land Survey (TOTAL), USDA National Agricultural Statistics Service and Economic Research Service.

—. 2016. Quick Stats 2.0. USDA National Agricultural Statistics Service. http://quickstats.nass.usda.gov/.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2015. On-Farm Energy Initiative. Environmental Quality Incentives Program (EQIP*)*, Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2016. Air Quality Initiative. Environmental Quality Incentives Program (EQIP). Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service California (NRCS-CA). 2016. California Air Quality Programs. Davis, CA. http://www.nrcs.usda.gov/wps/portal/nrcs/main/ca/air/quality/.

U.S. Department of Agriculture, Rural Development. 2016. *Rural Energy for America Program: Renewable Energy Systems & Energy Efficiency Improvement Loans & Grants*. Washington, DC.

U.S. Department of Agriculture, Rural Utilities Services. 2013. *Energy Efficiency and Conservation Loan Program: Final Rule*. Washington, DC.

U.S. Department of Energy (DOE). 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*, Oak Ridge National Laboratory, August 2011. http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf.

—. 2012. *Microhydropower Systems*. U.S. Department of Energy, Washington, DC.

—. 2013. *Smith Dairy Deploys Natural Gas Vehicles and Fueling Infrastructure in the Midwest*. Case Studies. U.S. Department of Energy, Energy Efficiency & Renewable Energy, Washington, DC.

—. 2015. *Propane Fuel Basics*. Alternative Fuels Data Center, Fuels & Vehicles: Propane. U.S. Department of Energy, Energy Efficiency & Renewable Energy, Washington, DC.

—. 2016. Ethanol Feedstocks. U.S. Department of Energy Alternative Fuels Data Center. http://www.afdc.energy.gov/fuels/ethanol_feedstocks.html.

U.S. Energy Information Administration (EIA), U.S. Department of Energy. 2011. *Review f Emerging Resources: U.S. Shale Gas and Shale Oil Plays*, July. http://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf.

—. 2012. *Annual Energy Review 2011*, DOE/EIA-0384(2011, U.S. Energy Information Administration, September 2012. http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf.

—. 2014a. "Electricity Data - Detailed State Data." U.S. Energy Information Administration. http://www.eia.gov/electricity/data/state/.

—. 2014b. *How Much Carbon Dioxide is Produced When Different Fuels Are Burned?* Frequently Asked Questions, U.S. Energy Infomation Administation, Washington, DC.

—. 2014c. Natural Gas Prices. U.S. Energy Information Administration. http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm.

—. 2015a. Drilling Productivity Report. U.S. Energy Information Adminstration. http:// http://www.eia.gov/petroleum/drilling/.

—. 2015b. *Market Prices and Uncertainty Report*. Short-Term Energy Outlook, U.S. Energy Information Administration.

—. 2015c. *Monthly Biodiesel Production Report with Data from December 2014*, U.S. Energy Information Administration, March 2015. http://www.eia.gov/biofuels/biodiesel/production/archive/2014/2014_12/biodiesel.pdf.

—. 2015d. Natural Gas Data: Natural Gas Spot and Futures Prices. U.S. Energy Information Administration. http://www.eia.gov/dnav/ng/ng_pri_fut_s1_d.htm.

—. 2015e. *November 2015 Monthly Energy Review*. U.S. Energy Information Administration, Washington, DC.

—. 2015f. How much of the oil produced in the United States is consumed in the United States? Frequently asked questions, U.S. Energy Information Administration. https://www.eia.gov/tools/faqs/faq.cfm?id=268&t=6.

—. 2015g. Petroleum and Other Liquids Data: Spot Prices. U.S. Energy Information Administration. http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm.

—. 2016a. Fuel Ethanol Overview. March 2016 Monthly Energy Review, U.S. Energy Information Administration, U.S. Deparatment of Energy, Washington, DC.

—. 2016b. Shale in the United States. Energy in Brief, U.S. Energy Information Administration, Washington, DC. http://www.eia.gov/energy_in_brief/article/shale_in_the_united_states Environmental Protection Agency,.cfm.

U.S. Environmental Protection Agency (EPA). 2004. *A Manual for Developing Biogas Systems at Commercial Farms in the United States*, EPA-430-B-97-015, U.S. February 2004. http://www.epa.gov/agstar/documents/AgSTAR-handbook.pdf=.

—. 2007. *Regulation of Fuels and Fuel Additives: Renewable Fuel Standard Program; Final Rule*, U.S. Environmental Protection Agency, Washington, DC.

—. 2010a. *Clean Agriculture USA - Cleaner Air Over Greener Fields*. Online. U.S. Environmental Protection Agency, Washington, DC.

—. 2010b. *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis*, EPA-420-R-10-006, U.S. Environmental Protection Agency, February 2010. http://www.epa.gov/otaq/renewablefuels/420r10006.pdf.

—. 2010c. *U.S. Anaerobic Digester: Status Report*, U.S. Environmental Protection Agency, October 2010.

—. 2011. *Common Safety Practices for On-Farm Anaerobic Digestion Systems*, U.S. Environmental Protection Agency, Office of Air and Radiation, December 2011. http://www.epa.gov/agstar/documents/safety_practices.pdf.

—. 2014a. *EPA Issues Direct Final Rule for 2013 Cellulosic Standard*. Regulatory Announcement. U.S. Environmental ProtectionAgency, Office of Transportation and Air Quality, Washington, DC.

—. 2014b. *Fuels and Engines*. Agriculture Topics. Natural Resources Conservation Service, U.S. Environmental Protection Agency, Washington, DC.

—. 2014c. *Global Methane Intiative*. Climate Change. U.S. Environmental Protection Agency, Washington, DC.

—. 2015a. *2014 RFS2 Data*. RIN Generation and Renewable Fuel Volume Production by Fuel Type. U.S. Environmental Protection Agency, Washington, DC.

—. 2015b. *Greenhouse Gas Inventory Data Explorer*. U.S. Environmental Protection Agency, Washington, DC.

—. 2015c. *Regulatory Impact Analysis for the Clean Power Plan Final Rule*. U.S. Environmental Protection Agency, Washington, DC.

—. 2016. U.S. Greenhouse Gas Inventory Report: 1990-2014. U.S. Environmental Protection Agency, Washington, DC.

Wallander, S., R. Claassen, and C. Nickerson. 2011. *The Ethanol Decade: An Expansion of U.S. Corn Production, 2000-09*, EIB-79, USDA Economic Research Service, August 2011. http://www.ers.usda.gov/media/121204/eib79.pdf.

Weber, J.G., J.P. Brown, and J. Pender. 2015. "Rural Wealth Creation and Emerging Energy Industries: Lease and Royalty Payments to Farms." In *Rural Wealth Creation*, Eds. J. Pender, B. Johnson, and M. Fannin. Routledge.

Weber, J.G., and C. Hitaj. 2015. "What can we learn about shale gas development from land values? Opportunities, challenges, and evidence from Texas and Pennsylvania," *Agricultural and Resource Economics Review* 44(2).

Weinheimer, J.A., and P.N. Johnson. 2008. *Energy Analysis of Cotton Production on the Southern High Plains of Texas*. Beltwide Cotton Conferences, Nashville, TN.

Worell, E., D. Phylipsen, D. Einstein, and N. Martin. 2000. *Energy Use and Energy Intensity of the U.S. Chemical Industry*. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA.

Xiarchos, I.M., and W. Lazarus, 2013. Factors Affecting the Adoption of Wind and Solar-Power Generating Systems on U.S. Farms: Experiences at the State Level. U.S. Department of Agriculture.

Xiarchos, I.M., and B. Vick. 2011. *Solar Energy Use in U.S. Agriculture: Overview and Policy Issues*, USDA Office of the Chief Economist, Office of Energy Policy and New Uses, April 2011. http://www.usda.gov/oce/reports/energy/Web_SolarEnergy_combined.pdf.

Glossary

Biofuel – Fuel derived directly from living matter.

Biomass – Organic matter, which may be used as fuel.

Biomass-based diesel – Diesel fuel derived from vegetable oils, animal fats, or algae.

Biomass feedstock – Renewable, biological material that can be used directly as fuel or converted to another form of fuel or energy product. Examples include cornstarch, sugarcane, and crop residues.

Biopower – The production of heat and electricity using renewable biomass as the feedstock. An example is biogas from methane digestion.

Carbon dioxide (CO_2) – A colorless, odorless gas produced by respiration and by burning carbon-based compounds.

Cellulosic biofuel – Fuel derived from nonfood-based feedstocks that include crop residues, wood residues, dedicated energy crops, and industrial wastes.

Clean Power Plan (CPP) – 2014 U.S. Environmental Protection Agency proposal to reduce carbon pollution from existing power plants under the Clean Air Act. The plan would establish carbon emissions rate-reduction targets for individual States and offer a 'building blocks' framework for States to meet those targets.

Distillates – One of the petroleum components produced in conventional distillation operations that separate chemical compounds with heat. Examples include diesel fuels and fuel oils.

Fossil fuels – Fuels formed in the geological past from the remains of living organisms. Examples include coal, petroleum, and natural gas.

Geoexchange – A central heating and/or cooling system that uses a geothermal heat pump or ground-source heat pump to transfer heat to or from the ground.

Greenhouse gas (GHG) – A gas that contributes to the greenhouse effect by absorbing infrared radiation and trapping heat in the atmosphere. Includes carbon dioxide and chlorofluorocarbons.

Horizontal drilling – A drilling process in which the well is turned horizontally at depth to expose more of the reservoir than can be achieved through a conventional vertical well. Horizontal drilling has contributed to the success of hydraulic fracturing by recovering gas from the small cracks made in low-permeability rock formations.

Hydraulic fracturing – A well-stimulation technique by which deep rock formations are fractured by pressurized liquid injections to create cracks that will improve the flow of natural gas, petroleum, and brine. Hydraulic fracturing is sometimes referred to as "fracking."

Lifecycle greenhouse gas emissions – The assessment of emissions associated with all stages in the life of greenhouse gases, from raw material extraction to disposal or recycling (cradle to grave).

Liquefied petroleum (LP) gas – Includes propane and butane. A fossil fuel gas used in heating appliances, cooking equipment, and vehicles.

Renewable energy – Energy derived from resources that naturally replenish on a human timescale, such as sunlight, wind, geothermal heat, and biological material. Examples include solar energy, wind power, and bioenergy.

Renewable Fuel Standard – Program created by the 2005 Energy Policy Act (RFS) and updated by the 2007 Energy Independence and Security Act (RFS2). The program established a mandate for blending renewable fuels into conventional transportation fuels in the United States.

Shale energy revolution – Advances in horizontal drilling and hydraulic fracturing technologies that led to increased natural gas production in the Barnett Shale (Texas) in the early 2000s and spread to the Haynesville (Texas and Louisiana) and the Marcellus (Pennsylvania) shales in 2007 during the time of high oil and natural gas prices in the United States. Tight oil production began in the Bakken play (North Dakota and Montana) in 2007 and in the Eagle Ford play (Texas) and Permian play (Texas and New Mexico) in 2011.

Shale plays – Shale formations that contain significant amounts of natural gas and/or tight oil and that share similar geologic and geographic properties.

Small hydropower – Hydropower plant with a generating capacity under 10 MW.

Tight oil – Petroleum that consists of light crude oil contained in shale or tight sandstone rock formations.