Executive Summary

The Renewable Fuel Standard (RFS) requires that biofuels such as ethanol and biodiesel be blended into the transportation fuel supply. The main potential public benefits of the RFS stem from greenhouse gas emissions reduction due to substitution from fossil fuels to biofuels. Additional effects of the program are to reduce oil imports and raise farm commodity prices.

The RFS is at a crossroads. Most greenhouse gas emissions reductions under the RFS were touted to come from cellulosic biofuel, which can be produced from the inedible parts of plants, but the technology has not developed sufficiently to make it cost effective. Instead, most biofuels are produced from corn or soybeans. Moreover, the RFS now requires more biofuel than the fuel industry can easily absorb. Congress and the Environmental Protection Agency, which administers the program, face important decisions about the future path of the RFS.

This paper draws three lessons from the RFS that are relevant to government policymaking in this and other areas:

1. Incorporate uncertainty when making, implementing, and analyzing policy;

2. Don’t give the regulator too much discretion because it enables political forces and legal challenges to undermine policy; and

3. Don’t mandate things that don’t exist.
Biofuels, the Renewable Fuel Standard, and the Farm Bill

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Biofuels account for more than 10 percent of farm crop revenue in the United States, so they are an integral part of the farm economy. In 2016, 40 percent of domestic corn production was used to produce ethanol, and a quarter of soybean oil was used for biodiesel. These biofuels are blended with petroleum products—ethanol with gasoline and biodiesel with diesel—and sold as transportation fuels.

The main policy governing biofuels is the Renewable Fuel Standard (RFS), which requires that at least a minimum amount of each category of biofuel be blended into the transportation fuel supply each year. The RFS was established by the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act (EISA) of 2007. The program sets ambitious standards for biofuel consumption, with the overt goals of reducing greenhouse gas (GHG) emissions and reducing dependence on foreign oil. An additional effect of the program is to expand demand for corn, soybeans, and some other crops raised by US farms.

The RFS is at a crossroads. Until 2013, the fuel industry met the RFS mandates without too much difficulty. However, the mandates now require more biofuel than the fuel industry can easily absorb. As a result, compliance costs have increased, which in turn have increased lobbying pressures on the Environmental Protection Agency (EPA), which administers the program. The EPA, and by extension Congress, faces important decisions about the future path of the RFS.

Farm bills have devoted relatively few federal resources to biofuels. The energy title in the 2014 Farm Act contained a projected $125 million per year for biofuels, less than 1 percent of projected non-nutrition spending. Actual spending since 2014 has been even lower as appropriations committees have reduced funding. Energy title funding focuses on the development of non-corn-based biofuels, which have potentially larger GHG reduction benefits than corn ethanol and which constitute all of the RFS-mandated growth in biofuels after 2015. As such, the energy title is best seen as an abetment to the RFS.

This paper addresses two questions:

- What lessons from the RFS are useful for the policymaking process?
- What farm bill initiatives could improve US biofuel policy?

I draw three lessons from the RFS that are relevant to government policymaking in this and other areas:

1. **Incorporate uncertainty.** Policymakers should make, implement, and analyze policy with a view to what might happen, rather than a single projection of what will happen.

2. **Do not give the regulator too much discretion.** Political forces and legal challenges can undermine policy if the regulating agency has discretion to repeatedly adjust the policy parameters.
3. Do not mandate things that do not exist.
Mandates are an inefficient and ineffective method for forcing technological progress.

These lessons relate to details of legislation and its implementation, which sets this paper apart from a typical paper on climate policy. Most economic analysis emphasizes a hypothetical first-best policy and evaluates existing policies relative to that ideal. For example, Stephen Holland et al. estimate that the RFS is more than three times more costly than cap and trade for reducing carbon emissions.4 This is an important point that should be made repeatedly, but reiterating it is not the objective of this paper.

A Primer on Climate Change

Greenhouse gases in the earth’s atmosphere play a pivotal role in keeping the planet warm enough for life to flourish. They act like a blanket, letting heat from the sun through to earth and then preventing that heat from escaping into space. The more greenhouse gas in the atmosphere, the warmer is the planet. The main greenhouse gas is carbon dioxide (CO2), but others include methane, nitrous oxide, and water vapor (clouds).

Carbon is absorbed from the atmosphere by living plants and passed along to animals that eat those plants. When these organisms die and decay, their carbon is either trapped underground or mixed with oxygen and emitted as CO2. Fossil fuels such as oil, coal, and natural gas were formed by decaying organisms that were trapped underground millions of years ago. Using these fossil fuels releases the sequestered carbon back into the atmosphere in the form of CO2.

The average temperature on earth has risen by 0.85° Celsius in the past century, mostly due to humans burning fossil fuels. Other human activities such as deforestation (especially through burning) and raising livestock have also contributed. Scientists estimate that temperatures will rise another 0.3° to 4.8° C in the next century, depending on the extent of mitigation activities.6

Two underreported facts stand out in studies of the economic effects of climate warming. First, the estimated total effects are not catastrophic. Second, there is substantial uncertainty around the consensus estimate.
The consensus estimate under “business as usual” conditions is that average temperature will increase a further 3° C by 2100, which will reduce world gross domestic product (GDP) permanently by 4 percent. The world would prefer not to lose 4 percent of GDP to climate change, and some regions and people will face very large effects. However, it is difficult to argue from that estimate that the aggregate economic effects of climate change will be dire. The reduction is equivalent to the loss of less than two years of average growth.

On the flip side, the cost of mitigating such modest effects should not be crippling, which explains why the estimated social cost of carbon (SCC) is not large relative to the price of fossil fuels. The consensus SCC estimate is presently $37 per ton of CO2, which translates to 38 cents per gallon of gasoline, 2 cents per kilowatt hour (kWh) of natural gas-generated electricity, and 3.5 cents per kWh of coal-fired electricity. The gasoline and natural gas price effects would be about 20 percent of current retail prices, and the coal price effect would be about 35 percent of current retail prices. Standard economic theory implies that if a carbon tax were imposed so that consumers were to pay 20 percent more for gasoline and natural gas and 35 percent more for coal, then they would be paying for the climate effects of using these fuels. The resulting outcome would be economically optimal.

This first fact suggests that climate change is much less of a problem than implied by the rhetoric used by environmental advocates. However, the second fact has the opposite implication. Estimating the economic impact of climate change requires forecasting decades into the future. Economic forecasters have little success predicting one year into the future, let alone what will occur decades from now. New clean-energy technologies will play an important role in climate-change mitigation, as may new carbon sequestration technologies, but the paths and scope of their development are impossible to predict. Climate systems move more slowly than economic variables, but are still difficult to forecast accurately over long horizons.

The extent of the uncertainty about climate change indicates that the economic impacts experienced by our descendants will likely diverge substantially from the current consensus prediction. In some plausible scenarios, the effects are benign. In other plausible scenarios, climate change has large catastrophic effects on the world. The possibility of disaster explains the difference in tone between environmental advocates, who emphasize the worst-case scenario, and cool-headed economists, who tend to focus on the consensus prediction. One theme of this paper is that economic analysts and policymakers need to think more seriously about the uncertainty rather than focusing on only the expected outcome.

The Renewable Fuel Standard

The 2007 RFS program established ambitious standards for biofuel use, with the goal of increasing consumption to 36 billion gallons (Bgal) per year by 2022. The EPA administers the program, and although the EISA statute provides specific biofuel consumption targets, the EPA is allowed discretion in setting each year’s mandates.

The RFS distinguishes among categories of biofuel and sets separate mandates for each. The biofuel categories are: (1) cellulosic biofuel, which can be produced from wood, grasses, or the inedible parts of plants; (2) biomass-based diesel, typically produced from oilseeds such as soybeans or canola, tallow, or used cooking oil; (3) other advanced biofuel, mostly ethanol produced from sugarcane but also any renewable fuels other than ethanol derived from corn; and (4) conventional biofuel, which is essentially ethanol derived from corn. The mandates are nested so that the advanced biofuel mandate can be met with any fuels in categories 1, 2, or 3. The total renewable mandate can be met by fuels in any of the four categories.

The RFS specifies minimum renewable fuel use for each calendar year from 2006 through 2022, as shown in Figure 1. It required 9 Bgal in 2008 and increased this level on an annual basis to 15.2 Bgal in 2012 and 36 Bgal in 2022. However, the RFS specified that no more than 15 Bgal of corn ethanol could count toward the mandate after 2015. The balance of the RFS was
to be filled by advanced biofuels, such as biodiesel from soybean oil and ethanol from cellulosic biomass (e.g., switchgrass, miscanthus, and corn stover). By 2022, almost half of the mandated renewable fuels are cellulosic.

The four categories of biofuel differ in their estimated impacts on lifecycle GHG emissions relative to gasoline and diesel. Cellulosic biofuels must generate a 60 percent reduction in emissions to qualify under the program. Biodiesel must generate 50 percent emissions reductions, as must other advanced biofuels. Conventional biofuels must generate at least 20 percent emissions reductions to qualify. The regulation was written this way to encourage a shift toward lower-emission fuels over time.

When President George W. Bush signed the EISA on December 19, 2007, he emphasized two benefits of the RFS. First, it would reduce dependence on foreign oil by expanding domestic fuel production. Second, it would reduce GHG emissions. However, the long history of biofuel lobbying activity suggests a third goal was the catalyst for the standard: increasing the demand for corn and soybeans.

Ethanol made from corn only recently became a significant motor-fuel ingredient in the United States, but it has a long history as a prospective motor fuel. In 1920, the US Geological Survey estimated that peak petroleum production would be reached within a few years. David White wrote, “In fact, it probably is no rash prediction to forecast a world’s shortage

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**Figure 1. RFS Mandates**

Notes: The volumes for 2006 and 2007 come from the first RFS, passed in 2005. The volumes from 2008 onward are from the second RFS, as specified in EISA. Source: 42 USC § 7545 (c)(2).
of petroleum within the next twenty years, with the likelihood that the world’s supplies will be insufficient within fifteen years.”

At the same time, US agricultural prices had declined as European agricultural production recovered from World War I. Lower prices motivated US agricultural producers to look to ethanol as an alternative use and source of demand for their crops.

The push for ethanol intensified in the 1930s, when the Great Depression brought further hardship to rural America. In the early days of the New Deal, members of the Farm Chemurgic Movement worked closely with the US Department of Agriculture (USDA) on a farm-relief program that would subsidize ethanol production from farm crops. However, by this time large new oil fields had been discovered in Texas, Oklahoma, and California. These discoveries led to high oil production and low prices. Ethanol was not price competitive and faded into the background until the oil shocks of the 1970s.

The first variant of the RFS was created by Congress in 1978. Additional ethanol bills were offered in 1987, 1992, 2000, 2001, 2003, and 2004 and consistently received strong support from the corn lobby. The 1978 Gasohol Motor Fuel Act proposed that production of alcohol motor fuel supply reach at least 1 percent of US gasoline consumption by 1981, 5 percent by 1985, and 10 percent by 1990. This bill never became law, but a weaker version was included in the 1980 Energy Security Act (ESA).

Instead of mandating ethanol production, the 1980 ESA directed the Departments of Energy and Agriculture to prepare and evaluate within the next year a plan “designed to achieve a level of alcohol production within the United States equal to at least 10 percent of the level of gasoline consumption within the United States.” However, the ensuing report concluded that this ethanol-use target, “though technologically attainable, is not economically feasible even under optimistic market scenarios.” As a result, ethanol constituted less than 1 percent of finished motor gasoline in 1990.

An environmental benefit of ethanol gave the corn-ethanol industry a new argument for favorable legislation. The 1990 amendments to the Clean Air Act required that, in regions prone to poor air quality, oxyginate additives be blended into gasoline to make it burn more cleanly. Ethanol and methyl tertiary butyl ether (MTBE), a natural gas derivative, were the main contenders to fulfill the oxyginate requirement. Ronald Johnson and Gary Libecap document the lobbying battle between advocates for ethanol and those for MTBE. Ethanol received some favorable treatment in the final legislation, but MTBE became the dominant additive because it was less expensive. Subsequently, however, leaks in underground storage tanks lead to MTBE contamination of drinking water, and as a result, at least 25 states banned MTBE.

Without competition from MTBE, ethanol cemented its place as a fuel additive in the 2005 Energy Policy Act. This law included the first RFS, mandating that 4 Bgal of ethanol be used in 2006 and gradually increasing to 7.5 Bgal per year by 2012. This 2012 quantity corresponded to 5 percent of projected domestic gasoline use. Thus, it represented a small expansion of the proportion of oxygimates in gasoline. In 2005, US oxyginate production (ethanol and MTBE combined) totaled 4.6 percent of finished motor gasoline supplied. Legislation to increase the RFS was introduced in Congress even before the 2005 Energy Policy Act had passed, and more bills followed in 2006. These proposals led to the current RFS.

The RFS is administered by the EPA through a system of tradable credits, known as renewable identification numbers (RINs). Each gallon of biofuel that is blended into domestic fuel generates a RIN. Obligated parties under the policy, typically oil refiners, must submit to the EPA a certain number of RINs for each gallon of petroleum fuel they sell. For example, in 2016, they were required to submit 0.101 RINs for each gallon of gasoline of diesel they sold. These RINs must include at least 0.0201 advanced biofuel RINs. In turn, the advanced RINs must include at least 0.0159 biodiesel RINs and at least 0.00128 cellulosic RINs.

RINs are typically generated by blenders, firms that blend wholesale fuels for sale to gas stations. Thus, to comply with the RFS, oil refiners need to purchase RINs from a blender. Some oil companies have blending operations, so they do not need to purchase RINs from another firm, but there are enough
obligated parties without blending operations to ensure a robust market for RINs. The price of RINs is determined by the extra cost of using biofuel in place of petroleum. The blender uses the proceeds from selling RINs to help pay for biofuel (if it is priced higher than petroleum) or to pay distribution costs (if blended fuel is more costly to deliver to consumers than pure petroleum). In effect the RIN is a subsidy to biofuel funded by a tax on petroleum.

Technical, Political, and Legal Challenges to the RFS

The RFS has run into two barriers. The first is that production of cellulosic biofuel continues to be close to zero, even though the RFS now mandates significant quantities. The second barrier, known as the blend wall, is that regular gasoline can contain up to 10 percent ethanol without affecting engines or fueling infrastructure. Gasoline with 10 percent ethanol is known as E10. The RFS now requires more biofuel than can be consumed in E10. Breaching the blend wall requires either expanded consumption of biodiesel, which does not face any relevant blend restrictions, or increasing sales of a high-ethanol blend of gasoline known as E85, which contains up to 85 percent ethanol and can be used only in flex-fuel vehicles.

The EPA, which administers the RFS, is authorized to set the required biofuel volumes below the mandate if there is insufficient supply. The second barrier because of the lack of cellulosic production. However, the insufficient-supply provision has met with stiff opposition when used to deal with the blend wall. The EPA argues that there is insufficient supply of E85 because the retail fueling infrastructure does not exist to get the fuel to consumers, whereas the ethanol industry argues that there is sufficient supply because there is enough ethanol to make enough E85 to meet the mandate.

The data reported in Figure 2 indicate that the market first hit the blend wall in 2010 and has hugged the blend wall since then. This was feasible under the RFS as long as the required cellulosic volume was set to zero. In 2013, however, the conventional ethanol mandate exceeded the blend wall, even without the cellulosic component. The EPA would either have to force the industry to burst through the blend wall or waive part of the conventional biofuel mandate. In August 2013, the EPA first hinted that it might reduce the 2014 mandate to relieve the blend wall constraint. Then, in October 2013, a Reuters news article leaked an early version of the EPA’s 2014 proposed rule. In November 2013, the EPA released a rule proposing to waive the RFS blend-wall quantities of the ethanol mandate for 2014.

Behind-the-scenes lobbying by the oil industry, which wanted the conventional mandate kept below the blend wall, and by the ethanol industry, which wanted to enforce the statutory volumes, prevented the EPA from releasing the 2014 and 2015 rules in a timely fashion. Not until December 2015 did the EPA finalize the rules for 2014, 2015, and 2016. The EPA finalized the 2017 rule in December 2016, so it appears to be back on track.

Another challenge appeared in 2016 when several oil refiners petitioned the EPA to move the compliance burden from oil refiners to blenders. Rather than oil refiners demonstrating compliance by turning in RINs to certify that sufficient biofuel has been blended into the fuel supply, the petitioners argued that blenders should be the ones to demonstrate compliance. Recalling that the RIN system acts like a subsidy to biofuel funded by a tax on petroleum, this proposal is akin to moving the point at which the tax is assessed. If the fuel system were perfectly competitive, this change would have no effect. In competitive markets, refiners would be compensated for the RIN tax liability by receiving a higher price for their product. The petitioners argue that they are not receiving such compensation and therefore the RFS would be more efficient if blenders were obligated. Recent research suggests some significant market power in parts of the fuel system, although it is unclear whether this lack of competition implies that moving the point of obligation would improve the RFS.

In November 2016, the EPA proposed to deny the petition to move the point of obligation. This ruling
opened a period for public comment, which expired on February 22, 2017. The agency has not yet made a final decision. Regardless of the potential economic efficiency improvements from moving the point of obligation, addressing this petition absorbs scarce EPA resources that could instead be directed toward addressing the blend wall and setting volumes for future years.

The RFS statute specifies that 24 Bgal of biofuel be used in 2017, including no more than 15 Bgal of corn ethanol. The EPA set 2017 volumes at 19.28 Bgal of biofuel, of which at least 4.28 Bgal must be advanced biofuel (i.e., not corn ethanol). The blend wall was projected at 14.4 Bgal for 2017 but is likely slightly higher because low gas prices cause people to drive more. The 0.6 Bgal gap between the blend wall and the allowable amount of corn ethanol will most likely be met by increased biodiesel use, but the gap is large enough that some expansion in E85 sales may be required. Increasing E85 sales would require increasing availability of the fuel. About 6 percent of registered vehicles in the US have flex-fuel capability, but

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**Figure 2. The Blend Wall**

Note: I subtract 1.5 times the biodiesel mandate to get the ethanol mandate. The legislation treats 1 gallon of biodiesel as equivalent to 1.5 gallons of ethanol because biodiesel has a 50 percent higher energy content than ethanol. The biodiesel mandate is set at the levels implied by the EPA final rule through 2016 and 2 Bgal thereafter. The blend wall is 10 percent of gasoline use. After 2016, I use the EIA projection of gasoline use to determine the expected blend wall.

less than 2 percent of gas stations sell E85. Private market investment in E85 infrastructure has been slow, but in early 2016, the USDA spent $100 million to fund installation of E85 fuel dispensers with the goal of doubling E85 retail capacity.

Looking ahead, the EPA may consider reducing the mandate permanently. The RFS legislation states that, if the EPA waives at least 20 percent of the mandated volume for two consecutive years, then it can modify the required volumes for all following years. The 2016 volume of 18.11 Bgal was 19 percent below the statute, and the 2017 volume was 20 percent below. Thus, it appears that the soonest the EPA could reset the volume of total renewable fuel would be for the 2019 and later compliance years.

However, waivers for the cellulosic and advanced components of the mandate have been much higher than 20 percent since 2013. Thus, the EPA could permanently reset the cellulosic and advanced components at any time. However, the only way to reduce the cellulosic and advanced mandates while keeping corn ethanol capped at 15 Bgal is to also reduce the total RFS mandate. It is unclear whether the EPA could use such an argument to legally reduce the total mandate before 2019.

Whatever the EPA does, the proportion of ethanol in the gasoline supply seems unlikely to drop much below 10 percent. The fuel system has adjusted its infrastructure to make E10 the standard fuel, and unless there is an extreme spike in relative corn prices, it will remain cost-effective.

Several elements of the RFS legislation and its implementation demonstrate that policymakers have not taken uncertainty seriously.

**Blend Wall.** The RFS was written in 2006 and 2007 when the economy was expanding and gasoline demand was expected to keep rising. The 2006 EIA projection placed the blend wall at 15.9 Bgal in 2013, rising to 16.5 Bgal in 2016. The corn-ethanol component of the mandate plateaus at 15 Bgal, so if the EIA projection had come true, we never would have hit the blend wall with conventional ethanol. Only the cellulosic component would have required breaching the blend wall.

The actual blend wall was 13.6 Bgal in 2013 and is projected to be 14.4 Bgal in 2017. Rather than being a billion gallons below the blend wall, the mandate was set at more than half a billion gallons above the blend wall. A mandate set above the blend wall raises compliance costs because it forces firms either to invest in the infrastructure to get E85 to market or to use additional biodiesel, which is more expensive than ethanol on a per gallon basis.

Not only does breaching the blend wall raise compliance costs, but a mandate close to the blend wall causes volatile compliance costs. Small changes in required volumes can push the industry to the other side of the blend wall and cause large changes in compliance costs. This volatility generates compliance cost uncertainty for firms. This uncertainty means that firms do not receive a strong signal about whether to invest in the infrastructure required to get E85 into the market.

The blend wall and the ensuing uncertainty about compliance costs could have been avoided if the statute had been written as a rate standard rather than as a volume standard. Requiring the market to blend a certain percentage of biofuel rather than a certain volume would have made the blend wall salient and would have clarified when the blend wall would be binding.

**Fuel Prices.** The EPA no doubt knew the blend wall constraint would be significant but paid little public attention to the issue. In February 2010, the EPA
released an extensive regulatory impact analysis (RIA) of the expected benefits and costs of the RFS. The EPA reported very large net benefits from the RFS in 2022 with estimates ranging from $12.8 billion to $25.97 billion a year. The estimates equal the sum of estimated reductions in fuel costs, improvements in energy security and health, and reductions in GHG emissions attributed to the policy in 2022. Each component is presented as a single number, except for the GHG emissions benefits for which the EPA presents a range depending on the SCC used by the agency.

The reductions in fuel costs attributed to the RFS were $11.8 billion, which is almost all the benefits in the low-SCC case and half the benefits in the high-SCC case. The fuel market benefits arose because the EPA estimated that ethanol would be less expensive than oil and therefore that using ethanol would save consumers money. In addition, despite acknowledging the vast uncertainty in projecting feedstock and oil prices in 2022, the EPA limited itself to the central oil price projections from the Department of Energy’s Annual Energy Outlook 2009, ignoring the high and low projections from that report. When the RIA was written in 2009, world oil markets were coming off of a historical volatile period with prices hitting $140 barrel in the summer of 2008 and bottoming out near $40 in January 2009. Despite this volatility, the EPA failed to consider more than one price trajectory.

Figure 3 plots actual ethanol and gasoline prices since 2009 and the prices assumed in the RIA. The EPA used a wholesale gasoline price of $3.42 per gallon (corresponding to a crude oil price of $116 per barrel) and an ethanol price of $1.716 per gallon. In fact, they reported three cases for ethanol, with a comically narrow and precise range of $1.688 to $1.732. Observed ethanol prices ranged from $1.42 to $3.15 over this period, while gasoline prices ranged between $1.02 and $3.31. Moreover, the two prices were positively correlated, with high ethanol prices typically corresponding with high gasoline prices. The RIA would have presented a much clearer picture of compliance costs if it had incorporated price uncertainty into its analysis.

Rather than incorporating price uncertainty, the EPA focused its analysis on detailed modeling of the many potential types of biofuel, their sources, and a thorough accounting of their costs. To do so, the agency relied on a set of large-scale engineering and economic models. Large-scale models require substantial effort to implement, and they generate copious statistics. To cite one of many examples, oil refineries produce two main products (gasoline and distillate) and a slew of minor products. The RIA presents the estimated change in oil refinery production of 47 different products over five regions of the US. Almost all of the information is irrelevant to the RFS. Such detailed output creates the impression of rigor and precision when in fact it reflects numerous modeling assumptions made about the relevant economic systems. Moreover, the complexity of the models and the time required to run them preclude reasonable accounting for uncertainty.

A complex model has numerous parameters that interact in often unknown ways. Suppose a modeler were to run the model with three different feasible values of the future price of crude oil. The resulting predictions of the model would depend on other parameters such as the price of ethanol, which necessitates running the model for, say, three different ethanol prices. Now, we have nine possible combinations to run—three ethanol prices for each of three oil prices. The results from these runs would depend on numerous other parameters, such as the prices of each of the refinery’s 47 products and many others. Running the model for different values of each parameter may be impractical computationally because some of these models take hours to complete a single run. Even if the computational challenges can be overcome, the modeler is left with hundreds of predictions from the model, each one from a different set of parameter values to which the modeler has no way to assign a probability.

Technology. The gasoline-powered internal combustion engine has reigned supreme for more than a century. Like all dominant technologies, it will eventually be replaced by something better, but no one knows what or when.

Plug-in electric cars (including plug-in hybrids) went from essentially zero in 2010 to 3 percent of US car sales in 2015. Solar electricity generation increased
more than 20 fold over the same period, and wind generation doubled. This does not mean that electric cars, charged by electricity from the wind and sun, will drive petroleum-powered vehicles out of the market, but it raises the possibility.

Alternately, new discoveries may keep oil competitive as a fuel source. In recent years, new technology has allowed US oil producers, through a combination of horizontal drilling and hydraulic fracturing, to extract oil from oil shale. US oil production in 2008 was lower than at any time since 1950. With this new technology, 2015 production was 89 percent higher than 2008 and the highest since the previous peak in the early 1970s.30

High shale oil production was a major factor in the 50 percent drop in oil prices in late 2014. Lower oil prices made gasoline-powered cars more appealing to consumers. In fact, fewer electric cars were sold in 2015 than in 2014. This does not mean that electric cars are destined to be a niche product, but it does raise that possibility.

Hydraulic fracturing has also generated large increases in US natural gas production. With this jump in supply, natural gas has supplanted coal as the cheapest fuel for electricity generation in many parts of the country. Cheap natural gas has also raised the prospect of expanding its use in transportation, which would reduce carbon emissions relative to gasoline. To
date, there has been little expansion in natural gas as a transportation fuel, in part because expansion would require a large investment in refueling infrastructure.31

Cellulosic biofuel is another potential new transportation fuel with climate benefits relative to gasoline. In spite of the RFS mandate, this technology has not produced significant amounts of fuel. In 2017, the EPA projects 13 million gallons of liquid cellulosic biofuel will be used in the US, which is about 0.01 percent of gasoline use.

No one knows which technologies will come to dominate in transportation, yet the RFS picks one: biofuel. Reaching the statutory volumes will require breaching the blend wall, which in turn will require substantial investment in new infrastructure at gas stations to dispense high-blend ethanol fuels. In September 2015, USDA distributed $100 million to fund 4,880 new fuel pumps and 515 storage tanks at 1,486 gas stations around the country.33 At present, 3,015 of approximately 170,000 US gasoline stations sell E85,34 so this funding will significantly increase capacity to deliver E85, but many more hundreds of millions will be required to make a substantial dent in the blend wall.

The infrastructure investment will be wasted if cellulosic biofuel does not become an economically viable fuel. This anecdote highlights a drawback of mandates in the presence of uncertainty about technological progress. Mandates encourage the industry to abandon alternative technologies in favor of the mandated technology, which can lead to technological lock-in, in other words, getting stuck with an inferior technology because the infrastructure already exists.

The Obama administration advocated an all-of-the-above approach to energy policy.35 One interpretation of this principle is that it is open to any potentially useful innovations. Following this principle, analysts would be well served to consider potential new technologies when evaluating new policies. In particular, they should ask whether the policy has a significant opportunity cost because it reduces the option to develop alternative technologies in the future.

Emissions. A further source of uncertainty—one central to climate policy—is the unknown amount of warming caused by carbon emissions and its economic impacts. The equilibrium climate sensitivity is a parameter that describes the long-term increase in the annual global-average surface temperature from doubling atmospheric CO2 concentration. Scientists estimate that the likely range for this parameter is 1.5°C to 4.5°C.36 The top of this range is three times the bottom. Economic models of climate change such as the DICE model37 specify the economic impact of warming as a quadratic function of the temperature increase, so the top of their range of economic impacts is nine times the bottom of the range. If we then allow for uncertainty about the economic damage function, or any of the other parameters in the model, the range of potential outcomes expands further.

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There is no agreement among economists on what this uncertainty means for climate policy. Martin Weitzman argues for aggressive carbon emissions reductions because of what he terms the dismal theorem.38 The dismal theorem states that the non negligible possibility of catastrophe dominates all other considerations in cost-benefit analysis of climate policy. Standard cost-benefit analysis that focuses on the most likely outcome will favor policies that are much too passive.

Robert Pindyck also emphasizes the uncertain effects of climate change, but argues that policies with insurance characteristics make more sense for avoiding extreme outcomes, rather than merely increasing the stringency of whatever policy would be applied in a world without uncertainty. He does not recommend specific policies.39 However, Daron Acemoglu and his coauthors show theoretically how a research
subsidy can have large benefits in addition to a carbon tax because it enables avoidance of environmental disaster. Avoiding the potential for environmental disaster through the use of a carbon tax would require a much larger and more costly tax.

Overall, analysts need to think about the distribution of outcomes when formulating and evaluating policy: focus projections of what could happen, rather than a single estimate of what will happen.

**Lesson 2: Do Not Give the Regulator Too Much Discretion**

The RFS legislation specifies the number of gallons of renewable fuel to be used each year. To implement the mandate, the RFS charges the EPA with converting the volume standard to a rate standard. Specifically, the legislation directs the EPA to take three steps by November 30 each year:

1. Obtain from the Energy Information Administration “an estimate, with respect to the following calendar year, of the volumes of transportation fuel, biomass-based diesel, and cellulosic biofuel projected to be sold or introduced into commerce in the United States.”

2. Divide the RFS-mandated number of biofuel gallons by estimated petroleum fuel use to compute the percentage standard.

3. Require that each obligated party (typically oil refiners) show evidence that enough biofuel entered the market to meet the percentage standard for the petroleum fuel they sold.

There is little discretion in these directions. The legislation gives the EPA a formula and a deadline by which to apply it. However, a subsequent clause introduces discretion: “EPA may waive the statutory volume in whole or in part if implementation would severely harm the economy or environment of a State, region, or the United States, or if there is an inadequate domestic supply.”

In 2012, a severe drought hit the Midwest, lowering corn yield by 16 percent from 2011 and generating a spike in prices. Governors from several states, including Arkansas and North Carolina, requested a waiver of the RFS on the grounds that firms in their states would be severely harmed. The affected firms were livestock producers and feed lots that rely on corn as an important source of animal feed. They hoped an RFS waiver would reduce corn demand from ethanol producers and thereby lower the price of corn to livestock producers.

The EPA denied the waiver request on November 27, 2012, and then began developing the 2013 RFS percentage standard. The agency proposed a rule in February, which it finalized in August 2013—after the year was two-thirds over. The EPA justified enforcing the rule for the whole year on the grounds that rule was not a surprise; it was essentially the same rule that had been proposed in February.

Figure 4 shows that RIN prices jumped from less than $0.05 to $1.40 per gallon in early 2013 as the industry realized that an above-blend-wall mandate would be enforced. The price had been below 6 cents per gallon for 2010 through 2012. This was the period when ethanol use was at the blend wall, but the RFS did not require above-blend-wall use of conventional ethanol (see Figure 2). Prices were slightly higher in 2009, when oil prices dropped relative to corn prices, causing ethanol to become more expensive than gasoline.

The EPA apparently reversed course in August 2013 when it announced, “EPA anticipates that adjustments to the 2014 volume requirements are likely to be necessary based on the projected circumstances for 2014.” This announcement along with several other announcements later that year caused RIN prices to crash from a high of $1.40 in July to $0.20 in November.

The biofuel industry reacted forcefully to the possibility of waivers, and the resulting political mayhem prevented the EPA from finalizing the required 2014 and 2015 biofuel volumes in a timely fashion. The industry spent almost two years in limbo, not knowing how much biofuel it should be using. Finally, in June 2015, the EPA proposed volumes for 2014, 2015, and 2016, which it finalized in December 2015.
Because 2015 was almost over by this time, it set 2014 volumes at actual 2014 consumption and 2015 volumes at expected consumption.

The proposed 2016 volumes were initially lower than expected, causing RIN prices to drop from $0.75 to about $0.40 in June 2015, but the final volumes turned out higher, causing RIN prices to jump back up to about $0.75 in December.

In their study the 2013 fluctuations in RIN prices, Lade, Lin Lawell, and Smith show how a change in the expected future stringency of the mandate affects current RIN prices and, therefore, current compliance costs. This link arises because RINs can be banked for use in future compliance years, which means that RIN prices adjust to smooth expected compliance costs over time. If compliance is expected to be expensive next year because of the blend wall, then RIN traders will save current RINs, which reduces the number available for current compliance and raises current RIN prices.

The long delays in finalizing percentage standards created uncertainty in the industry. Investments in E85 infrastructure at this time would have made it possible to deliver more E85 to consumers, lowering marginal compliance costs. However, such investment has not yet happened. One problem with the uncertainty created by delays in agency decisions is that it deters investment and thereby undermines the statute.

A larger problem with agency discretion, however, is that it allows industry lobbies to direct policy. This problem is exacerbated if the policy's objectives are
murky. Although energy security and climate-change mitigation are the policy’s stated objectives, the history discussed earlier indicates that the corn lobby is a dominant driver of this policy. This group is motivated to maximize the amount of corn ethanol used, rather than climate policy. The other important lobby groups are the petroleum industry, which is motivated to minimize its costs of complying with the legislation, and the livestock industry, which is motivated to minimize the amount of corn used for ethanol. It is unlikely that a lobbying battle among these parties will produce effective climate policy because none of them are motivated by climate concerns.

The RFS is not the only legislation that has granted discretionary power to an agency. Both the Affordable Care Act and the Dodd–Frank financial reform act charged agencies with implementing often vaguely written legislation, opening up the opportunity for industry lobbies to drive policy in a nontransparent way.

Regulator flexibility can be beneficial. One way to incorporate uncertainty into policy implementation is to allow the regulating agency discretion to adjust over time. The potential reset of biofuel volumes in the RFS is a good example. If too little biofuel is being produced that the EPA must issue two consecutive 20 percent waivers, then the agency could reset the volumes for all years rather than issuing a waiver every year. However, note two features of the reset: First, the statute specifies the formula the EPA should apply to determine whether a reset is required. Second, the purpose of the reset authority is to reduce the burden of annual rulemaking, rather than making the agency issue a new waiver every year.

These features highlight how the RFS could have reduced counterproductive EPA discretion in its implementation. Annual rulemaking has been possible only under perfect conditions. The 2012 drought and the 2013 blend wall caused long delays in setting the percentage standards. One simple fix would be to require percentage standards to be set at less frequent intervals, such as once every three years. Setting percentage standards over a longer horizon would also have had the advantage of making the blend wall more transparent so that it operates more like a rate standard.

The clause that allows a waiver if implementation would cause “severe economic harm” has not been useful because it is too vague. It has produced challenges that have only delayed rulemaking. If such a clause were desired as part of the legislation, then it should have taken the form of a price cap on RINs. If costs of compliance exceed the cap, then firms are not forced to comply. Rather than using biofuel at RIN prices above the cap, obligated parties could purchase RINs from the EPA at the cap price. This adjustment would remove EPA discretion and remove the ability for rival industries to lobby the agency for favorable treatment.

Specifying transparent rules and formulas in legislation would place the policy burden on Congress rather than the regulating agency. This is especially important when the agency must mediate among competing industries, none of which has incentives aligned with the EPA, as with the RFS.

Lesson 3: Do Not Mandate Things That Do Not Exist

The RFS requires increasing amounts of cellulosic biofuel, but commercial production of that fuel has not materialized. The statute required cellulosic biofuel beginning in 2010, with volumes rising from 0.1 Bgal in 2010 to 1 Bgal in 2013 and 4.25 Bgal in 2016. Actual cellulosic biofuel use was zero in 2010 and 2013. It reached 0.14 Bgal in 2015 and is slated to reach 0.31 Bgal in 2017.

Originally, the expectation was that the cellulosic mandate would be met with liquid fuels—namely diesel and ethanol made from cellulosic material such as crop residue, switchgrass, miscanthus, and wood. The EPA’s RIA projected that 69 percent of cellulosic biofuel would be cellulosic diesel and the remaining 31 percent would be cellulosic ethanol. However, less than 2 percent of the cellulosic biofuel RINs generated in 2015 came from these two sources. The remainder was renewable natural gas (biogas) generated from landfills and other similar facilities.

The high percentage contribution of biogas to the cellulosic mandate was enabled by a rule proposed by
the EPA in June 2013 and finalized in July 2014. This rule allowed biogas to count toward the cellulosic mandate by stating that “biogas generated by landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW [municipal solid waste] digesters are predominantly cellulosic in origin.” Before the rule these fuels, which are used in natural gas–powered vehicles, had qualified as advanced biofuels for RFS compliance.

For 2017, the EPA projected that 4.2 percent of cellulosic biofuel RINs would be generated by liquid fuels. This is 4.2 percent of a cellulosic volume requirement that is 5.7 percent of the statutory volumes, thus only 0.2 percent of the cellulosic liquid fuels prescribed in the RFS is being used.

The RFS did spur investment in research and development of cellulosic liquid fuels. In 2007, the US Department of Energy Biomass Program provided $385 million to support six large-scale cellulosic ethanol plants. Several hundred million dollars of Department of Energy money followed in later years to support cellulosic research and development. The major oil companies invested more than a billion dollars in biofuels research, much of it in partnership with universities and biofuel companies. Since that time, these companies have mostly divested from cellulosic biofuels, but research continues in universities, institutes, and biofuels firms. Nonetheless, large-scale production of liquid fuels from cellulosic materials remains prohibitively costly.

The RFS has an escape valve that has allowed the EPA to waive the cellulosic mandate due to insufficient supply. Otherwise, the industry would have faced a choice between paying extremely high compliance costs and evading the regulation. Recent examples of such evasion in a similar context include Volkswagen’s attempt to evade US air quality standards by installing software that turns on the vehicle’s emissions-control systems only when it is being tested. Another example is automakers’ sending “golden vehicles” to be tested for compliance with Europe’s ever tightening fuel economy standards. These golden vehicles often have no back seats, nondurable tires, and other features that improve their fuel economy by up to 35 percent over standard road vehicles.

Although it mitigates the potential for fraud and evasion, the escape valve also discourages private industry investment in research and development. If no one invests in the technology, then there will be no supply, and the EPA will waive the mandate. The mandate was not a credible threat.

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**Policy is better when the policy instrument directly targets the policy objective.**

How the RFS is implemented also limits its effectiveness in spurring the desired amount of investment. In principle, a firm that develops a successful cellulosic biofuel technology would be able to generate a stream of valuable RINs that it could sell to recoup the costs of research and development. In practice, once the new technology has been developed, the firm that created it is unlikely to be able to monopolize it. New firms will enter and produce cellulosic biofuel at a low marginal cost, thereby lowering the price of RINs. Thus, unless firms believe that the patent system would allow them to recoup their investment cost, they will underinvest in the new technology even in the presence of a mandate.

Perhaps researchers will produce a breakthrough that will make cellulosic biofuels feasible. Lesson 1 suggests that such research should continue. However, until that time the cellulosic mandate must be considered a failure. Its only benefit has been to spur investment into cellulosic biofuel technology, but if the government wants to increase funding for research, it should directly fund research. If the government wants to encourage private firms to invest in the technology, it should offer matching grants. Policy is better when the policy instrument directly targets the policy objective.
Farm Bill Energy Title

The energy title first appeared in the 2002 Farm Bill, which authorized grants, loans, and loan guarantees to encourage research, development, and adoption of agriculture-based renewable energy. In the 2008 Farm Bill, the energy title shifted toward non-corn-based biofuels. This switch was motivated partly by concerns about economic and environmental consequences from directing such a large proportion of the corn crop into the fuel supply and partly by the impetus to support the RFS goal of expanding production of advanced biofuel. The 2014 Farm Bill extended most programs from the 2008 bill with new funding, although projected spending was less than 1 percent of projected non-nutrition spending in the bill.49

In terms of mandatory funding, the three largest programs in the 2014 energy title were the Rural Energy for America Program (REAP, $250 million), the Biorefinery Assistance Program ($200 million), and the Biomass Crop Assistance Program (BCAP, $125 million). These were the only programs with more than $100 million in total mandatory funding in 2014–18.

REAP provides grants and loan guarantees to rural small businesses and agricultural producers for research and development of renewable energy systems. It includes bioenergy, anaerobic digesters, geothermal, hydrogen, solar, wind, and hydropower, but it excludes any mechanism for dispensing energy at retail. The Biorefinery Assistance Program provides loan guarantees for construction and/or retrofitting of demonstration-scale biorefineries to understand the commercial viability of advanced biofuel production. BCAP offers financial assistance to owners and operators of forest and agricultural land who wish to produce biomass feedstocks.

Beyond the farm bill, the USDA has conducted other initiatives to support biofuels. Most notably, in 2015 the Biofuel Infrastructure Partnership (BIP) supplied $100 million in grants to fund up to half of the costs of installing tanks, fuel pumps, and related infrastructure to dispense higher ethanol blends such as E15 and E85 at vehicle fueling locations. The economic argument for such spending is based on a network externality: A retail station will not invest in new infrastructure unless it thinks it will sell a lot of E85 or E15, and consumers are not going to switch to those fuels unless they are widely available.

At the very least, the BIP could have been used to estimate the magnitude of the network externality and the process of new fuel adoption. This would have required detailed data from participating stations on sales and prices before and after the intervention. Even better, the program could have used an experimental design to randomize the allocation of funds in a way that would have enabled researchers to quantify the network externality. Instead, the funds were dispensed with few data requirements and no experimental design.

Can measures such as the farm bill’s energy title and the BIP improve the efficiency of the RFS? GHG emissions reductions are the main potential welfare benefit; thus, improving RFS efficiency requires that energy title spending must lower the total cost of achieving those emissions reductions. The RFS will generate substantial emissions reductions only if large volumes of cellulosic biofuels become available.

Significant use of cellulosic fuel first requires that technology and production processes develop sufficiently to make production of the fuel cost-effective. No one knows whether or when that will occur; cellulosic biofuel advocates have overpromised for many years. Significant barriers remain, including the high costs of transporting bulky cellulosic materials to a biorefinery, storing the materials without significant spoilage, and converting cellulosic biomass into fuel.

Most economists recommend subsidizing research into climate-change mitigation technologies, of which cellulosic biofuel is one example. This recommendation stems from the contention that private firms underinvest in research and development because potential spillovers (positive externalities) from new technologies or the inadequacies of patent law would preclude them from extracting the full benefits of their investments. Thus, a case could be made for the federal government to continue subsidizing cellulosic biofuel research and development through programs such as REAP.
However, cellulosic biofuel is just one of many potential climate-change mitigation technologies. It is beyond the scope of this paper to assess whether the marginal research dollar should be directed toward cellulosic biofuel rather than solar power, wind power, vehicle electrification, or the numerous other possibilities. Moreover, it is beyond the scope of the farm bill to make this assessment. Funding for climate-change mitigation research and development would be better handled by an agency that can compare potential benefits across sectors, such as the National Science Foundation or the Department of Energy.

Getting cellulosic biofuel to market also requires the retail infrastructure to deliver these fuels, most likely in E85. It seems unlikely that an absence of retail infrastructure is delaying the development of cellulosic fuels. Such infrastructure could be built quickly if the technology existed to produce the fuel cost-effectively, and private firms would have a strong incentive to make the required investments. Thus, there appears to be little public good benefit to funding retail E85 infrastructure construction now.

In sum, the arguments for significant spending in the farm bill’s energy title are unconvincing. If there is to be significant spending, the 2014 Farm Bill at least seems pointed in the right direction—namely research and development of cellulosic biofuels. To maximize the benefits of such spending, the government should avoid repeating the mistakes of the BIP, which forfeited an opportunity to measure the effectiveness of the program and thereby spend government money more effectively in the future.

Conclusion

The year 2016 was the warmest year recorded on earth since at least 1880. The same was true with 2015 and 2014. Seven of the warmest recorded years since 1880 have occurred in the past nine years. Alarmed by the scientific consensus that carbon emissions from burning fossil fuels are the main cause of this warming, many governments have enacted policies to promote alternative fuels and reduce fossil fuel use.

Researchers have weighed in on the design and effectiveness of these policies. A Google Scholar search for “climate policy” returns about 130,000 hits. These thousands of studies included important points such as (1) the least expensive policy would be to put a price on carbon through a carbon tax or a cap-and-trade program, (2) research and development into clean energy and carbon sequestration technologies is imperative, and (3) carbon emissions represent a global externality, so coordinating policy across countries is vital. Rather than reiterate these well-established points, this paper is concerned with the lessons we can draw from 10 years of the RFS, which is a centerpiece of US climate policy.

There are three general lessons:

1. **Incorporate uncertainty.** Policymakers should make, implement and analyze policy with a view to what might happen, not a single projection of what will happen.

2. **Do not give the regulator too much discretion.** Political forces and legal challenges can undermine policy if the regulating agency has the discretion to repeatedly adjust the policy stringency.

3. **Do not mandate things that don’t exist.** Mandates are an inefficient and ineffective method of forcing technological progress.

These lessons extend to many policy areas. Specific to the RFS, these lessons produce recommendations that, in hindsight, would have improved the policy. These recommendations are discussed throughout the paper, but I collect them here to highlight them:

1. The mandate would have been better specified as a rate standard than a volume standard. Compliance costs are driven by the rate of biofuel blending rather than the amount of biofuel. Compliance cost volatility would have been lower, and the industry would have been able to make investment decisions with a clearer view of future compliance costs (Lessons 1 and 2).
2. Incorporate uncertainty explicitly in future rulemakings. The blend wall and lack of cellulosic constraints would have been more transparent if the regulatory impact analysis had explicitly incorporated uncertainty (Lesson 1).

3. Rather than discretionary waiver authority, the RFS should have tied waivers to compliance costs and set a RIN price cap. If RIN prices rise to the cap, then allow obligated parties to purchase RINs from the EPA at the cap price rather than requiring additional biofuel (Lesson 2).

4. The EPA should be required to make multiyear rules rather than annual rules (Lesson 2).

5. Research into cellulosic biofuel technology should be funded directly, rather than indirectly through the cellulosic mandate (Lesson 3).

Can the farm bill assist in these improvements? I conclude that the only potential contribution from the farm bill’s energy title is Recommendation 5 — namely to subsidize research into cellulosic biofuel technology. However, I argue that the farm bill is not the optimal vehicle for funding such research. Rather, it should be handled by an agency that spans all climate-change mitigation technologies and can better assess the payoffs to the marginal research dollar.

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Notes

1. This paper draws heavily from research performed jointly with Gabriel Lade and Cynthia Lin Lawell.


5. A network externality exists when the value of a product depends on the number of users. For example, if enough consumers use a new fuel, then sufficient fueling stations will exist to make it appealing for more consumers to adopt that fuel. Network externalities create a chicken and egg problem in developing markets for new fuels.


16. Ethanol was allowed a one-pound waiver in the Reid vapor pressure requirement.


18. A gallon of biodiesel actually generates 1.5 RINs because biodiesel contains 50 percent more energy than ethanol.

19. A third possibility is E15, which is a blend of 15 percent ethanol and 85 percent gasoline. E15 is approved for use in all cars built since 2001, but it has not been adopted by the industry because it requires new tanks and dispensers to be installed at gas stations and fails to meet environmental requirements for summer gasoline (the Reid vapor pressure requirement).
20. The petitioners also make more nuanced arguments that moving the point of obligation to blenders would increase the incentive to blend biofuel and thereby lower RIN prices.


23. In its proposed rule released in June 2015, the EPA proposed waiving 22 percent of the mandate, but the final rule brought the waiver back below 20 percent.


27. Ibid., 824, Table 4.4-26.


29. Constructing a complex model is like stacking building blocks to make a tower, and uncertainty analysis is like trying to ascertain which blocks can be removed without the tower collapsing, much like in the game Jenga. When building the tower, small errors in the placement of some blocks can compound to make the tower unstable, and the large number of blocks makes it difficult to determine how much each block could be moved without the tower collapsing. It is better to build a simpler tower.

30. In the same paper in which he predicted peak petroleum, David White also wrote, “Plainly, if the United States is to have oil to satisfy its needs in the future, it must secure adequate reserves in foreign countries, buy oil from foreign oil companies, or depend on oil shale production to fill the void.” White, “The Petroleum Resources of the World,” 129. It took 100 years, but the US has exercised all three of those options.


32. Total cellulosic biofuel use is projected at 311 million gallons, but most of this is renewable natural gas.


36. Intergovernmental Panel on Climate Change, Climate Change 2014.

37. Nordhaus, DICE 2013R.


42. Ibid.
44. Lade, Lin Lawell, and Smith, “Policy Shocks and Market-Based Regulations.”
45. US Environmental Protection Agency, “Renewable Fuel Standard Program,” 70, Table 1.2-3.