Fueling a Clean Transportation Future

Smart Fuel Choices for a Warming World

Union of Concerned Scientists

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The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

More information about UCS and the Clean Vehicles Program is available on the UCS website: *www.ucsusa.org*

This report is available online (in PDF format) at *www.ucsusa.org/FuelingaCleanFuture*.

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A NOTE ON THE FEBRUARY 2017 CORRECTED VERSION

The original release of this report made an incorrect inference based on preliminary research. The error became apparent upon subsequent publication of the final analysis, so we have removed the specific claim and the reference to the preliminary analysis. The revised report reflects the literature available at the beginning of 2016, when this report was originally published. Subsequent analysis will be reflected in future publications.

Cutting oil use dramatically is essential to the comprehensive transformation of our energy system that is required to avoid the worst impacts of climate change.

In 2012, the Union of Concerned Scientists (UCS) unveiled a practical plan to cut projected U.S. oil use in half by 2035 through improvements in vehicle efficiency and by accelerating the use of innovative clean fuels. The good news is that we are off to a solid start. After years of stagnation, the efficiency of our passenger cars and trucks has improved by about 20 percent. Americans are driving less, and sales of cleaner fuels and electric vehicles (EVs) are rising.

But there is a largely unrecognized problem undermining these efforts: the oil we use is getting dirtier. The resources broadly described as oil are changing, with major climate implications. The global warming pollution associated with extracting and refining a barrel of oil can vary by a factor of more than five. As oil companies increasingly go after unconventional, hard-to-reach sources such as tar sands and use more intense extraction techniques such as hydraulic fracturing (fracking), dirtier sources of oil have become an increasingly large part of the mix, and wasteful practices are needlessly increasing emissions. Because we use so much oil, even relatively small changes in emissions per barrel add up to very large increases in pollution over time.

It doesn't have to be this way.

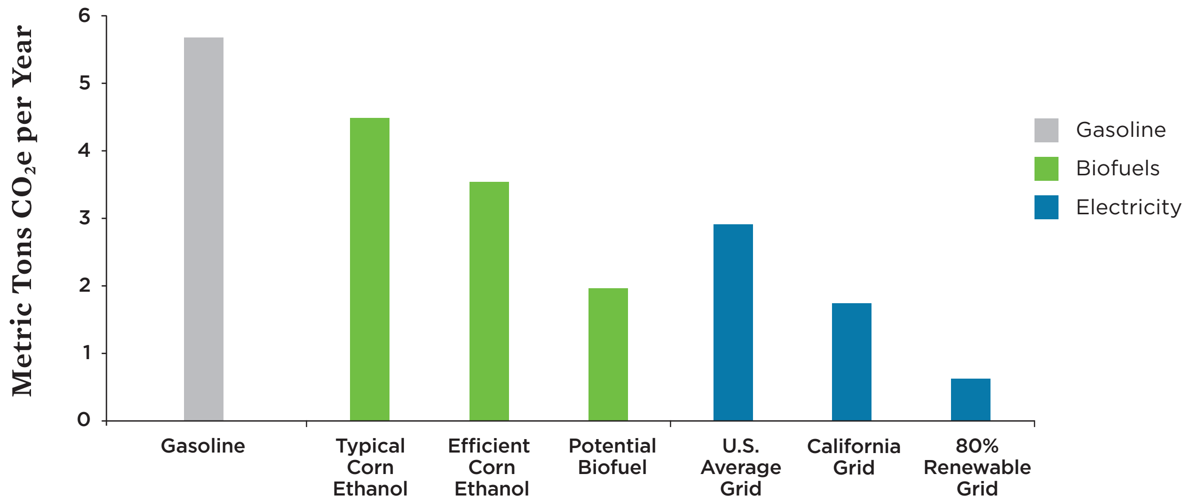
This report points the way to a cleaner transportation future by describing key ways we can clean up our transportation fuels. This report builds on the UCS Half the Oil plan by explaining how our major transportation fuels are changing and what we can do to reduce emissions from fuel production. Our clean fuels—electricity and biofuels—are already cutting oil use and emissions from transportation, but more work is required to deliver on their potential. Oil is getting steadily more polluting, but by holding oil companies accountable to reduce avoidable emissions and avoid the dirtiest sources, we can check that mounting climate damage and make sure that the oil we continue to use has the lowest global warming emissions possible.

Oil Is Getting Dirtier

Oil is the largest source of U.S. global warming pollution and for more than half a century has been the dominant source of transportation fuel. Hidden behind the pump is a global supply chain for oil that is changing in ways that have important consequences for the climate. As the easily accessed oils that characterized the oil booms of the last century are dwindling, the oil industry is looking increasingly to ever-riskier sources of oil and more polluting practices in production.

[***As easily accessed oils dwindle, the oil industry is looking increasingly to ever-riskier sources of oil and more polluting practices in production.***]

FIGURE 1. Compared with Gasoline, Alternatives Are Clean and Getting Cleaner



A typical car produces 6.7 metric tons of global warming pollution each year, once emissions from oil extraction and refining are added to tailpipe emissions. Biofuels and electricity are cleaner, and have the potential for dramatic improvements in the future.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 miles per gallon, or mpg) for a year (driving 12,000 miles). This is compared with the energy equivalent amount of ethanol. For electricity the emissions represent the production of fuel (e.g., coal, natural gas) and consumption by power plants to generate a quantity of electricity needed for a similar vehicle traveling the same distance, adjusted for electric drive efficiency.

SOURCE: CARB 2015A; CARB 2015D; UCS ANALYSIS; NEALER, REICHMUTH, AND ANAIR 2015; HAND ET AL. 2012.

[Even small increases in the emissions of the oil supply chain add up quickly. Steps must be taken to reduce emissions from oil extraction and refining.]

The surprising truth is that global warming emissions associated with extracting and refining a barrel of oil vary from less than 50 kilograms to 250 kilograms, depending on where the oil comes from and how it was extracted and refined. Some oil extraction techniques use large amounts of natural gas to generate energy to pump oil and water, and to generate steam. Natural gas that is extracted along with oil is sometimes simply burned in place (flared) because oil operators start extracting oil without providing the infrastructure necessary to bring the gas to market. Emissions are also much higher for unconventional fossil resources like Canadian tar sands, whose emissions can be higher by as much as 100 kilograms per barrel than more conventional crude oil.

Even small increases in the emissions of the oil supply chain add up quickly. Over the course of 2015 to 2035, the addition of just one kilogram of emissions per barrel of oil per year (a rise of less than 1 percent per year) would increase cumulative emissions from oil production and refining by approximately one billion tons—roughly the tailpipe emissions of all of the gasoline-powered vehicles in the United States in 2014.

Clean Fuels Are Getting Cleaner

While oil is getting dirtier, other fuels are getting cleaner. The UCS Half the Oil plan highlights the importance of advanced biofuels and EVs in meeting oil-savings targets. But maximizing the benefits of biofuels and EVs depends on both scaling up these solutions and making sure these fuels get cleaner over time. This potential, for both, is real.

Biofuels. The use of biofuels in the United States has expanded dramatically since 2002. This expansion has cut oil use significantly. In 2009, oil's share of transportation energy fell below 95 percent for the first time since 1958, largely because of increased biofuel use. Ethanol now accounts for about 10 percent of every gallon of gas. But the rapid increase in the use of corn for fuel also put pressure on crop prices and highlighted trade-offs and limitations with food-based biofuels in general, and corn ethanol in particular. Fortunately, advanced biofuels made from non-food resources offer a better path to continue to cut oil use and emissions.

The ethanol being blended into gasoline today reduces emissions by about 20 percent compared to gasoline. Ethanol produced in today's most efficient ethanol facilities has emissions reduced by another 15 percent. Advanced biofuels made from wastes—including cellulosic ethanol made from agricultural residues—are coming to market now, and environmentally friendly perennial grasses offer further opportunities to expand biofuel production while complementing food production and enhancing the sustainability of the U.S. agricultural system. The potential scale of biomass resources is vast. Biofuel production can triple while protecting our food system and environment. By seizing these opportunities, global warming emissions from biofuels can be cut by more than 60 percent compared to gasoline on an energy equivalent basis.

Electricity. EVs cut oil use by getting their power from the grid rather than a gasoline pump. How much they cut global warming pollution, therefore, depends on the grid used to charge them. A battery EV charged on the average U.S. grid produces about 50 percent of the global warming pollution produced by a gasoline-powered vehicle. But in many parts of the country the grid is much cleaner. In California, which has more EVs than any other state, charging the same vehicle produces just 35 percent of the emissions of a conventional vehicle.

As the use of coal to produce electricity falls, the grid gets steadily cleaner. However, to avoid risky overreliance on natural gas, it is important to invest in expanding the use of clean renewable energy from wind and solar power. EVs can facilitate utilities' efforts to integrate more wind and solar resources, leading to a synergy between two crucial elements of a comprehensive approach to reaching the deep emissions reductions required to stabilize the climate.

The Road Ahead

With oil getting dirtier and appealing alternatives getting cleaner, the road ahead for cleaner U.S. transportation is clear. But oil will remain a significant part of our transportation fuel mix for many years to come. A few key steps must be taken immediately to prevent emissions from oil extraction and refining from continuing to climb.

ELIMINATE WASTEFUL PRACTICES

It is incumbent upon responsible energy companies to minimize global warming emissions from their own operations and their supply chains. The first step is to make sure oil companies change wasteful practices. The widely used practice of flaring marketable natural gas is the product of a flawed regulatory system. In addition, the use of energy-intensive practices for oil recovery can be reduced through the use of technologies such as solar-thermal steam generation. And, the higher emissions from some extremely polluting fossil fuels such as tar sands are not cost-effectively mitigated with existing technology, and their use should be curtailed.

REQUIRE DISCLOSURE AND TRACKING

One key step for ensuring that oil companies act responsibly is to require greater disclosure and tracking of emissions from oil production. More is known about the impacts of one gallon of ethanol that makes up 10 percent of our gasoline mix than the impacts of the gasoline that makes up the rest, particularly about extracting and refining the oil.

While government agencies, companies, and trade groups collect and publish a great deal of information about oil markets, comprehensive accounting of emissions from oil extraction and refining is inadequate. Open-source models of oil extraction and refining have been developed, and these are being used to assess overall U.S. and global oil production as well as incorporated into lifecycle assessment models for transportation fuels. Working with these models, the Carnegie Endowment has developed the Oil Climate Index, which covers 30 major global oil fields and highlights both the wide variability of different sources of oil and the lack of transparent public information required to make accurate assessment of the world's oil fields.

MAKE OUR CLEAN FUELS CLEANER

While minimizing emissions from the production and use of gasoline is important, a low-carbon transportation system must shift steadily away from oil toward cleaner fuels. To maximize the climate benefits of this transition, we must ensure that these clean fuels get cleaner over time. This means shifting biofuel production toward advanced biofuels produced at appropriate scale and in a sustainable manner, and cleaning up the grid with the increased use of renewable sources of electricity.

These strategies to reduce the emissions associated with all of our transportation fuels complement the UCS Half the Oil plan to cut oil use and together they move us toward a clean transportation future.

[CHAPTER 1]

Clean Transportation for a Stable Climate

Transportation is one of the largest sources of global warming pollution after electricity generation, and cutting emissions from transportation is both challenging and essential to avoid the worst impacts of climate change. A low-carbon, clean transportation future will look different in many ways, with different vehicles and a different look to our communities—and it will be powered with different fuels. This report examines how the sources and roles of transportation fuels are changing, including three key automotive fuels—gasoline, ethanol, and electricity. We consider what can be done to reduce the emissions from each of these fuels between now and 2050, and outline four key steps for moving steadily—and rapidly—to a cleaner transportation future.

The Emissions of Transportation Fuels Are in Flux

All of our transportation fuels are changing. Some of these changes are visible, as when the owner of an electric vehicle (EV) plugs in a car instead of filling up at a gas station. But many of the important changes in our fuel system are far less obvious. The oil used to make gasoline is changing, as dirtier sources (such as tar sands) and more intensive oil-extraction methods (such as hydraulic fracturing) change the nature of oil. Biofuels such as ethanol are an increasingly significant part of the fuel mix and are changing as production processes get more efficient and biofuel producers look beyond corn grain to non-food, lower-carbon agricultural resources such as corn stalks and perennial grasses. Electricity is a growing transportation fuel as well and is changing as coal-fired power plants are replaced with cleaner sources of power such as natural gas and, more importantly, renewable electricity from

[*Cutting emissions from transportation is essential to avoiding the worst impacts of climate change.*]

solar and wind power. The changes in these fuels' emissions have important consequences for the climate.

To understand the full story, it is important to consider not just which fuels the nation's vehicle fleet uses, but how these fuels are produced. Driving a car fueled with gasoline or ethanol, or charging the batteries of an EV, produces varying levels of global warming pollution depending on how the fuel is produced. Meaningful comparisons require considering not just the tailpipe emissions of the vehicle, but also the emissions released during the fuel's production.

Three Major Fuels

This report assesses the major changes in our transportation fuel system, with one chapter devoted to each of three principal transportation fuels: gasoline, ethanol, and electricity. Other fuels such as diesel and biodiesel, natural gas and biomethane, jet fuel, and hydrogen are also important, and our approach to assessing the emissions profiles of transportation fuels can be applied to these as well.

In each chapter, we consider how the fuel is used, production methods in use today, ways in which these methods are changing, and what these mean for the future. Our primary focus is on global warming emissions, but we describe some

BOX 1.

Lifecycle Analysis and Units

The practice of adding up a complete accounting of emissions from the production, distribution, and use of a fuel is called lifecycle analysis, and there is extensive technical literature devoted to this topic. The results cited in this report draw from this literature, particularly from analysis performed by the California Air Resources Board (CARB) for administration of that agency's Low Carbon Fuel Standard. Comparing results from different studies presents significant challenges, and CARB's analysis is the most comprehensive and up-to-date available. Moreover, the analysis is the result of years of open stakeholder and expert engagement.

In this report we deliberately do not focus on lifecycle analysis per se, but rather on describing the practices in the real world that have the biggest impact on a fuel's lifecycle. Precise lifecycle analysis requires a narrow focus on a very specific set of comparisons, while the goal of this report is the opposite—that is, to broaden focus to the U.S. transportation fuel system today and how it can and should evolve. To facilitate meaningful comparisons, each chapter presents a simple figure comparing the total global warming emissions of gasoline, biofuel, or electricity measured in the metric tons of CO_2e associated with the production and use of the amount of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). These emissions range from almost 6 metric tons (hereafter simply "tons") of global warming pollution for a car using gasoline to less than 1 ton for a car using electricity produced on a future grid supplied with 80% renewable energy. Details of calculations, approximations, and assumptions are described in the captions, chapters, and a technical appendix online at *www.ucsusa.org/FuelingaCleanFuture*.

Within the chapters on gasoline, biofuel, and electricity, we also step back and broaden our view to understand challenges facing whole sectors—changes shaping the oil industry, global and U.S. agricultural production, and the entire U.S. electricity grid. These sectors produce more than just transportation fuel, and changes to one product often have complex implications for the sector as a whole. This leads us to consider emissions from oil production in general, rather than trying to isolate the impact of producing gasoline, which is just one of several products made from oil (albeit the largest), or to consider how the whole electricity grid is changing rather than just the small share of the grid that charges EVs. Within discussions of specific fuels we largely adopt the units most often used in the associated literature. Discussions of global warming emissions are reported throughout in metric units—grams, kilograms, or (metric) tons—of CO_2e pollution using a 100-year global warming potential to convert other global warming pollutants such as methane into CO_2 equivalent values (Myhre et al. 2013). Oil is reported in barrels, distances in miles, ethanol in gallons, and corn in bushels. In some cases, more than one set of units is relevant, and we have included a second set of units in parenthesis.

other significant impacts of fuel production as well. In each case, future emissions depend upon choices that fuel producers make today about sources of fuel and how the materials are processed. To illustrate the effect of these choices, we compare three sources of each fuel. For gasoline we consider oil extracted from depleted oil wells, "tight" oil accessed using hydraulic fracturing (or fracking), and oil extracted from tar sands. Thus, the gasoline chapter covers the old and the new, changes in technology as well as different types of fossil resources. For biofuels, we consider corn-grain ethanol, cellulosic ethanol made from corn stalks, and cellulosic ethanol made from perennial grasses. This covers the food-versus-fuel trade-offs, the potential to make biofuels from wastes and residues, and the opportunity to make biofuels increasingly from environmentally preferable crops. For electricity, we consider power generated from coal, natural gas, and renewable sources like wind and solar power; cover major changes underway today; and describe a vision for a future grid that can meet our long-term energy needs and climate goals.

Clean Fuels Are Getting Cleaner; Oil Is Getting Dirtier

One broad finding in this report is that as electricity and biofuels are getting cleaner, oil is getting dirtier. This is not simply because of the inherent properties of the fuels, because it is possible to produce electricity and ethanol in highly polluting ways. Rather, electricity and biofuels are getting cleaner because producers are subject to careful scrutiny of the global warming emissions associated with the fuels' production, and public policy is holding producers accountable to reduce these emissions. However, the same level of scrutiny is not being applied to the different sources and methods of producing gasoline. In addition, oil companies are not obligated to reduce emissions from their supply chains. For the United States to avoid the worst consequences of climate change, all fuel producers have to minimize their global warming pollution. Once the oil industry incorporates this obligation into its complex supply chains, its operations will change in a number of ways—some subtle, others dramatic—as it responds to market demands while simultaneously minimizing the emissions that change the climate in dangerous ways.

All Fuel Producers Must Be Accountable to Clean Up Their Fuels

Gasoline, biofuels, and electricity are three very different fuels, and we anticipate that their roles—together with those of other transportation fuels not described in detail in this report—will change over the next few decades. We anticipate the role of electricity in a clean transportation sector steadily growing, the use of gasoline steadily falling, and biofuels evolving from having a complementary role in gasoline blends to a complementary role with electricity in certain parts of the transportation sector, that are more difficult to electrify, such as aviation.

As these roles evolve, it is critical that all transportation fuels be produced in a manner that minimizes the emissions associated with their production and use. This means changing not just the quantity of various fuels produced, but their quality, measured on a lifecycle basis.

All Fuel Producers Must Minimize Their Emissions

Our report closes with a short chapter highlighting some key overarching conclusions and discussing the implications for public policy. Fuel supply chains are complex, as is the transportation sector. While broad performance-based policies like the California Low Carbon Fuel Standard can provide support for improvements across the transportation fuel supply as a whole, more specific policies addressing individual challenges are needed as well. Multiple policies implemented by different agencies at the state and federal levels are necessary to support the needed transformation of our transportation sector broadly, and the production of transportation fuel in particular. While the report's focus is not primarily on policy, we highlight in our conclusions how a few key existing and proposed policies advance the goals we describe. The test of a policy's effectiveness should be how effectively it motivates actual reductions in pollution from fuel production and use. A focus on real-world outcomes provides a reality check on more theoretical policy assessment. In future work, we will take up specific policy questions in greater detail.

BOX 2.

Low-carbon Fuel Standards: Performance-based Clean Fuels Policy

Regulatory frameworks for gasoline, biofuels, and electricity at the federal level are generally quite separate. But some states, led by California, are moving forward with a broad performance-based standard for transportation fuel that recognizes the many potential strategies to reduce emissions from these fuels and allows these strategies to compete on the basis of their performance. The California Low Carbon Fuel Standard tracks the global warming emissions from the production and use of all transportation fuels and requires steady progress in cleaning up the overall pool of transportation fuels. The policy requires that by 2020 the fuels used in the state have 10 percent lower global warming emissions per unit of energy than they had in 2010. This means using a larger share of clean fuels, like advanced biofuels and electricity. But the policy also recognizes that emissions from fuels depend upon how they are made, and emissions accounting is therefore based on a full lifecycle accounting. The result is that less-polluting methods of ethanol production—from agricultural residues instead of corn grain, for example—generate more credit. The policy also recognizes emissions reductions from innovative measures to reduce emissions from oil production, such as the use of concentrating solar power rather than natural gas to generate steam used in oil extraction (CARB 2015c).

The California Low Carbon Fuel Standard is providing support for investment in clean fuels and setting an example for other jurisdictions. Oregon, for example, has a similar policy called the Clean Fuels Program, and other states are moving forward with measures to track upstream emissions from their fuels, collecting the information that is a precursor to actions to reduce these emissions.

Beyond the policy's direct benefits—the reduction of global warming emissions—it is informing policy makers and the public across the country and around the world. CARB has played a crucial role catalyzing the analysis of transportation fuel emissions. Much of the research cited in this report was performed by CARB or under contract by researchers at California universities and elsewhere. CARB's contribution to research in this area is amplified by its practice of relying on open-source models; holding numerous public workshops; convening expert work groups; and commissioning peer reviews on topics including lifecycle analysis, sustainability, indirect land use change (ILUC), and high-carbon-intensity crude oil. The value of CARB's insight is hard to quantify in tons of global warming emissions avoided, but sound policy rests on sound science, and California is providing a great deal of both.

[**CHAPTER 2**]

Gasoline and Oil

For as long as most Americans can remember, gasoline has been the only fuel they buy to fill up the cars they drive. However, hidden from view behind the pump, the sources of gasoline have been changing dramatically. Gasoline is produced from crude oil, and over the last two decades the sources of this crude have gotten increasingly diverse, including materials that are as dissimilar as nail polish remover and window putty. These changes have brought rising global warming emissions, but not from car tailpipes. Indeed, tailpipe emissions per mile are falling as cars get more efficient. Rather, it is the extraction and refining of oil that are getting dirtier over time.

The easiest-to-extract sources of oil are dwindling, and the oil industry has increasingly shifted its focus to resources that require more energy-intensive extraction or refining methods, resources that were previously too expensive and risky to be developed. These more challenging oils also result in higher emissions when used to produce gasoline (Gordon 2012). The most obvious way for the United States to reduce the problems caused by oil use is to steadily reduce oil consumption through improved efficiency and by shifting to cleaner fuels. But these strategies will take time to fully implement. In the meantime, the vast scale of ongoing oil use means that increases in emissions from extracting and refining oil can substantially undermine climate progress.

Fortunately, there are important mitigation measures that can reduce avoidable emissions, and choices about whether the dirtiest resources should be tapped. Clear disclosure and tracking of emissions from the entire oil supply chain are needed to show oil producers and investors which sources carry more or less climate risk, and policies are needed to prevent oil from getting any more polluting than it already is.

Heat-trapping emissions from producing transportation fuels such as gasoline are on the rise, particularly emissions released during extracting and refining processes that occur out of sight, before we even get in the car.

This chapter examines how gasoline is used, how it is produced, and how the oil used to make gasoline is changing. Three important sources of oil are examined in more detail: oil from old depleted wells, "tight" oil accessed by hydraulic fracturing (fracking), and extra-heavy crudes like tar sands. Finally, we consider some promising routes by which the rising emissions of oil extraction and gasoline refining can be mitigated. Given that gasoline will be used as a transportation fuel for decades to come, opportunities to reduce emissions from oil production must be identified quickly and implemented widely.

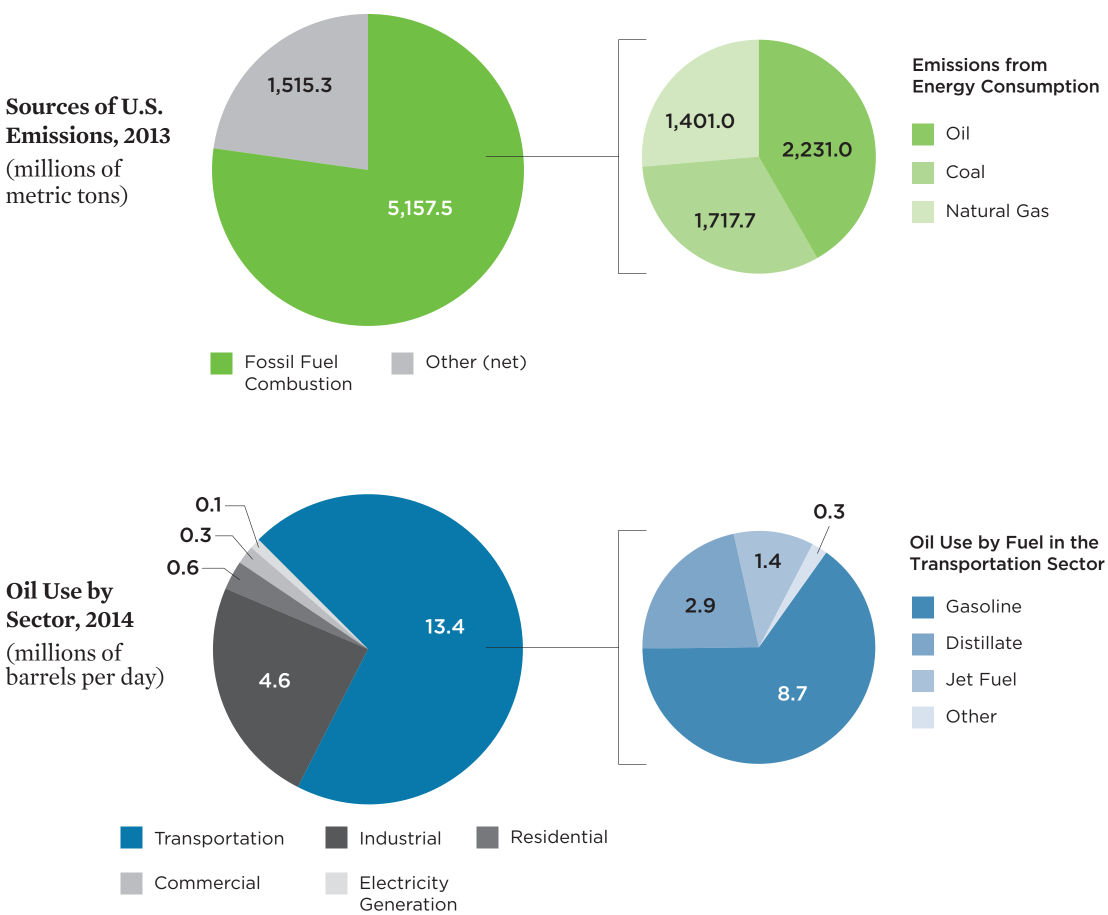
BOX 3.

Oil and Gasoline Are Not the Only Things Causing Climate Change, but They Are Among the Biggest

Fossil fuel combustion accounts for the vast majority of U.S. global warming pollution (EPA 2015a), and of the three primary sources of fossil fuel associated carbon emissions, oil is the largest (EIA 2015b). Most of the oil is used in the transportation sector, and gasoline constitutes the majority of transportation fuel. Emissions from U.S. gasoline use alone amount to about 1 billion tons of CO_2.

As these statistics make plain, transportation in general, oil in particular, and especially gasoline are among the most significant sources of global warming pollution. Cutting global warming emissions enough to stabilize CO_2 concentrations and avoid the most damaging impacts of climate change will require deep reductions in emissions across the whole economy (IPCC 2014). And emissions reductions from the transportation sector must start with dramatic cuts in oil use over the next few decades.

FIGURE 2. Reducing Emissions from Gasoline Is Key to Mitigating Global Warming



Fossil fuel combustion is the largest source of the heat-trapping emissions that cause global warming. Of the three major fossil fuels, oil accounts for the largest share of CO_2 emissions. The majority of oil is used for transportation, and within that category, the largest share of oil is used in the production of gasoline. Reducing gasoline and oil use is crucial to reducing global warming emissions.

SOURCE: EPA 2015A; EIA 2015B.

Use of Gasoline and Oil Today, and Related Emissions

Coal rather than oil launched the industrial revolution; in 1900 oil was a minor source of energy and had an insignificant role in the transportation sector. Oil's importance grew through the 1920s, and in the years shortly after World War II, as coal-fired trains were replaced by diesel locomotives, oil began 50 years of almost total dominance of the transportation sector (see Figure 3, p. 10). Oil supplied 95 percent of transportation energy from 1958 to 2008, and fell below this level only in 2009 as biofuels grew to become a small but increasingly significant part of the transportation fuel pool (Chapter 3, p. 25).

> ***After World War II, as coal-fired trains were replaced by diesel locomotives, oil began 50 years of almost total dominance of the transportation sector.***

Gasoline use rose steadily for three decades in the post–World War II years, until oil price shocks associated with the oil embargo in the 1970s led to the introduction of fuel economy standards in the mid-1970s (see Figure 4, p. 11). The rising fuel efficiency of new cars combined with another oil price spike at the end of the 1970s led to a significant drop in the nation's gasoline consumption. In the 1980s, oil prices fell and fuel economy standards stagnated, and gasoline use resumed its upward trajectory. In the late 2000s, after 20 years of relatively low oil prices, prices rose sharply, and booming global demand and another round of political turmoil in the Middle East led to oil price spikes. Higher oil prices refocused consumers and policy makers on fuel economy, and in 2007 new standards were passed by Congress and signed into law, although not fully implemented until 2012. As a result, the cars, minivans, and light trucks sold today have higher efficiency

TIMELINE 1. Changes in the Oil Industry

1900 | 1925 | 1950 | 1975 | 2000

1901
Oil is discovered at the Spindletop oil field in Texas; oil accounts for just 2 percent of U.S. energy use, and almost four times as much capital is invested in manufacturing locomotives and railroad equipment as motor vehicles in the United States (EIA 2012; Census Bureau 1975).

1945-1960
In the post–World War II boom years, oil rapidly becomes the dominant transportation fuel. Oil accounts for 80 percent of transportation energy in 1950 and 95 percent in 1958 as the automobile age comes into full swing, the interstate highway system is built, and railroads shift from coal-fired steam locomotives to diesel power.

1973
The first Arab oil embargo causes oil prices to triple and highlights the political and economic vulnerabilities that the nation's heavy oil use imposed.

1975
In response to the embargo, the first fuel economy standards for cars are implemented, improving the efficiency of cars from 13 mpg in 1975 to 23 mpg 1985.

1990
The Exxon Valdez spill releases more than one-quarter million barrels of crude oil into Prince William Sound, off the coast of Alaska, making it the largest U.S. maritime oil spill to that point in time.

2009
The Securities and Exchange Commission expands legal definitions of oil to include tar sands and other unconventional sources including oil and gas extracted from coal and shales (SEC 2009). This expands what oil companies can count among their "proven reserves."

2010
The BP Deepwater Horizon offshore drilling rig explodes and sinks, killing 11 people and releasing about five million barrels of oil into the Gulf of Mexico.

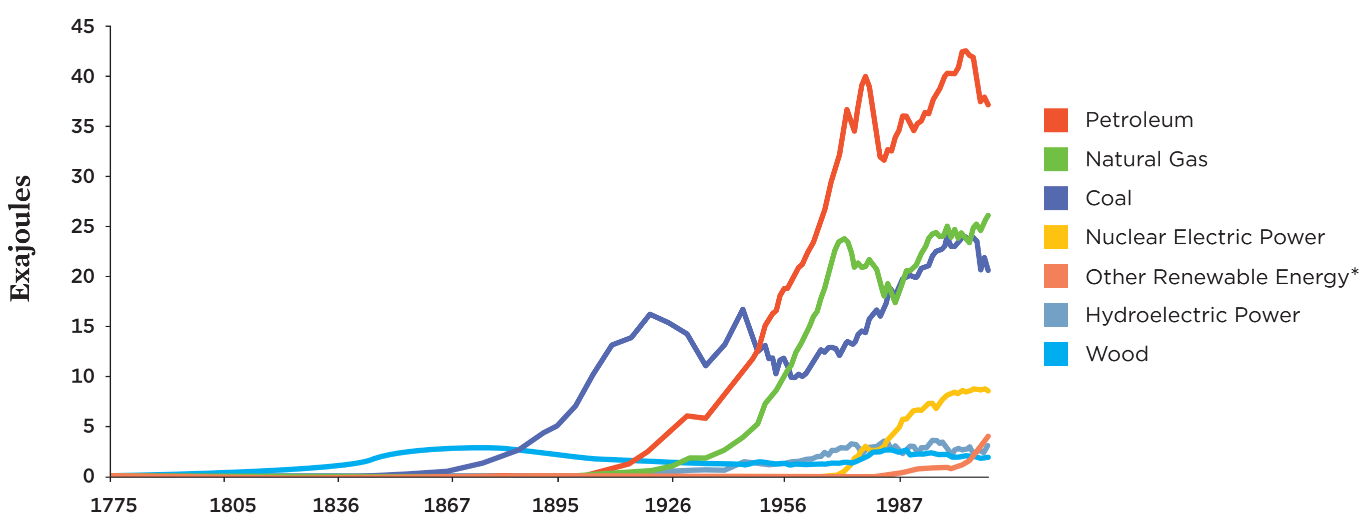
than in the past, ranging from less than 20 mpg to as high as 50 mpg. The average efficiency of new passenger cars and trucks sold in 2014 was 28 mpg for cars and 20 mpg for trucks, with a sales-weighted average overall of just over 24 mpg (EPA 2014a; DOE 2015), which is 20 percent higher than in 2006. Efficiency improvements are expected to continue as standards get more stringent over time, pushing toward an average real-world fuel economy of 37 mpg by 2025 (UCS 2015a, UCS 2011a). Already, millions of gasoline-powered hybrid electric vehicles (HEVs) on the road today get up to 50 mpg.

Automobile drivers' habits have played an important role in the nation's gasoline consumption over time. One key reason that gasoline consumption fell after 2007 was the reduction in the number of miles Americans drove their cars. The average number of miles travelled in a vehicle annually—vehicle miles traveled (VMT)—fell on a per-capita basis by more than 6 percent in 2014 compared to its peak in 2005 (see Figure 4). This was due in part to Americans' increased use of telecommuting, bicycling, public transit, and other alternatives to driving (Dutzik and Baxandall 2013). Following the dramatic fall in oil prices in 2014, per-capita VMT increased somewhat, but it is still well below its previous peak, and changing demographics and attitudes toward transportation choices may be leading to more lasting decreases. A shift toward more dense urban development together with new transportation services like ride-sharing, car-sharing, and regional bike-sharing services are changing the way people access transportation, moving away from the near-universal car ownership that has prevailed since World War II.

> ***Millions of gasoline-powered HEVs on the road today get up to 50 mpg.***

Recent progress in fuel efficiency and reduced VMT demonstrates that a cleaner transportation system is a realistic goal, but continued action in all of these areas is needed to maintain this progress over the long term. Complacency in the 1980s undermined early progress cutting oil in the 1970s, and low oil prices lulled policy makers into allowing vehicle efficiency standards and other oil-saving policies to stagnate. Avoiding the same mistake now is critical. To chart a path toward steady progress, the Union of Concerned Scientists (UCS) developed a practical plan to cut projected oil use in half by 2035 (see Box 4, p. 12). Even as progress on reducing oil use proceeds, however, it remains important to clean up all of the fuels the nation's drivers use, including clean fuels like

FIGURE 3. U.S. Primary Energy Consumption Estimates by Source, 1775–2011

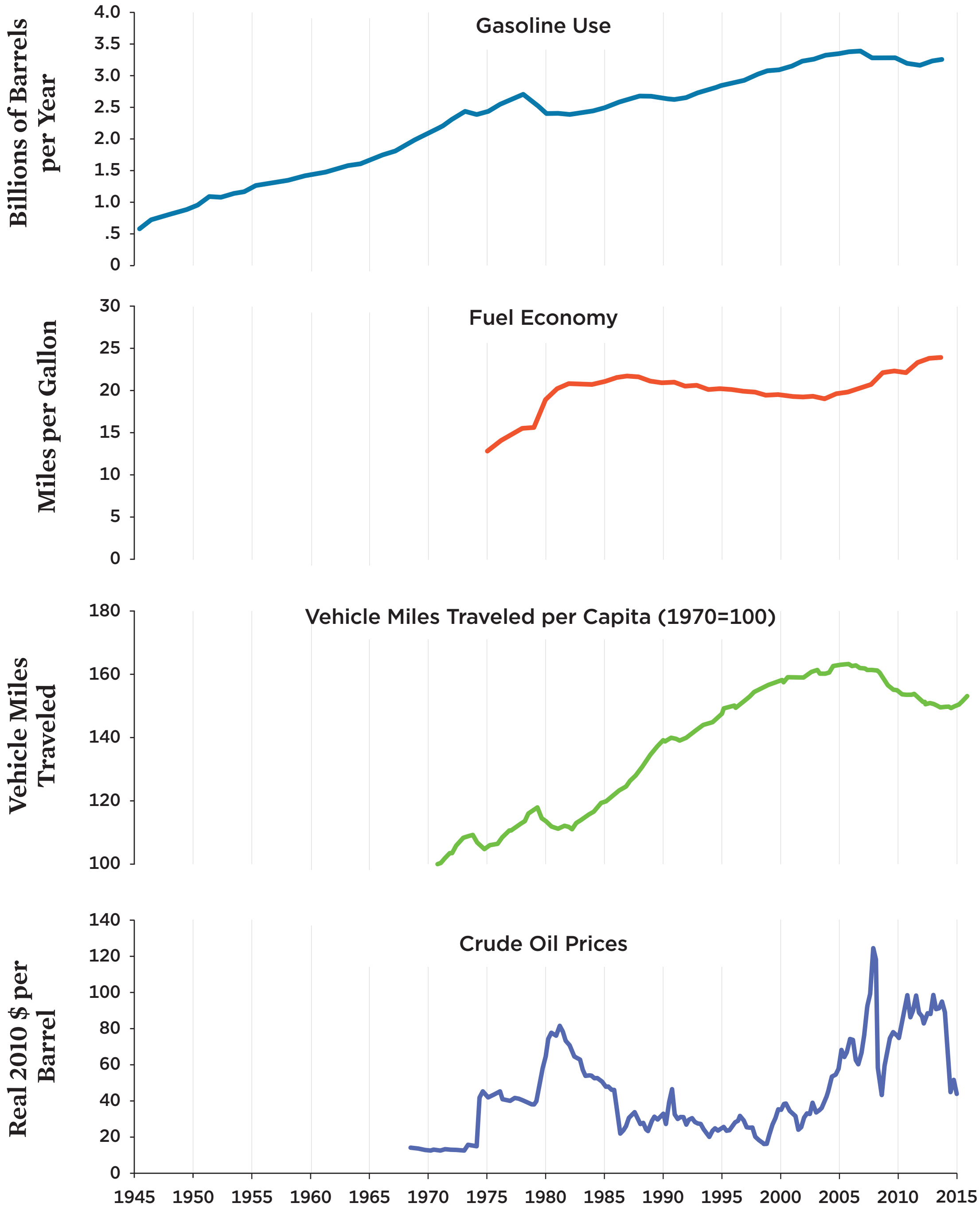


Since the 1940s, petroleum has been the largest source of energy in the United States.

* Geothermal, solar/photovoltaic, wind, waste, and biofuels.

SOURCE: EIA 2012.

FIGURE 4. Historical U.S. Gasoline Use and Key Factors that Influence It



Changes in gasoline use depend upon fuel economy, vehicle miles traveled, and crude oil prices.

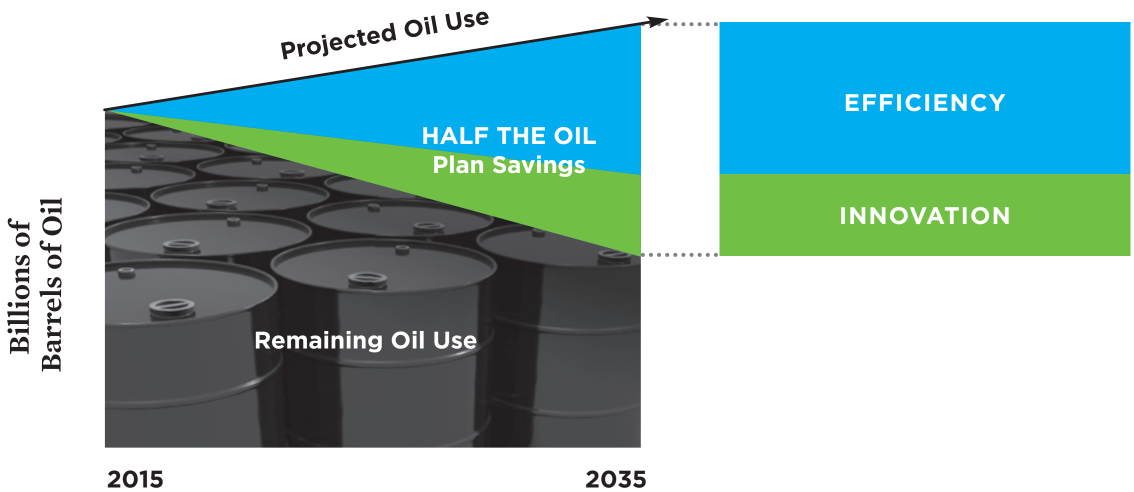
SOURCE: EIA 2015B; EPA 2014A; BLS 2015; DOT 2015; EIA 2015D.

BOX 4.

Half the Oil

The most straightforward way to reduce the pollution and other problems caused by oil is to use less of it. UCS has developed a plan to cut projected oil use in the United States in half by 2035 by aggressively improving the efficiency of all uses of oil—not just for cars using gasoline, but trucks, trains, planes, and ships, as well as industrial uses—and expanding the use of innovative technologies including EVs and advanced biofuels (UCS 2012a). Important early progress demonstrates that these strategies are realistic and can lead to the desired results, but further progress on more efficient vehicles, cleaner fuels and other innovative oil-saving solutions is required to deliver on their full potential.

Yet, even as oil use falls, it remains a major source of pollution. Under the UCS Half the Oil plan, although oil use would fall to 11 million barrels per day by 2035, cumulative oil use between 2015 and 2035 would still be approximately 100 billion barrels (EIA 2015a, UCS 2012a). If we made less progress on oil-saving strategies, we would see even higher oil use during that period.



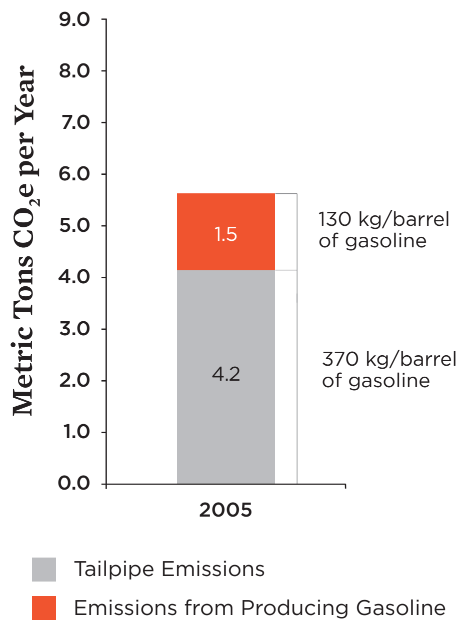
advanced biofuels (see Chapter 3) and electricity (see Chapter 4), and also the oil that will continue to be used for decades to come.

Production of Gasoline, and Related Emissions

The most obvious source of global warming emissions from gasoline are the CO_2 emissions from a car's tailpipe during the operation of a gasoline-powered vehicle. But the combustion emissions from gasoline are by no means the whole story. Emissions from oil extraction and refining oil into gasoline are also major sources of global warming pollution. A typical new car getting 25 mpg that is driven 12,000 miles per year has emissions of 4.2 metric tons of CO_2e global warming pollution (hereafter simply tons CO_2e). The emissions produced through extracting and refining the oil add on average 1.5 tons of CO_2e, an additional 35 percent (CARB 2015a). Moreover, the 1.5 ton figure is an average that includes a very wide range of types of oil, some of which produce far more global warming emissions than the average. As we discuss below, detailed annual tracking of the production emissions per gallon of U.S. gasoline is not available. However, the shift toward more polluting sources of oil and more extreme extraction

[The shift toward more polluting sources of oil and more extreme extraction and refining methods is increasing emissions.]

FIGURE 5. Emissions from Oil Production



While using vehicles is the most obvious source of emissions from gasoline, producing the gasoline involves substantial emissions from extracting and refining oil. The magnitude of these emissions depends on which sources of oil are used, and how these sources are extracted and refined.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles).

SOURCE: CARB 2015A.

and refining methods is increasing emissions. This means that even as the tailpipe pollution from driving a car is falling, the pollution associated with producing a gallon of gasoline is rising.

EASY OIL IS RUNNING OUT

Conventional, easy-to-access oil is running out. But the result is not gasoline shortages. Rather, the oil industry has shifted its focus to unconventional fossil resources and extraction methods. The prototypical "gusher" that marked the discovery of the Spindletop oil field in Texas in 1901 is no longer an accurate representation of where oil comes from or what oil production looks like. As oil fields age and their output declines, oil companies are turning to oil resources once thought to be too risky or too expensive to exploit, establishing and rapidly scaling up production of unconventional sources of oil that are costly, physically difficult, and energy-intensive to extract and refine compared to "easy" oil. So long as continued demand for oil exists, oil companies will find technical means to develop these increasingly challenging and risky fossil fuel resources (Gordon et al. 2015).

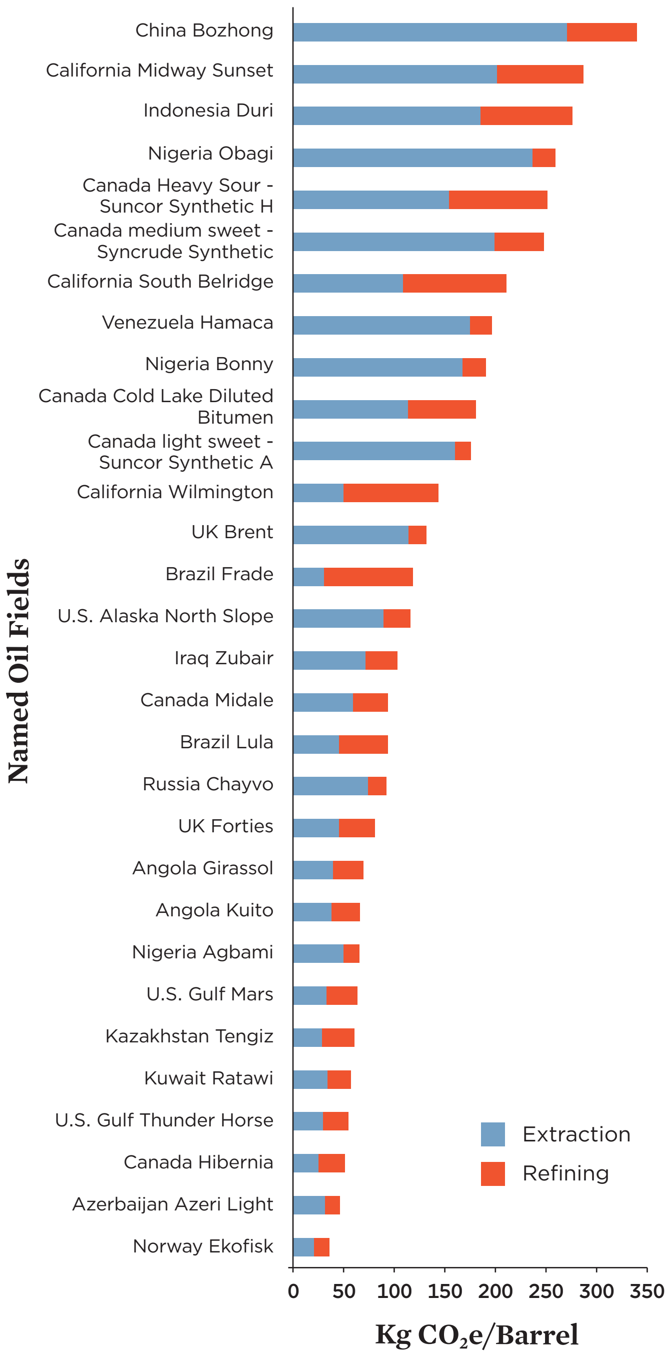
The common image of oil as a dark liquid with the viscosity of cooking oil captures just the center of a wide range of hydrocarbons that are now used to make gasoline and other transportation fuels. At one end of the spectrum is ultra-light oil, a thin liquid with the viscosity of nail polish remover. At the other end of the spectrum are bitumen and kerogen, long-chain hydrocarbons with the viscosity of caulk or putty (Gordon 2012). Just off the spectrum on the light end are methane and other components of natural gas, which are often found together with lighter oils. At the very heavy end is coal, which shares features and uses with some of the heaviest sources of oil. Different types of oil are made into different products, with very different impacts on the climate.

With different types of oil come different techniques to extract and refine them. From fracking tight oil in North Dakota to surface mining tar sands in Canada, new extraction techniques and the different types of oil that they produce mean that the total emissions of driving a car are changing, although not in ways that drivers can see or control. These changes are occurring before the gasoline gets to the gas station and are a function of the choices, actions, and inactions of oil companies and their supply chains.

[***New extraction techniques and the different types of oil that they produce mean that the total emissions of driving a car are changing, although not in ways that drivers can see or control.***]

Researchers at the Carnegie Endowment, Stanford University, and the University of Calgary recently released the Oil Climate Index, a set of three linked open-source models for oil extraction, refining, and use that illustrate the increasing complexity of the oils used to produce transportation fuels and other petroleum products. Their initial work looked at 30 representative sources of crude oil from around the world, finding that the global warming emissions from extracting

FIGURE 6. Emissions from Extracting and Refining Oil Can Vary



According to the Oil Climate Index, emissions from extracting and refining emissions can vary dramatically, depending on the sources of oil and the extraction and refining practices and methods.

SOURCE: GORDON ET AL. 2015.

one barrel of oil ranged from 22 to 270 kg CO_2e, and emissions from refining ranged from less than 15 to more than 100 kg CO_2e (Gordon et al. 2015).[1]

The Oil Climate Index takes an in-depth look at many of the key factors that differentiate the world's varied oil resources. In this report we highlight just three that illustrate some of the key issues at play in the changing world of oil production:

- **Depleted oil wells** that require a great deal of water and steam to extract oil
- **Tight oil** production using hydraulic fracturing and associated gas flaring
- **Tar sands oil** and the associated emissions from mining and processing

DEPLETED OIL WELLS

As oil wells age—some of the wells in Texas and California are more than 100 years old—the pressure drops and the flow of oil slows. The remaining oil is typically heavier and does not flow easily out of the ground, requiring more aggressive recovery techniques, and it is also more energy-intensive to refine. Heavy oils are more resistant to flow due to their higher viscosity. When a new well is drilled, there may be sufficient pressure for the oil to flow without pumping, but this initial pressure-driven flow is generally sufficient to extract only 10 percent or so of the available oil. Once the pressure falls, pumping is driven by an electric motor, which requires energy and generates additional emissions.

PUMPING LOSSES

Once the easily accessible oil runs out, oil producers often pump water into the ground (see Figure 7), which allows more oil to be recovered. Anywhere from 20 to 40 percent of the total recoverable oil in a field can be extracted by injecting water into the oil field at an injection well. However, in the case of water-flooded oil wells, much of the injected water comes out together with the oil. Thus, over time, more and more water must be pumped into the ground and back out again to get less and less oil, with some older wells using 30 barrels of water for each barrel of oil extracted. As the ratio of water to oil increases, so too do the emissions per barrel. According to the the Oil Production Greenhouse Gas Estimator (an open-source oil emissions calculator), lifting an additional 10 barrels of water per barrel of oil increases production emissions from oil extraction by 15 kg CO_2e per barrel (El-Houjeiri et al. 2015). With average oil extraction emissions of about 70 kg CO_2e per barrel, an additional 15 kg is a meaningful increase (CARB 2014).

1 *Although non-transportation uses are beyond the scope of this report, the Oil Climate Index considered how the whole barrel of oil is used—not just the gasoline derived from it, but also other transportation fuels such as diesel, jet, and marine fuels, as well as other petroleum products used outside of transportation (Gordon et al. 2015).*

Antandrus/Creative Commons (Wikimedia Commons)

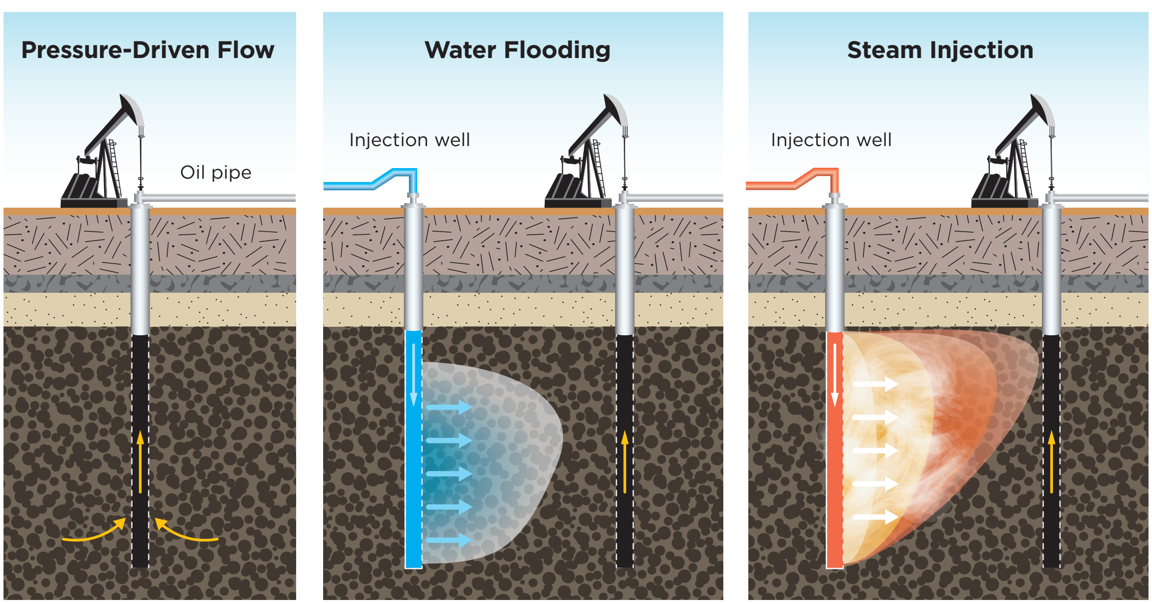
Lost Hills Oil Field in California has been producing oil for over 100 years. As wells age, more energy is required to extract the remaining oil from the ground, and more emissions are released in the process.

STEAM INJECTION

Water is not the only thing pumped into oil wells. Over time, flooding wells with water becomes ineffective, and other techniques are required to continue production. These techniques, which increase pressure and change the physical properties of the oil, are referred to as enhanced oil recovery. They consist of injecting either steam, other gases (including methane or CO_2), or chemicals into oil wells to make the oil flow more easily, enabling the recovery of more oil than would be possible by simply pumping or flooding the wells. In general, up to 60 percent of the total recoverable oil in an oil field can be extracted using these techniques.

In the United States, steam injection (also called thermal-enhanced oil recovery) accounts for 20 percent of the volume of oil produced each year. In California in particular, steam injection is the most prevalent form of oil extraction for older wells and in fields with heavy oil. In addition to the energy required to run the pumps, energy is required to make steam. Different types of oil and different wells require different amounts of steam, and sometimes steam can be efficiently procured from a power plant that generates both steam and grid electricity. Typical quantities of water used in steam-flooded wells in California are between three and six barrels of water (converted to steam) used to extract one barrel of oil. Each barrel of water converted to steam increases emissions by about 25 kg CO_2e per barrel (El-Houjeiri et al. 2015; Brandt

FIGURE 7. Extracting Oil from Depleted Wells



When a new oil well is drilled, oil can easily be extracted using the internal pressure of the well. Over time however, this easy oil will stop flowing, and enhanced recovery methods are needed. Water injected into the oil field makes further extraction possible, and when these secondary techniques are no longer effective, injecting steam, other gases, or chemicals can facilitate further oil recovery. These methods require more and more energy to extract less and less oil, raising the emissions of each barrel produced.

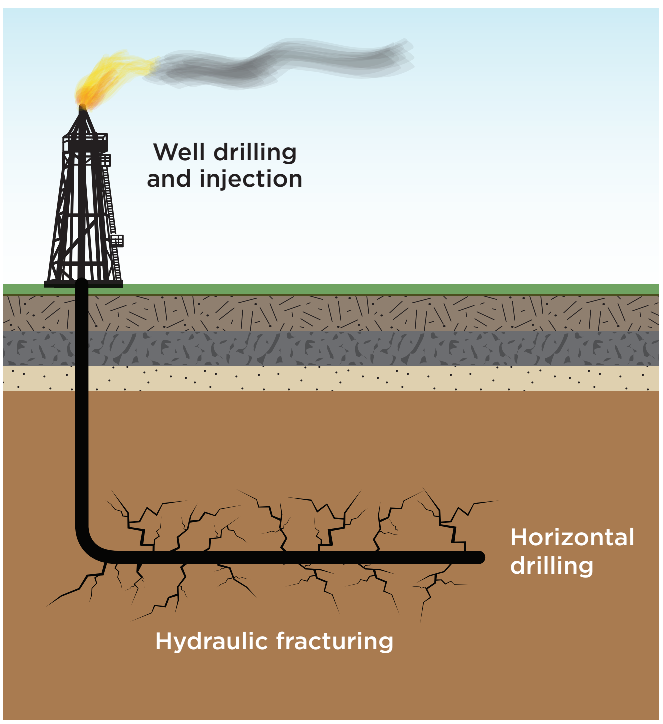
and Unnasch 2010), compared to 75 kg CO_2e per barrel associated with extracting an average barrel of oil (CARB 2014).

TIGHT OIL

Tight oil is found in shale deposits, especially in the Bakken field in North Dakota and the Eagle Ford field in Texas. (Because tight oil is found in shale deposits, it is often called "shale oil," which can cause confusion with oil shale, an entirely different resource. In this report the term "tight oil" is used to avoid this confusion.) Tight oil is extracted using horizontal drilling and hydraulic fracturing (fracking), techniques that were not as widely used before 2010, but became much more common when oil prices rose. Tight oil accounts for a growing share of U.S. oil production and is produced at a scale that is significantly changing the global oil marketplace (Hamilton 2014). Fracking uses pressure to create cracks in porous rocks and injects chemicals and sand to keep the cracks open, allowing oil and natural gas from the pores to flow out. The extraction process creates local air and water pollution, a great deal of road traffic, high water use, and other problems that make it a problematic source of oil (Goldman et al. 2013; Gordon 2012).

The tight oil developed in the United States to date tends to be a relatively light crude. These light tight oil deposits also come with many intermediate-molecular-weight hydrocarbons called natural gas liquids, which—instead of being processed into gasoline or diesel—are typically used in the chemical industry or for other purposes. An important feature of tight oil from North Dakota and Texas is that both oil and natural gas are present in the same formations and are

FIGURE 8. Extracting Tight Oil Using Hydraulic Fracturing



As gas prices and oil demand rise, producers have turned to extracting tight oil using horizontal drilling and hydraulic fracturing. A relatively new process, this involves using pressure to create cracks in porous rocks, and injecting water, sand, and chemicals to keep those cracks open and allow oil to flow. This process uses substantial energy and water, creates local air and water pollution, and is often associated with extensive production of gases as well as crude oil. Most of the gas is sold, but in some cases the gas is flared at the well, a wasteful and polluting practice that can be avoided by building the infrastructure needed to bring the gas to market or reinjecting it into the well.

Lindsey G/Creative Commons (Wikimedia Commons)

Extracting tight oil, like in the North Dakota operation pictured here, requires an energy-intensive hydraulic fracturing process.

produced from the same wells. The relative fraction of oil to gas differs from region to region and dictates the design, management, and utility of the resources extracted in these regions. For example, the Marcellus shale in the northeastern United States produces primarily gas, while the Bakken and Eagle Ford are exploited largely to access liquid oil, although a great deal of gas comes up with the oil.

Gassy oils like those produced in the Bakken field in North Dakota require different techniques, infrastructure, and equipment to manage. Methane, the main component of natural gas, is a potent greenhouse gas, with 34 times the global warming potential of CO_2 over a 100-year time frame and 86 times the global warming potential over a 20-year time frame (Myhre et al. 2013). Releases of methane and other gases from oil wells—or venting—can dramatically increase the emissions associated with oil production. Therefore, it is very important that methane not be released into the atmosphere, which can be accomplished by reinjecting it into the well, where it can maintain pressure and assist in the oil recovery process, or transporting it by pipeline to be sold for use in electricity generation or for other purposes. However, since 2007, oil producers rushing to bring oil to market have increasingly resorted to burning the natural gas—flaring it and releasing it into the atmosphere—rather than building the necessary infrastructure to prevent its release into the atmosphere and bring it to market (see Box 5).

[Releases of methane and other gases from oil wells—or venting—can dramatically increase the emissions associated with oil production. It is very important that methane not be released into the atmosphere.]

The surge in tight oil production since 2010 has outpaced the development of infrastructure required to transport the oil to market. Train shipments moving oil to U.S. refineries have grown from less than 10,000 train cars in 2008 to more than 435,000 in 2013, and with them an increased frequency of derailments. Because of the higher volatility of some tight oil compared to conventional crude, derailments of these fuels also have more often caused fires (Frittelli et al. 2014).

BOX 5.

Flaring

The routine combustion of useable natural gas from oil wells might seem counterintuitive: why would an oil producer burn something that it could sell for a profit? The rapid expansion of tight oil extraction occurred more rapidly than the build-out of infrastructure necessary to gather, process, and transport the associated gas to market. Producers prioritized getting liquid fuels to market quickly and used their capital to drill new wells rather than first putting in place the necessary pipelines and other gas infrastructure. Instead, the natural gas was vented to the atmosphere or burned at the well site. These flares are visible by satellite, and analysis of the satellite data has been used to calculate the extent of flaring from countries around the world (Elvidge et al. 2009).

In the North Dakota oil fields, the rapid expansion of wells has not been accompanied by a similar expansion in producers' capacity to recover the natural gas; therefore, flaring and venting have substantially increased. On average, less than 5 percent of natural gas produced in North Dakota

continued next page

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When tight oil is extracted, natural gas rises along with the liquid oil. Because the oil is often the more profitable product, fossil fuel companies prioritize extracting the oil over capturing the natural gas, choosing instead to flare the natural gas in order to reach the oil. Flaring is a very emissions-heavy practice and is currently surging in North Dakota.

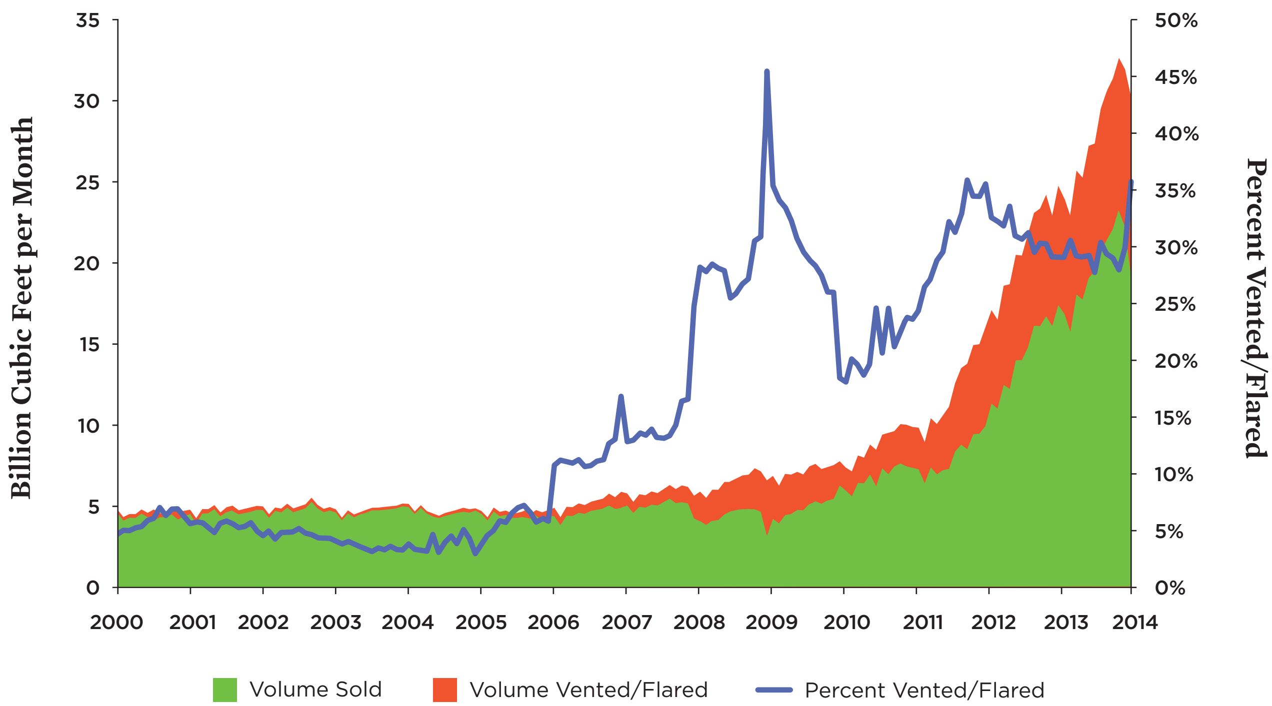
BOX 5. (CONTINUED)

was flared between 2000 and 2005, but after 2005 venting and flaring grew quickly as tight oil production accelerated. Between 2011 and 2013, more than 30 percent of natural gas was vented and flared, and given the rapidly rising overall natural gas production, the result was a very large increase in global warming emissions of CO_2, methane, and other pollutants without producing any useful product or service.

Flaring is surging in North Dakota, but it need not be. Tight oil production has also been growing at the Eagle Ford formation in Texas, but in Texas less than 1 percent of extracted natural gas has been vented or flared, owing to the more extensive network of pipelines to collect and market natural gas. Oil fields in Norway also flare and vent very little natural gas. Norway effectively banned the routine use of flaring in 1972; oil production projects there must either reinject natural gas or put in place the infrastructure to sell the gas prior to commencing production. Norway's major oil industry therefore has very low upstream emissions: Norway's Ekofisk field was found to have the lowest upstream emissions of 30 major global oils evaluated as part of the Carnegie Endowment Oil Climate Index. By contrast, the two oils with the highest extraction emissions in the index, China Bozhong and Nigeria Obagi, are gassy oils produced with extensive venting and flaring, increasing their emissions substantially.

Inadequate information on tight oils prevented the inclusion of any U.S. tight oil sources like Bakken and Eagle Ford fields in the Oil Climate Index (Gordon et al. 2015). But more recent analysis from the Stanford research team working with Argonne National Laboratory and other groups is increasing our knowledge of the emissions from this increasingly important source of oil and highlights the role played by flaring in the total emissions of these oils (Brandt et al. 2015; Ghandi et al. 2015).

FIGURE 9. North Dakota Monthly Natural Gas Production



Venting or flaring natural gas is an avoidable source of global warming pollution that occurs when oil producers extract oil without putting in the required infrastructure to manage the natural gas, and instead release it into the atmosphere (venting) or burn it on site (flaring). As oil production increased in North Dakota so too did venting and flaring, which averaged less than 5% between 2000 and 2005 and has increased to more than 30% from 2011 to 2013. Because the quantity of gas has increased as well, the total quantity of venting and flaring in 2011 to 2013 is more than 25 times higher on an absolute basis than it was between 2000 and 2005.

SOURCE: EIA 2015C.

TAR SANDS AND EXTRA-HEAVY CRUDE

Tar sands, also referred to as oil sands, are composed of approximately 10 to 18 percent bitumen in a matrix of soil including sand, clay, and quartz, as well as water (Gordon 2012). Creating gasoline and diesel from tar sands is a very different process from the use of conventional oil, as bitumen is an extra-heavy crude that is semi-solid at room temperature. These tar sands do not look like oil. Indeed, prior to a 2010 ruling by the Securities and Exchange Commission, tar sands resources were not included as proven reserves in U.S. oil companies' financial reporting (SEC 2009).

Tar sands are extracted by either surface mining or in situ recovery. Surface mining is used for tar sands that are within 75 meters of the ground surface, while in situ recovery is used for deeper reservoirs (Charpentier, Bergerson, and MacLean 2009). The vast majority of the world's reserves of tar sands are located in Alberta, Canada. Approximately 20 percent of the Canadian reserves of tar sands are within 75 meters of the surface and can therefore be surface mined; the remaining 80 percent of Canadian reserves would have to be mined in situ, which can significantly increase extraction emissions (CAPP 2015a).

SURFACE MINING

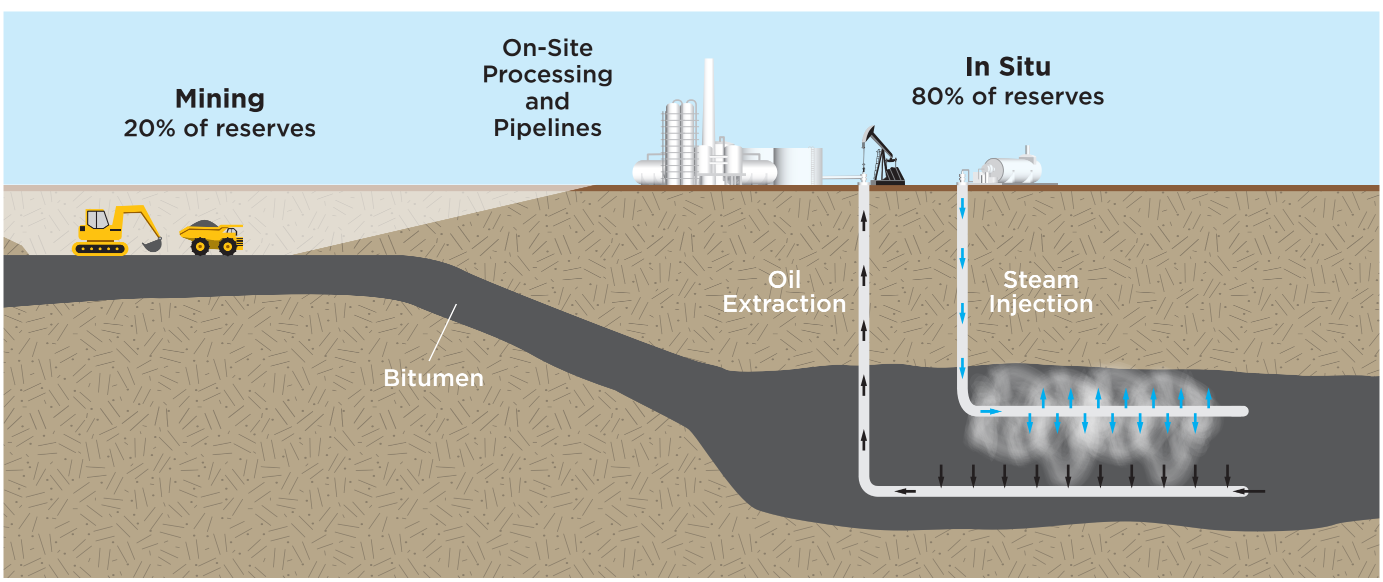
Tar sands reserves accessible to surface mining cover approximately 1,800 square miles of Alberta, an area larger than Rhode Island (CAPP 2015a). The surface mining, also known as open-pit mining, of tar sands involves removing all of the ground above the tar sands and exposing its entire surface area for mining. The tar sands are then physically gathered by enormous trucks in much the same way that coal is extracted during open-pit mining.

Once the tar sands are mined, the bitumen is separated from the soil matrix using water and heat in an energy-intensive process that generates carbon emissions and leaves behind highly polluted water. Once separated, the bitumen is still too viscous to flow through pipelines; therefore, prior to transportation it must be either upgraded or diluted. Upgrading is another energy-intensive process, converting bitumen into synthetic crude that more closely resembles conventional crude oil. Alternatively, bitumen can be diluted with lighter hydrocarbons to enable it to flow through pipelines to refineries, where it is further processed.

IN SITU RECOVERY

In instances when tar sands reserves are deeper than 75 meters, in situ recovery techniques are employed. In situ mining requires steam (or solvents) to lower the viscosity of bitumen enough to be pumped out of the reservoir for further processing. This oil-recovery approach requires injections of massive amounts of steam, which requires heat generated from natural gas as well as a great deal of water, all of which lead to emissions even higher than for surface-mined tar sands oil (Cai et al. 2015).

FIGURE 10. Extracting Oil from Tar Sands



Tar sands are a mixture of clay, sand, and bitumen—an extra-heavy crude that is solid at room temperature. They are collected either by surface mining, in which soil covering the tar sands deposits is removed and the bitumen is trucked to upgraders for further processing, or in situ mining, in which massive amounts of steam are injected into the ground to make the tar sands flow. The emissions from both methods of collecting tar sands are very high, and the process to convert tar sands into gasoline and other products is very energy-intensive.

BOX 6.

Tar Sands Mining Destroys Forests and Contaminates Water

Surface mining destroys the boreal forest ecosystem found above Alberta's tar sands and releases the associated soil carbon. Projected land area disturbed between 2012 and 2030 is estimated to be 500 km^2 for surface mining and 2,400 km^2 for in situ mining, with combined emissions from land use of more than 100 million tons CO_2e (Yeh et al. 2015). Water used to process the tar sands is also a major concern, as it becomes heavily polluted and is held in very large artificial reservoirs (tailings ponds) that cover a total area of 176 km^2 (67 square miles) (CAPP 2015b). Pollutants from these tailing ponds are finding their way into plants, fish, and birds, posing risks to wildlife and people who consume the fish from the region (Schindler 2014).

UPGRADING AND REFINING

Refining tar sands oil is a more energy intensive and polluting process than refining conventional crude oils. Tar sands oil is composed of extremely heavy hydrocarbons and is also often high in contaminants such as sulfur, which must be removed either as part of the process of making synthetic crude or later at the oil refinery in the process of making finished fuels such as gasoline. Emissions associated with extracting and refining a barrel of tar sands oil are also higher, ranging from 180 to 250 kg CO_2e per barrel of oil (Gordon et al. 2015).

The Future of Oil and Gasoline

With smart policies, gasoline use in the United States should decline steadily over the next several decades, as vehicles become more efficient, the use of clean fuels like electricity and biofuels continues to expand, and transportation options that reduce travel by car are more widely adopted. However, even with steady progress, gasoline will remain a major part of the U.S. transportation fuel mix for decades to come. Other oil-based fuels like diesel and jet fuel will likely also remain significant parts of the fuel mix through 2050. As a consequence, the emissions associated with extracting oil and producing gasoline, diesel, and other transportation fuels will continue to be an important part of our country's total transportation emissions through 2035 and beyond.

Even with steady progress in cutting oil use, improving vehicle efficiency, and ramping up EVs and biofuels, the United States will still be using 11 million barrels per day—or 4 billion barrels per year—of oil in 2035 (see Figure 11). Cumulative oil use in those two decades will be about 100 billion barrels, or more if oil reduction strategies are not implemented aggressively (EIA 2015a, UCS 2012a). If emissions associated with oil extraction and refining rise by just 1 kg of CO_2e per barrel each year (less than 1 percent) over this time frame, the cumulative additional emissions would be almost 1 billion metric tons of CO_2e, almost as much as tailpipe emissions from all gasoline-powered vehicles in the United States in 2014 (EIA 2015b).

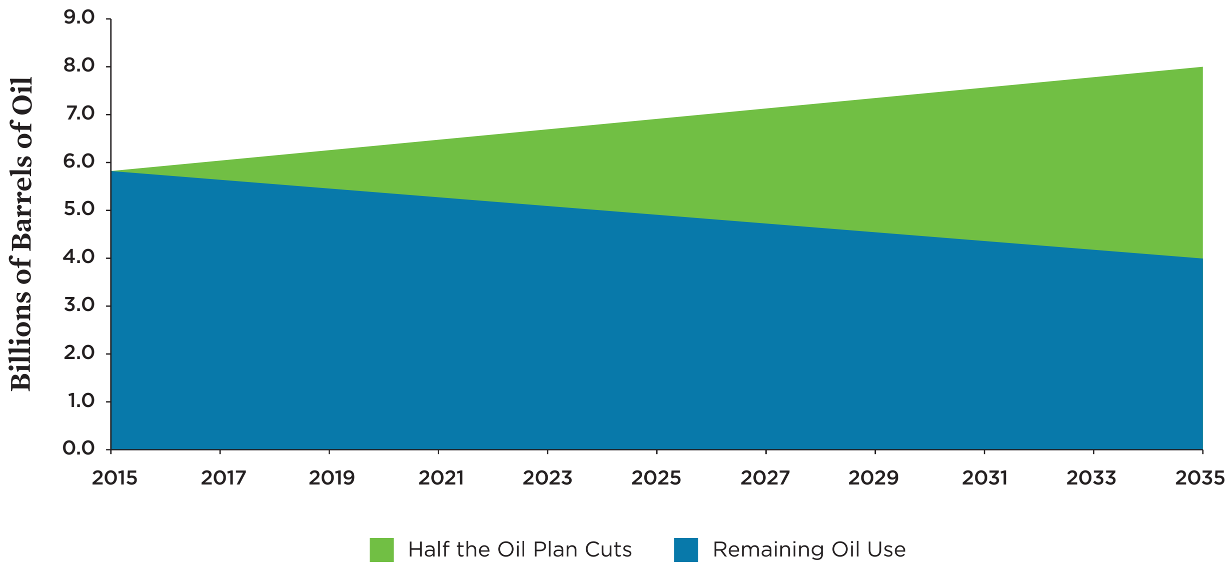
It is crucial that oil producers and refiners—even as they continue to produce gasoline and other fuels—clean up and reduce global warming emissions from their operations. There are ample opportunities for them to do so.

> ***The emissions associated with extracting oil and producing gasoline, diesel, and other transportation fuels will continue to be an important part of our country's total transportation emissions through 2035 and beyond.***

ELIMINATE ROUTINE FLARING

Flaring natural gas associated with oil production generates high levels of emissions. Fortunately, it is unnecessary and can be readily avoided. Flaring materially increases carbon emissions while reducing the energy production and economic activity associated with a given oil well. Oil production without flaring would create jobs, not just for oil extraction but for building and operating the required infrastructure for responsible energy production and distribution. The products would include the liquids as well as the natural gas. Where bringing gas to market is not practical or economic, gas can also be reinjected into the well and be used to maintain pressure required for continued oil extraction. The economic circumstances that make flaring an attractive option today are not an inevitable feature of the oil itself, but a result of the

FIGURE 11. The UCS Half the Oil Plan



The UCS Half the Oil plan outlines how the United States could reduce its projected oil use by 50 percent by 2035 through increasing vehicle efficiency and increasing the use of innovative clean fuels. However, even with these aggressive oil saving measures, 100 billion barrels of oil would still be used between 2015 and 2035, and emissions associated with producing oil would continue to be very significant, especially if oil production continues to get more polluting over time.

> ***The economic circumstances that make flaring an attractive option today are not an inevitable feature of the oil itself, but a result of the flawed regulatory system that does not hold oil producers accountable for their carbon emissions.***

flawed regulatory system that does not hold oil producers accountable for their carbon emissions.

Russia, Nigeria, Iran, and Iraq have been among the largest flaring countries, but increasing flaring from tight-oil production brought the United States higher in the ranking in recent years. The United Nations is coordinating a program aimed at phasing out the routine use of flaring by 2030, but meeting these goals requires action by oil-producing countries and the oil industry.

USE RENEWABLE SOURCES OF HEAT FOR STEAM GENERATION

Oil extraction from depleted wells often relies on steam generation that is most commonly produced by burning natural gas, adding substantially to the emissions associated with oil production. However, burning natural gas is by no means the only cost-effective way to generate steam. For example, concentrating solar energy is a highly effective means of generating steam that is already used extensively for electricity generation. For oil extraction located in areas with high solar-generating potential, including many oil fields in California and elsewhere around the world, this is an important opportunity for oil producers to reduce emissions.

Analysis by CARB found that using solar steam reduces emissions from oil production by 29 kg CO_2e per barrel of steam, and CARB is implementing a policy providing emissions reduction credits under its Low Carbon Fuel Standard for oil companies that adopt this innovative technology (CARB 2015b).

© GlassPoint Solar

Using solar energy to generate steam creates less emissions than creating steam by burning natural gas.

PRIORITIZE RESOURCES THAT CAN BE PRODUCED WITH MINIMAL UPSTREAM EMISSIONS

Oil industry emissions from steam generation and flaring can be readily and cost-effectively mitigated with existing technology, keeping emissions from oil extraction and refining from rising and perhaps even reducing them somewhat. But not all upstream emissions are easily managed. In particular, the tar sands and other extra-heavy crudes are among the most carbon-intensive oils currently being produced. Until practical mitigation measures are in place to reduce the emissions from extracting and refining these sources, their use should be reduced or eliminated.

Oil companies have highlighted the potential for technologies such as carbon capture and sequestration to mitigate the high upstream emissions of tar sands at some point in the future. However, this technology is not in widespread use today, and it is unclear whether it will be a realistic and cost-competitive carbon mitigation strategy on a large scale. As time continues to pass with mitigation remaining uncertain, investments in tar sands production, pipelines to transport it to market, and refinery investments to process it are locking in place one of the dirtiest sources of transportation fuel we have.

Decisions about which fossil resources to extract should take into consideration their full climate impact, especially because, once initial investments and infrastructure are put into place, the capital- and infrastructure-intensive projects may operate for many decades into the future. Policy makers and investors need accurate disclosure and comprehensive evaluations about the climate implications of these important decisions.

[***The tar sands and other extra-heavy crudes are among the most carbon-intensive oils currently being produced.***]

USE RENEWABLE INPUTS AND IMPROVE EFFICIENCY AT REFINERIES

In addition to oil producers' choices regarding oil extraction, oil refiners have significant opportunities to cut emissions associated with refining crude oil into gasoline and other products. These include investing in more energy-efficient equipment and integrating renewable resources into their operations. Renewable resources could include renewable electricity, bio-methane from wastewater treatment in place of natural gas, or replacing a portion of their fossil fuel crude with bio-crude produced from wastes or low-carbon sources. Refineries are complex and each is unique—the specific opportunities that make sense in each one will differ. But large refineries are major carbon emitters, and oil companies have the expertise and technology to reduce their emissions. This opportunity must not be lost.

Conclusions and Recommendations

Oil is changing and with it is the climate impact of driving a car. While the window sticker on a new car indicates the oil use and carbon emissions from the operation of the car, no such information is provided at the gas pump about emissions from the production of the gasoline. Easy oil is running out, and new sources of oil and different technologies used to extract and process it are increasing the carbon emissions of gasoline. However, some key mitigation measures are available to prevent oil from getting dirtier than it already is. To accomplish this requires reducing avoidable emissions and avoiding the dirtiest sources of oil.

MANAGING EMISSIONS FROM OIL PRODUCTION IS CRITICAL

Even with aggressive action to cut projected oil use in half by 2035 with efficiency and innovative transportation fuels such as electricity and biofuels, the United States is still on course to use 100 billion barrels of oil between 2015 and 2035 (EIA 2015a; UCS 2012a). Extracting and refining each barrel of oil has emissions of roughly 130 kg of CO_2e per barrel, and because of changes in oil production, these emissions could rise significantly as production shifts to more energy- and carbon-intensive oil sources and extraction techniques (Gordon et al. 2015).

BOX 7.

Major Carbon Emitters

The majority of fossil fuel CO_2 emissions released since the industrial revolution can be traced to just 90 entities, including the largest oil companies (Heede 2014).

These companies have known for decades that their products were major contributors to climate change, but rather than seek to reduce this harm, many of the companies instead have knowingly worked to deceive the public about the risks and realities of climate change (Mulvey and Shulman 2015).

Oil Companies with the Largest Cumulative Emissions

Entity	2010 Emissions $MtCO_2e$	Cumulative 1854–2010 $MtCO_2e$	Percent of Global $MtCO_2e$ 1751–2010
Chevron, USA	423	51,096	3.52%
ExxonMobil, USA	655	46,672	3.22%
Saudi Aramco, Saudi Arabia	1,550	46,033	3.17%
BP, UK	554	35,837	2.47%
Gazprom, Russian Federation	1,371	32,136	2.22%
Royal Dutch/Shell, Netherlands	478	30,751	2.12%
National Iranian Oil Company	867	29,084	2.01%
Pemex, Mexico	602	20,025	1.38%
ConocoPhillips, USA	359	16,866	1.16%
Petroleos de Venezuela	485	16,157	1.11%

A recent analysis traced the cumulative emissions of CO_2 and methane between 1751 and 2010 and found that more than 60 percent of the total fossil fuel associated emissions could be attributed to 90 private and state-owned entities. The top 10 listed above are led by the largest oil companies in the world.

Note: $MtCO_2e$ stands for million metric tons carbon dioxide equivalent.

Given the enormous scale of emissions from oil, even an increase of a 1 kg per barrel per year will lead to an increase of a billion metric tons of CO_2 between 2015 and 2035, and increases two or three times as large are certainly possible unless the oil industry minimizes unnecessary emissions and avoids the dirtiest resources.

> ***Comprehensive disclosure is needed to clarify which emissions associated with oil extraction, refining, and use are avoidable and which fossil resources are most polluting.***

DISCLOSURE AND TRANSPARENCY ARE THE FIRST STEP

While some information on oil industry emissions is reported in a variety of contexts, the oil industry is not held to the same level of accountability for its carbon emissions as automakers, electric utilities, or the biofuels industry. Comprehensive disclosure and reporting are needed to clarify which emissions associated with oil extraction, refining, and use are avoidable and which fossil resources are most polluting. Researchers have developed estimates of emissions from a number of different sources including data collected by regulators in various jurisdictions, voluntary disclosure of carbon emissions by some of the major oil companies, and data and secondary observations such as satellite data on flaring. Given the importance of these emissions, more direct reporting requirements and tracking are necessary to inform investors, regulators, and policy makers.

OIL COMPANIES MUST BE HELD ACCOUNTABLE TO REDUCE EMISSIONS FROM THEIR OPERATIONS

Oil is not a singular product, and every oil well and oil refinery is the subject of many decisions that have significant consequences for global warming pollution. Choices about which sources of unconventional oil are developed and how they are extracted and processed can substantially affect the global warming emissions generated by the 100 billion barrels the United States will consume by 2035. As the largest producers of fossil fuels in the industrial age, oil companies have a major responsibility for climate change, and should reduce emissions and avoid the dirtiest sources of oil in order to reduce the global harm caused by their products.

[**CHAPTER 3**]

Biofuels

Biofuels are an important and rapidly changing part of the nation's fuel supply, the fastest-growing alternative fuel since 2000, and already a key component of our fuel system. While the use of biofuels is likely to continue to grow over time, they are not likely to supply a majority of the overall transportation energy demand in the United States because of intrinsic limitations of land availability and competing uses for crops. Understanding the benefits, risks, and potential improvements for biofuels is critical to mapping a path forward to a future of cleaner transportation fuels and progressively lower global warming emissions.

Ethanol is the most widely used biofuel, while other biofuels such as biodiesel and biomethane are also increasingly important, as are so-called drop-in biofuels. The latter are chemically identical to their fossil fuel analogs and can be blended with gasoline, diesel, or jet fuel at any level and used in the existing fleet of vehicles without modification. For simplicity, this report focuses primarily on different types of ethanol. Many of the issues discussed here apply to other biofuels as well.

In this chapter, we examine the evolving role of ethanol in our gasoline fuel mix and the impact of food-based fuels on

DAVID ILIF/Creative Commons (Wikimedia Commons)

Ethanol made from corn is the most widely used biofuel. While ethanol is a cleaner fuel than oil, increasing corn production affects food prices and increases erosion, water pollution, and habitat loss. For these reasons, additional biofuel sources should be considered.

agriculture, food production, and land use. We examine more sustainable non-food sources of biofuel as well as opportunities to clean up the biofuels production processes, and we forecast the potential for reducing global warming emissions from biofuels by 2050.

Ethanol Use in Gasoline Blends

Ethanol is often considered as a substitute for gasoline, but its primary role to date has been as a gasoline additive, improving the properties of the gasoline into which it is blended. Ethanol adds oxygen to a gasoline blend, which can reduce air pollution. It also has a higher octane rating than gasoline, which improves the combustion properties of the blended fuel. However, ethanol has lower energy content per gallon than gasoline, making it less valuable when used primarily for energy (for example, as the major component of a vehicle fuel). This has implications for the economic competitiveness of different ethanol blends on the market today and for future blends as well.

The primary use of ethanol in the United States today is as a high-octane blending component of gasoline. This 10 percent ethanol blend, called E10, now comprises most of the gasoline sold in the United States.

Higher-octane fuels allow engines to function at higher compression ratios without engine knock, which improves their efficiency (Leone et al. 2015). The octane level of gasoline has been increased in several ways over the years, but all of the approaches have serious trade-offs—lead is a neurotoxin and was phased out of gasoline in the 1970s, and methyl tertiary butyl ether (MTBE) was used for both oxygen content and octane, but was phased out due to a concern about groundwater contamination in the 1990s (EPA 1999). Ethanol gained a foothold as a source of oxygen in the post-MTBE era and has grown to become an important octane booster today (EPA 2014b; Kitman 2010; Kovarik 1998). Oil refiners can also generate high-octane blending components internally by additional refinery processes, but these have added costs and other trade-offs.

A variety of policy supports favored ethanol, including tax credits, air-quality rules, and the federal Renewable Fuel Standard that required the steadily increasing use of biofuels. The widespread adoption of E10 occurred relatively quickly, starting in 2002 and accelerating in 2005. By 2010, almost all of the gasoline sold in the United States was a 10 percent blend of ethanol. The E10 transition was facilitated by changes in the relative prices of ethanol, gasoline, and alternative potential high-octane blending components and by public policies (Babcock and Fabiosa 2011). Many of the policies that initially supported the scale-up of corn ethanol—including tax credits for blending ethanol and a tariff on imported ethanol—have ended. The most significant federal biofuels policy, the Renewable Fuels Standard, remains in effect, although its implementation has been mired in controversy and uncertainty. But even in the absence of continued policy support,

TIMELINE 2. Changes in the Biofuel Industry

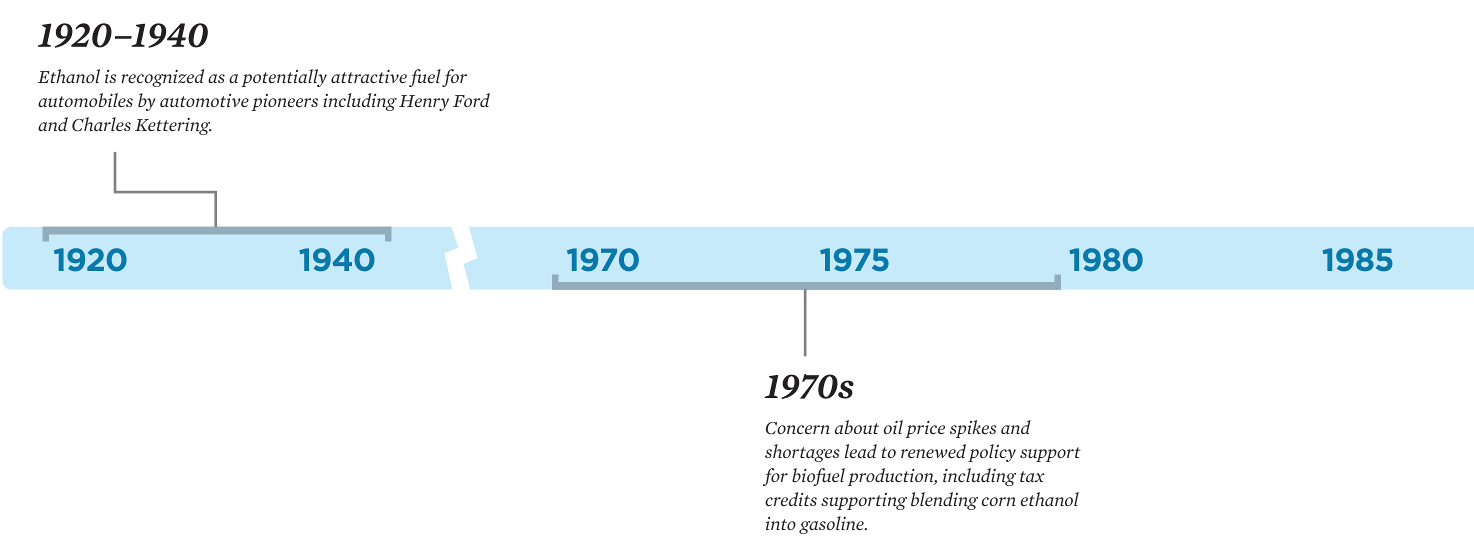
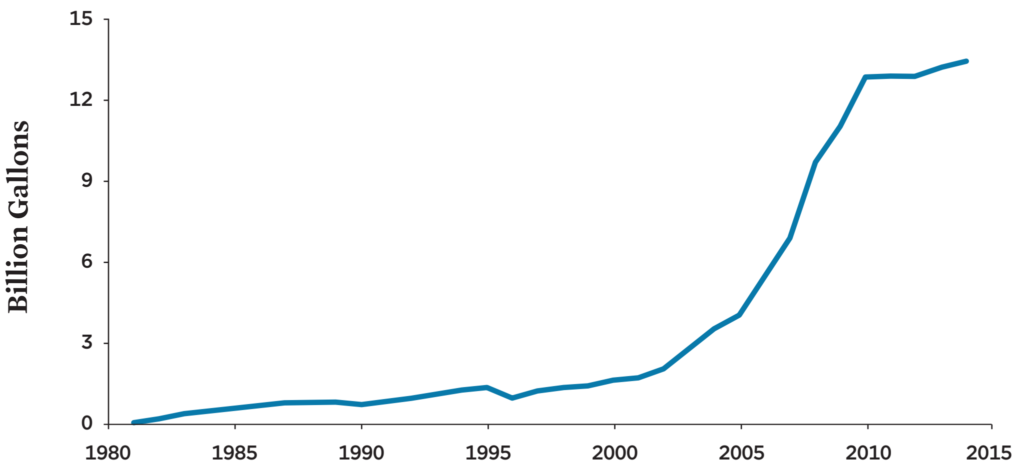


FIGURE 12. U.S. Ethanol Use

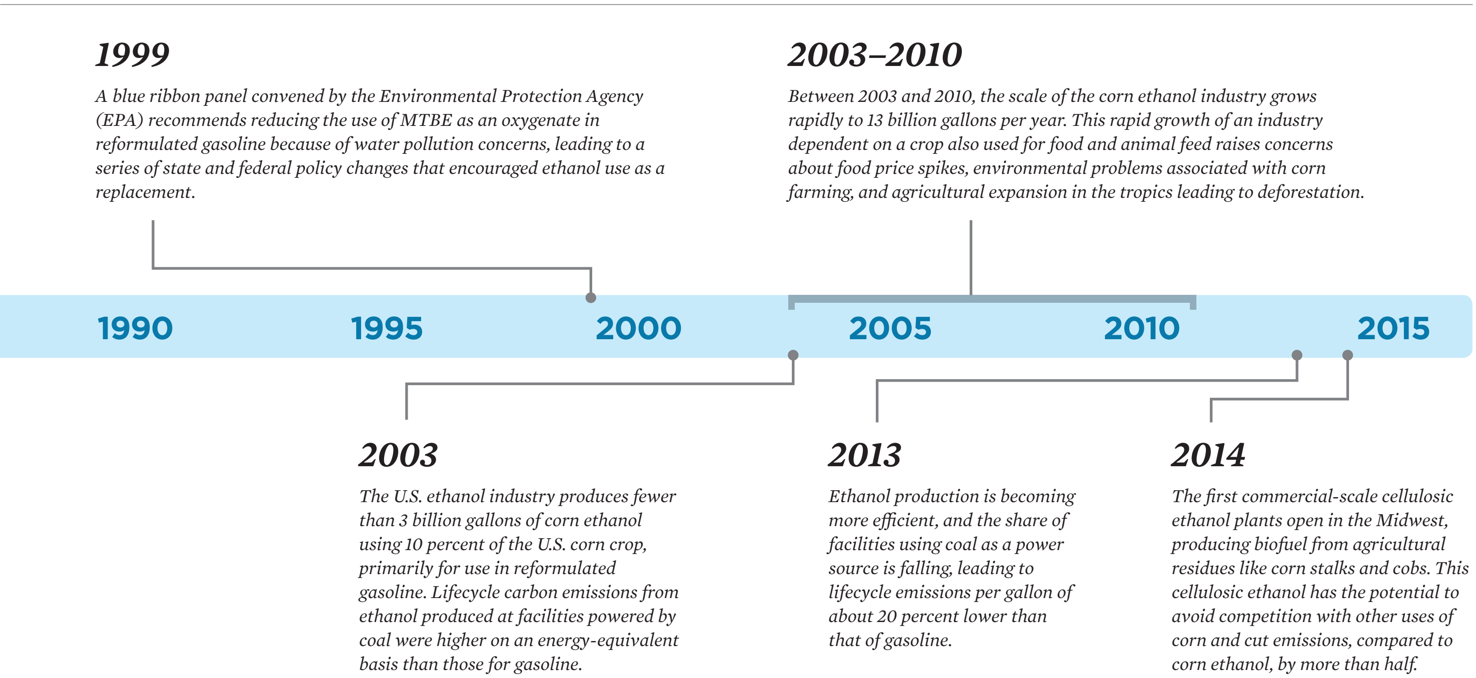


As refiners and fuel distributors switched from using ethanol as an oxygenate in certain markets to using it as a source of octane in E10 nationwide, the quantity of ethanol use increased rapidly. It plateaued in 2010 once most of the gasoline in the U.S. was already being blended with 10 percent ethanol.

SOURCE: EIA 2015B.

economic analyses suggest that ethanol will continue to compete effectively against alternative high-octane gasoline blending components, making it likely that ethanol will continue to be blended into gasoline at 10 percent regardless of changes in policy (Irwin and Good 2015; Babcock and Fabiosa 2011).

With ethanol's role in E10 now effectively a settled matter, the key questions are if, when, and how higher blends of



ethanol will increase ethanol use beyond E10. There are at least three scenarios for increasing ethanol blending, as well as an increasingly important role in the U.S. transportation fuel mix for other types of biofuels. The benefits of expanding the use of ethanol depend on how the ethanol is made (discussed in the next section) and how the ethanol is used.

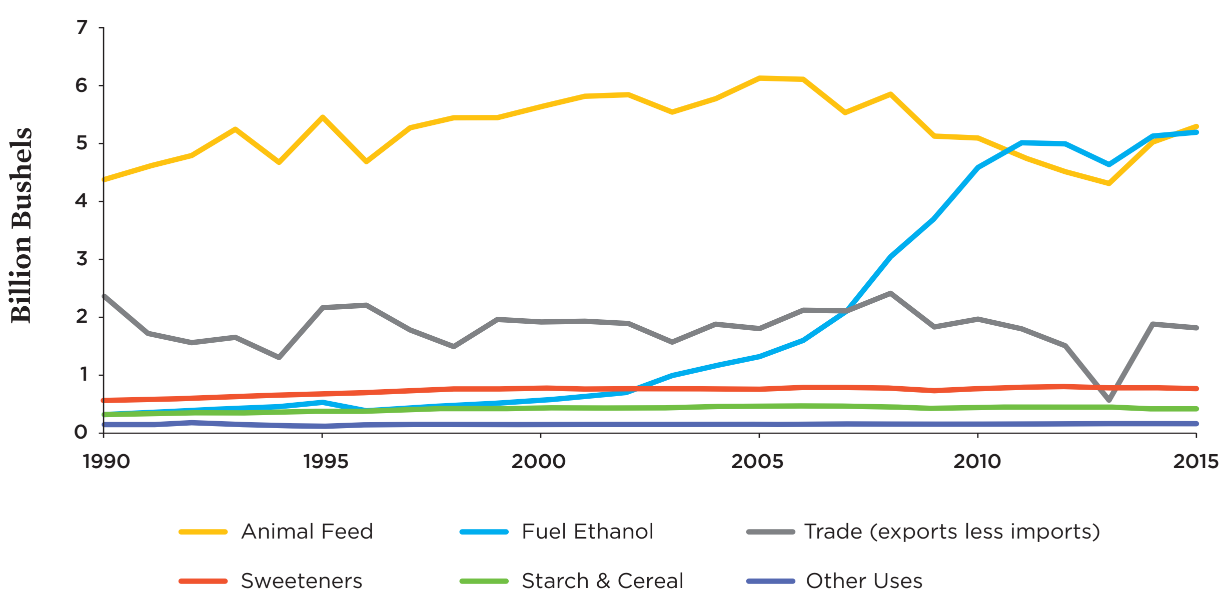
In addition to E10, ethanol is currently sold as a higher blend called E85 (which has an ethanol content between 51 and 85 percent) that is used in specially designed flex-fuel vehicles that accept any ethanol blends, from straight gasoline up to E85. Used to power a flex-fuel vehicle, ethanol is primarily a source of energy, rather than a high-octane blending component. Flex-fuel vehicles running on higher ethanol blends get approximately 25 percent fewer miles to the gallon because of the lower energy content of ethanol; therefore, E85 must be sold at a commensurate discount to induce consumers to choose it (Babcock and Pouliot 2013). E15 (a 15-percent blend of ethanol and gasoline) is also sold on a very limited basis, but can in principle be used in many of the cars on the road today. In the future, mid-level blends (between 20 and 40 percent ethanol) may be used in vehicles optimized to take advantage of the high octane and other properties of these blends. Ethanol used in an optimized vehicle would not have the same reduction in fuel economy as a flex-fuel vehicle operating on E85, which makes it more cost-effective to use ethanol in mid-level blends than as E85 (Leone et al. 2015).

However, at the present time, the infrastructure to distribute blends other than E10 is limited. E85 is available at less than 3 percent of gas stations, most of them concentrated in the Midwest, and E15 and other blends are available at far fewer stations (AFDC 2015; NACS 2015). This presents economic and logistical obstacles to the use of higher ethanol blends. Overcoming these obstacles is technically feasible: Brazil has successfully implemented the distribution of ethanol at several blending levels, demonstrating its feasibility and providing useful lessons. But the necessary changes to cars, fuel retail stations, and fuel regulations will require coordination among automakers, fuel producers, refiners, distributors, and retailers, as well as state and federal regulators. Numerous other parties will also be affected directly or indirectly by associated changes in fuel or agricultural markets, adding political complexity to what is already likely to be a technically challenging process.

Ethanol Production and Related Emissions

Biofuels are distinct from oil and electricity as transportation fuels in that they are not just an increasingly important part

FIGURE 13. Uses of U.S. Corn



The use of corn for producing fuel ethanol has increased significantly since 2000, and now competes with animal feed as the number one use of corn in the United States.

SOURCE: ECONOMIC RESEARCH SERVICE 2015.

of the energy and transportation systems, but are also an important part of the U.S. and global agricultural (and therefore food) system. Moreover, as the scale of demand for biofuels increased, so too has the intensity of agricultural production and the footprint of agriculture, both of which have important implications for climate change and other environmental problems. Below, we consider the problems that the rising production of corn ethanol causes in the U.S. agricultural system. We also consider how the expanded production of biofuels in the United States indirectly affects the global footprint of agriculture and what that means for deforestation and climate change. Lastly, we discuss how these and other factors influence the full lifecycle emissions associated with ethanol production and how better sources of biofuels and cleaner production methods can significantly reduce these lifecycle emissions by 2050.

EXPANDED USE OF CORN FOR FUEL CAUSES SERIOUS PROBLEMS

Ethanol can be created from a wide variety of sources including sugar, starch, biomass, and even natural gas, but the vast majority of the ethanol produced in the United States today is made from corn starch. As corn ethanol use has scaled up in the last decade, so has the demand for corn. Ethanol grew from being a minor use of corn (in 2000 more corn was used to make sweeteners than ethanol) to becoming one of the largest domestic uses of corn. Animal feed is still the largest use of corn on a net basis, since most corn exports are used for animal feed and about 30 percent of the corn grain used for ethanol production is returned to animal feed markets after the starch has been utilized. On a net basis, ethanol accounts for about one-quarter of U.S. corn consumption and has accounted for virtually all growth of corn consumption in the United States since 2000.

The very rapid increase in the utilization of corn for fuel put pressure on markets for corn, particularly because the increase in ethanol use happened rapidly, occurred while global demand for corn and other grain was rising, and coincided with major droughts in important grain-producing regions like Australia in 2008, Russia in 2010, and the U.S. Midwest in 2012. While the expansion of biofuel use was certainly not the only factor affecting food prices, it was one of several important factors leading to significant price increases for corn and other cereal grains (Babcock and Fabiosa 2011). Higher and less stable commodity grain prices had a relatively minor impact on U.S. consumers—mostly reflected in slightly higher prices for meat, eggs, and dairy—but basic commodity prices account for a small share of total U.S. food budgets. The impact was greater for people living in extreme poverty globally, for whom basic cereal crops make up a larger part of the diet and food constitutes a much larger share of families' incomes.

FIGURE 14. Ethanol Use Can Affect Food Prices

Rapid increase in the use of corn for ethanol between 2005 and 2010 together with other factors contributed to a major global spike in food prices. The price shock affected those in poverty most severely, because they rely on cereal grains for a larger share of their diet. The Food and Agriculture Organization (FAO) Food Price Index is a measure of the monthly change in international prices of a basket of food commodities. It consists of the average of five commodity group price indices, weighted with the average export shares of each of the groups for 2000-2004. Prices are in real terms normalized to 100 for 2002–2004.

SOURCE: FAO 2015.

BOX 8.

More Intense Corn Production Is Hard on Land, Water, and Wildlife in the United States

While total cropland acreage in the United States has fallen slightly since the late 1970s, demand for ethanol has increased acreage used for corn at the expense of other crops (Economic Research Service 2015; Nickerson et al. 2011). Corn is especially hard on the environment, intensifying erosion, water pollution, and habitat loss more significantly than other crops. The rising demand for corn ethanol exacerbates these problems.

- **Erosion.** Corn farming leaves land vulnerable to erosion from heavy rains. Increased demand for corn versus other crops has increased the share of land planted to corn and exacerbated existing problems (Cox, Hug, and Bruzelius 2011).
- **Water pollution.** Corn farming as it is typically practiced in the U.S. Midwest includes the intensive application of nitrogen and phosphorous fertilizer. This fertilizer causes serious pollution problems for ground and surface water in the Midwest, and the pollution flows down the Mississippi River to the Gulf of Mexico, where it causes a "dead zone." Corn farming is the largest source of this pollution, and the extra acreage of corn devoted to ethanol production set back efforts to reduce this pollution (UCS 2011b).
- **Habitat loss.** Growing demand for corn has expanded the Corn Belt into states such as North and South Dakota, where it has resulted in the conversion of some of the last remaining grasslands—an important habitat for birds and other wildlife—into cropland (Lark, Salmon, and Gibbs 2015).

Ethanol use in fuel stabilized after 2010. Crop prices started to come down as farmers in the United States and around the world increased corn production to satisfy the additional demand and rebuilt stocks depleted by the simultaneous droughts and ethanol expansion. Recent assessments of the impact of biofuels on food markets have been more nuanced than reports published at the height of the food crisis and have suggested that biofuel expansion can either increase poverty or play a productive role in the food system if biofuels are produced at appropriate scale and supported by more flexible policies that stabilize crop prices and put food needs first (Chakravorty, Hubert, and Ural Marchand 2015; Graziano Da Silva 2015; Ivanic and Martin 2014).

But while corn production can rise to simultaneously address demand for food and fuel, this rising production has costs—both direct environmental impacts of more intense corn production in the United States (see Box 9, p. 32) and indirect impacts as crop production around the world increases to replace the crops made into fuel in the United States, in part at the expense of tropical forests that store a great deal of carbon.

[***The international expansion of agriculture has come through a combination of farming existing land more intensively and expanding the area used for crop production, often at the expense of forests.***]

EXPANDING THE SCALE OF GLOBAL AGRICULTURE HAS CONSEQUENCES FOR FORESTS AND CARBON IN THE TROPICS

The United States is one of the world's largest agricultural exporters, and changes in crop prices and consumption in the United States are felt around the world. Therefore, as the United States has devoted a greater share of its agricultural output to fuel production, other agricultural producers around the world, in particular, those in Brazil, Indonesia, and other tropical countries, have increased production of the crops that might otherwise have been imported from the United States. This international expansion of agriculture has come through a combination of farming existing land more intensively and expanding the area used for crop production, often at the expense of forests, the primary source of new agricultural land in recent decades (Babcock and Iqbal 2014; Gibbs et al. 2010). Deforestation releases huge amounts of carbon stored in trees and soils, causing environmental damage and undermining the carbon benefits of using biofuels in place of fossil fuels.

But deforestation is not an inevitable consequence of rising crop production. While some countries, such as Indonesia, still have massive emissions from the expansion of palm oil plantations at the expense of forests and carbon-rich peat soils, other tropical countries such as Brazil have significantly reduced deforestation even as production of soybeans and beef, for example, have risen rapidly (Boucher et al. 2014). This complex link between increased agricultural production and deforestation has important implications for the lifecycle analysis of biofuels, discussed in Box 9.

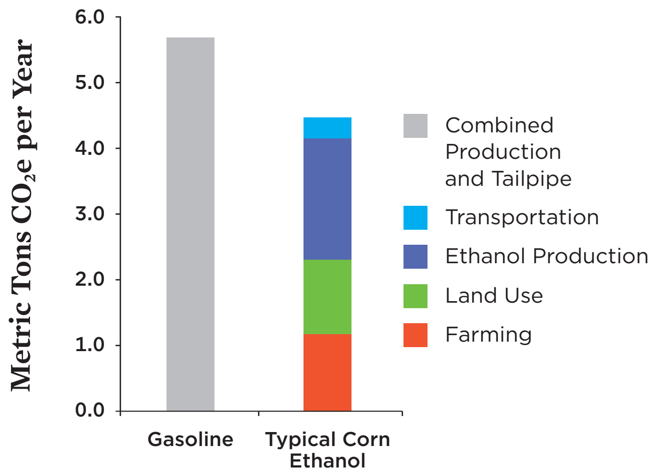
ETHANOL PRODUCTION HAS DIFFERENT EMISSIONS DEPENDING ON CROP CHOICE AND PRODUCTION METHODS

Global warming emissions associated with ethanol production fall into three major categories: 1) those resulting from crop production, including fertilizer production and use; 2) emissions from land use change, an indirect consequence of expanding the footprint of agriculture to accommodate fuel production while continuing to produce food; and 3) the production of ethanol itself, especially emissions from fossil fuels used for power and heat.

Lifecycle analysis is used to calculate these emissions, but it is worth noting that precise lifecycle analysis results depend to some degree on how the analysis is conducted. For example, a lifecycle analysis based on a particular ethanol facility or set of facilities operating today will be conducted differently and produce different results than the lifecycle analysis of a projected industry operating at some future date. Methodological differences and uncertainties are even more significant when the indirect land use emissions are considered (see Box 9). As a consequence, a more meaningful comparison of results is possible within a single lifecycle analysis approach than is possible between different studies. In this report we have drawn most of our comparisons from lifecycle analysis conducted by the California Air Resources Board. This analysis is attractive because of the breadth of fuels compared using a consistent analytical framework and because of the extensive public process of stakeholder engagement and expert consultation (CARB 2015a; CARB 2015c; and associated rulemaking documents). The results are used below, converted into tons of CO_2e emissions associated with driving a 25 mpg car 12,000 miles in a year. As discussed above, ethanol is typically blended with gasoline rather than used by itself, so the conversion is based on the amount of energy in the fuel, although typically this energy is provided by a mixture of gasoline and ethanol. This approach captures ethanol's contribution to the overall fuel blend on an energy-equivalent basis.

- **Emissions from farming.** Growing corn typically involves significant use of chemical fertilizers, which create emissions during their production and use. Other emissions come from fuel to drive tractors and other farm equipment. Together, these add up to about 1.18 tons CO_2e per year for a 25 mpg car—or, as often expressed in the literature, 20 grams (g) CO_2e per megajoule (MJ).
- **Emissions from land use change.** Expanding the use of corn to make ethanol increases the demands on the global agricultural system as a whole. Some of that demand is met by the expansion of cropland onto acres previously occupied by forests or used for other purposes, which can release carbon that has been stored in plants and soils into the atmosphere. Estimating these indirect land use change (ILUC) emissions is complex and subject to considerable uncertainty (see Box 9), but CARB calculates emissions for corn ethanol from ILUC at about 1.14 tons (20 g/MJ).
- **Emissions from ethanol production.** Energy is needed to convert corn into ethanol; in particular, a great deal of heat is needed to distill the ethanol from something like beer, the initial product of fermentation, into the pure ethanol (200 proof) that is blended into gasoline. A typical ethanol facility today uses natural gas as a source of heat and has production emissions of 1.85 tons (32 g/MJ), but these emissions vary a great deal from one facility to another depending on the energy source and efficiency of the operation. Some older facilities use coal for heat, which can increase production emissions by as much as

FIGURE 15. Ethanol Is Cleaner than Gasoline



Major components of the lifecycle emissions for ethanol include farming, land use change, and ethanol production.

Note: TThe global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). This is compared with the energy equivalent amount of ethanol.

SOURCE: CARB 2015A.

BOX 9.

Emissions from Indirect Land Use Change

Expanding the scale of agricultural production to produce both food and increasing amounts of fuel has important implications for the size and intensity of the global agricultural system. When cropland expands at the expense of other non-crop land uses like pastures, grasslands, and forests, carbon sequestered in trees and soils is released into the atmosphere. These land use changes are not generally the result of directly converting forests to the crops used to make biofuels, but are linked to expanded biofuels production indirectly through global markets for agricultural commodities. This phenomenon has come to be called indirect land use change (ILUC), and it is both technically challenging and hotly contested by advocates for or against biofuels. Initial estimates of ILUC by Searchinger et al. were so high that those authors concluded that using crops for fuel was, under almost any circumstance, far more polluting than gasoline (2008).

However, the link between shifting Midwestern corn from feed to fuel markets and deforestation across the globe is complex and depends on many factors. Since Searchinger's initial 2008 paper, academic researchers and environmental regulators around the world have been using a variety of global agricultural economic models to quantify these connections and estimate ILUC emissions. Estimates from more recent analyses have been lower than those in the initial Searchinger et. al study, but remain subject to a high degree of uncertainty. By its nature, ILUC analysis is technically challenging and produces results that depend on detailed data for land use in the major agricultural areas around the world, soil carbon stocks in forests and other ecosystems, and specific economic parameters (called elasticities). Results also depend upon model structure and even value judgements such as how the analysis treats reduced food consumption associated with crop price increases (Plevin et al. 2015).

Taken as a whole, the literature provides strong evidence that land use change is a significant component of the emissions of crop-based biofuels, although not so high as to make all crop-based biofuels necessarily worse than fossil fuels, as suggested by the initial Searchinger et al. study. Using land to grow fuel is neither always a climate disaster nor always a climate solution, but has practical limits and environmental consequences that must be carefully balanced against other considerations (Martin 2015).

one ton, while other facilities use more efficient processes or lower-carbon sources of fuel, such as biomethane, which can reduce emissions by a similar amount.

The Future of Biofuels

Biofuels in general, and corn ethanol in particular, have been put forward for decades as a solution to oil shortages and more recently offered as a way to reduce carbon pollution from cars. Corn ethanol also promised to create stronger demand and raise prices for corn at a time when corn prices were very low. Since 2000, the United States has made remarkable progress on many of these goals, so much so that new challenges have emerged on several fronts, including the need to:

- balance the demand for biofuels with the competing uses of crops and land, including food production and forest protection;
- avoid environmental problems caused by more intensive farming of existing agricultural land; and
- address distribution and marketing obstacles to the expanded use of advanced biofuels at levels higher than our current vehicles and infrastructure were designed to easily accommodate.

While most biofuels in use today are made from corn starch, sugar, and vegetable oil, biofuels can be made from non-food sources including various types of wastes and more environmentally friendly crops.

FUELS MADE FROM WASTES, RESIDUES, AND AGRICULTURAL BYPRODUCTS

Making biofuels from wastes, agricultural residues, and agricultural byproducts avoids the need to expand crop production and the associated emissions and also reduces land use change. Thus, these biofuels can have low total lifecycle global warming emissions. Wastes come from many different sources including food production, town and city residents (municipal solid waste and wastewater), industry, and agriculture (e.g., manure). Agricultural residues include corn stalks, wheat straw, and forest residues like slash piles of branches left by logging operations. Agricultural byproducts like inedible corn oil or animal fats can also be made into fuels. Some wastes and byproducts used to make biofuel today include:

- methane gas collected from landfills, manure digesters, and water-treatment facilities, which can power heavy-duty vehicles (UCS 2015b); and
- used cooking oils and fats that can be made into biodiesel.

Other technologies are coming on line now, or will in the near future, that open up new pathways to make clean fuels from other waste streams, including:

- agricultural residues like corn stalks that can be made into ethanol at cellulosic ethanol facilities; and
- municipal or industrial wastes that can be used to make ethanol or other biofuels.

One of the largest potential sources of agricultural residues in the United States is corn stover: corn stalks, husks, and cobs. Three commercial-scale facilities producing cellulosic ethanol from corn stover are starting up in the Midwest. A recent UCS analysis found that up to 155 million tons of agricultural residues can be available to make biofuel by 2030, enough to make more than 12 billion gallons of cellulosic ethanol; this would almost double ethanol production in the United States without the cultivation of any additional cropland (UCS 2014a). Using agricultural residues for energy, however, requires changes to agricultural practices and must be limited to a level that protects the soil from erosion and prevents the loss of carbon from the soil (English et al. 2013). Excessive or poorly managed residue removal can lead to reduced soil carbon, which would lower the climate benefits of the fuel and the productivity of the agricultural land (Murphy and Kendall 2015). But with appropriate agricultural practices,

BOX 10.

Cellulosic Biofuels

The process of making starch or sugar into ethanol has been known for millennia, but new cellulosic biofuel facilities are making ethanol from the tough fibrous parts of plants' cell walls that human beings cannot digest. These fibers are composed of cellulose, hemicellulose, and lignin. Cellulose and hemicellulose, like starch, are long chains composed of sugars, except that in cellulosic biomass the sugars are bound more tightly than in starch, which make them more difficult to break down and digest. Bacteria in the digestive tract of ruminant animals like cows can digest these tough fibrous parts of plants, and recent developments in biotechnology are creating industrial systems of enzymes that can break down cellulosic material into sugars that are subsequently fermented into ethanol. Lignin, another component of cellulosic biomass, can be burned to generate the heat and power needed to run the fermentation and distillation processes, reducing a facility's need for natural gas or sources of heat and power and thereby reducing the emissions associated with the biofuel production process.


Extension Farm Energy Community of Practice/Creative Commons (Flickr)

After corn grain is harvested, the corn stover (stalks, husks, and cobs) is left behind. Some of this material must be left behind to protect the soil, but in many cases some of it can be used to make ethanol. Here, corn stover is seen baled for harvest.

BOX 11.

Too Much Waste-based Biofuel Can Turn a Solution into a Problem

Waste-based biofuels reduce the environmental impact of fuel production but are by definition a niche market, creating a new use for a waste or a higher use for a low-value product than previously existed. If waste-based biofuels expand too much and outgrow their niche, their benefits can be reduced or they can create other problems. For example, if a farmer has a sustainable management plan that benefits from removing a portion of her corn stover, then using that stover for fuel is an opportunity for the farmer and can increase clean-fuel production. But if too much stover is removed from a field, the harm to the environment undermines the benefit. Another example is biodiesel made from used cooking oil. Most of the potential waste-based biodiesel feedstocks have at least some existing uses; for example, used cooking oil or animal fat is also often used as animal feed or to make soaps and detergents. Making biodiesel from these feedstocks creates additional opportunities to find good uses for these low-value products, but if demand for waste-based biodiesel outstrips the available supply, existing users of these substances will need substitutes, and some may even switch to using new vegetable oil. Once this shift begins, further expansion of waste-based biodiesel is no longer avoiding expanded production of vegetable oil, and the theoretical benefits are not matched in the real world. The scale of waste-based biofuels production needs to be matched to the sustainable supply of waste feedstocks to deliver the maximum potential benefits.

such as reduced plowing and the planting of cover crops, corn stover can produce ethanol with low net carbon emissions (Pratt et al. 2014).

Technologies are also being developed to turn waste gases from steel mills into ethanol or ordinary household garbage into jet fuel. Turning trash into valuable clean fuels is an important opportunity to expand the production of clean fuels.

SMART AGRICULTURE, BETTER CROPS, AND MULTI-FUNCTIONAL LANDSCAPES

The most promising opportunity to scale up biofuels comes from cellulosic biofuels made from perennial crops that not only can produce high yields of very low-carbon fuels, but can simultaneously address existing environmental problems with the agricultural sector.

Perennial crops are attractive as a source of biofuels because of their potential to produce high yields of very low-carbon biofuel on land that is less suitable for other crops (Dwivedi et al. 2015). Moreover, perennial crops offer tremendous environmental advantages over annual crops because they are planted once every 5 to 10 years (or more) and harvested many times. By providing year-round cover and deep root systems these crops reduce erosion and water pollution, build soil carbon, enhance biodiversity (creating habitat for pollinators, birds, and other species), and provide many other valuable ecosystem services (Liebman and Schulte 2015; Asbjornsen et al. 2014; Werling et al. 2014; Smith et al. 2013). Some land is relatively more suitable for perennials than corn in terms of both yield potential and environmental performance. When the specific part of the landscape that offers the greatest benefits can be targeted, perennials can enhance the overall sustainability of the agricultural system while expanding production of low-carbon biofuel. While it will take time to develop an efficient large-scale supply chain for perennial grasses, they offer the potential for up to 400 million tons of sustainable low-carbon biomass per year by 2030, enough to produce more than 30 billion gallons of ethanol, more than twice as much as corn ethanol produced in 2014 (UCS 2012b).

Perennial crops are attractive as a source of biofuels because of their potential to produce high yields of very low-carbon biofuel on land that is less suitable for other crops.

Perennial crops offer the opportunity to simultaneously cut oil use and improve agriculture, but realizing this dual benefit will require smart policy coordination that recognizes and supports both benefits. Shifting to perennial crops has costs for farmers, while the environmental benefits of such a shift, such as reduced water pollution and greater carbon sequestration, accrue to society at large; therefore, time and effective policy support will be necessary to realize potential benefits (Housh, Khanna, and Cai 2015). By expanding the production of biofuels made from environmentally preferable perennial crops that function as a complimentary part of the agricultural system—rather than exacerbating the harsh tradeoffs associated with corn ethanol—we can ultimately increase the potential scale of low-carbon biofuel that can cut oil use and global warming emissions throughout the U.S. transportation sector.

Conclusions and Recommendations

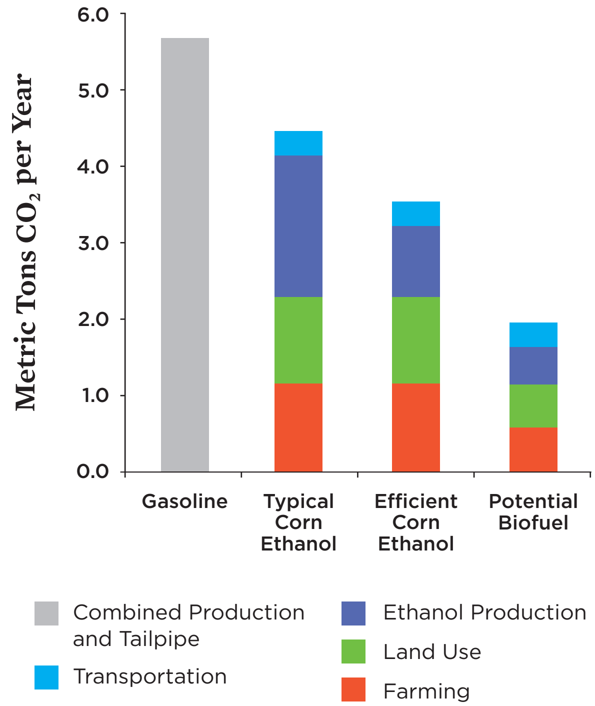
While today's biofuels offer limited benefits and significant challenges, the potential for cleaner biofuels is substantial. Ethanol is cutting oil use and emissions as part of gasoline blends today, and over the long term biofuels are especially valuable for parts of the transportation sector that are particularly challenging to power with electricity, such as avaiation. Biofuels are cleaner now than they were 10 years ago, and they can become much cleaner still.

There are already many types of biofuels in production today, and many more are in development. In this chapter, we focused primarily on three types of ethanol that exemplify important trade offs: 1) corn ethanol representing the progress and problems with first-generation biofuels made from major commodity food crops; 2) corn stover ethanol representing the next generation of biofuels made from waste materials and agricultural residues; and 3) cellulosic ethanol made from perennial grasses representing the potential for environmentally friendly crops that also enhance the sustainability of the agricultural system. Rather than offering speculative estimates of potential future emissions for each source of biofuel, we conclude by considering the three major sources of emissions from their production—agriculture, land use change, and biorefineries—which provides a useful framework within which to understand opportunities to improve these fuels.

EMISSIONS FROM FOSSIL FUEL USED IN BIOFUELS PRODUCTION MUST BE REDUCED

One of the key reasons for corn ethanol's limited climate benefits is the extensive use of fossil fuels in the process of making it. Smart engineering can reduce or eliminate these fossil inputs in a variety of ways, paving the way for cleaner biofuels. Lower-carbon fuel choices and more efficient processes at biorefineries can reduce emissions from biofuel production. The most efficient corn ethanol facilities in the Midwest have reduced production emissions by as much as 50 percent by adopting advanced technologies including using combined heat and power systems, using biogas from anaerobic digesters as a source of process heat, and co-locating with feed lots, which eliminates the need to dry the coproduct of ethanol production before feeding it to livestock (CARB 2015d; EPA 2010).

FIGURE 16. Efficiency and Non-food-based Feedstocks Can Make Biofuels Even Cleaner



While improvements have been made to ethanol production, the potential exists to reduce emissions throughout the entire lifecycle of biofuels. Emissions reduction strategies include using biogas from anaerobic digesters as a source of process heat and switching from corn to wastes, residues, or perennial grasses.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). This is compared with the energy equivalent amount of ethanol.

SOURCE: CARB 2015A; CARB 2015D; UCS ANALYSIS.

A byproduct of cellulosic biofuels is lignin, which can be burned to generate heat, completely replacing the fossil fuels needed to power the biofuel production process and even providing extra heat or electricity that can offset fossil fuel use at adjacent biorefineries or put power onto the grid. The reduced use of fossil fuels for heat and power is a major reason that cellulosic ethanol generally has much lower carbon emissions than corn ethanol.

As the biofuels industry matures, it will have substantial additional opportunities to cut carbon emissions from biofuel production. Like other large-scale industrial process, corn ethanol production has become more efficient as it scaled up over the last decade; the industry has taken advantage of countless small opportunities to improve, from more efficient enzymes, to reduced energy and water consumption, to a more diversified product portfolio optimized for local markets. The most efficient corn ethanol facilities have already cut production emissions by half, and with the potential for further optimization and the use of lignin as a process fuel, significant additional progress is achievable. In our judgement, emissions at biorefineries can realistically be reduced to an average of 0.5 ton per 25 mpg car by 2050.

AGRICULTURAL EMISSIONS CAN BE REDUCED THROUGH BETTER FARMING AND CROPS

Emissions from the cultivation of crops are a significant part of the total emissions of biofuels. While it is difficult to draw meaningful generalizations across a wide variety of crops, soils, and practices, there are significant opportunities to reduce emissions from agriculture using a wide range of strategies. The largest share of biofuels' emissions are from chemical fertilizer production and use, and improved crop varieties and crop rotations can reduce or eliminate the need for these fertilizers. While it is unrealistic to expect the total elimination of fertilizer use or emissions, to say nothing of emissions from tractors and combines, we expect that further improvements between now and 2050 could reduce agricultural average emissions associated with biofuel production by half.

EMISSIONS FROM LAND USE CHANGE MUST BE REDUCED

The impact of biofuels on land use change emissions is challenging to quantify now, and even more difficult to predict far out into the future. However, some general conclusions are clear. First, fertile land is a scarce resource with multiple competing uses, so using more of it to produce fuel means using less of it for other purposes. Recent analysis has focused primarily on how much expanded biofuels production contributes to emissions from deforestation. Several decades from now, it may be more appropriate to consider how biofuels production compares to using more land for growing forests that sequester carbon. In either case, there is a significant opportunity cost to using land for biofuels production that cannot be ignored in considering the climate costs and benefits of biofuels. However, land use emissions can be reduced.

Increasing the productivity of fuel production on a given parcel of land directly reduces land use change emissions per unit of energy, since the energy obtained increases while the land use stays the same. Therefore, emissions per unit of fuel production can be reduced through achieving higher crop yields, harvesting multiple crops per year, using a portion of the crop residues, or growing high-yielding perennial crops. Also, not all land is equally suitable for all crops. Crops that are adapted to less fertile land will reduce competition with other crops and associated land use change. Finally, the way in which biofuel crops are integrated into our agricultural system can make a big difference, with strategic integration of perennials in cropping systems providing the opportunity to increase production of cellulosic biomass with only minor reductions of conventional crop production while improving environmental outcomes at the same time.

> ***[We expect that further improvements could reduce agricultural average emissions associated with biofuel production by half by 2050.]***

Taken together, the potential exists to reduce the land-use emissions of biofuels by improving yield and efficiency and targeting the most appropriate crops and land. In our judgement, with well-considered policy support, land use emissions per unit of fuel can be cut in half by 2050.

TRANSPORTATION EMISSIONS ARE LIKELY TO REMAIN ROUGHLY CONSTANT

Moving crops and fuels around the country is a small but significant part of the biofuels emissions profile. We do not anticipate significant changes in these emissions because, while operational efficiencies and scale can certainly reduce emissions per ton, biomass-based fuels may require more transportation of bulky feedstocks like corn stover than is currently the case for grain-based fuels like corn ethanol.

BIOFUELS CAN GET MUCH CLEANER, BUT THERE ARE LIMITS

Lifecycle assessments for potential future cellulosic biofuel production are often more optimistic than our projection; some even suggest that biofuels can have net negative emissions, reducing carbon in the atmosphere. These results are a function of credits added to the lifecycle analysis for activities external to the fuel production process such as cogeneration of power, soil carbon sequestration, or other factors. While these credits may be reasonable in a particular lifecycle analysis framework, they can obscure the fact that biofuels will continue to have real emissions. Farming and fuel production generate emissions that can be substantially reduced but cannot realistically be entirely eliminated. Using land for fuel production has an opportunity cost that can be reduced by strategic integration of biofuel feedstocks into the agricultural system at an appropriate scale, but this cost also cannot be entirely eliminated.[2]

Biofuels have the potential to be much less polluting than they are today, to scale up significantly, and to play a more constructive role in the U.S. agricultural system. But realizing this potential is by no means automatic, and expanding production of corn ethanol will deliver limited global warming emissions reductions at mounting costs in other areas. However, with innovative technology, significant investment, and smart policies for both transportation fuel and agriculture, biofuels can be a core element of our clean-fuel future.

[Biofuels have the potential to be much less polluting than they are today and to play a more constructive role in the U.S. agricultural system.]

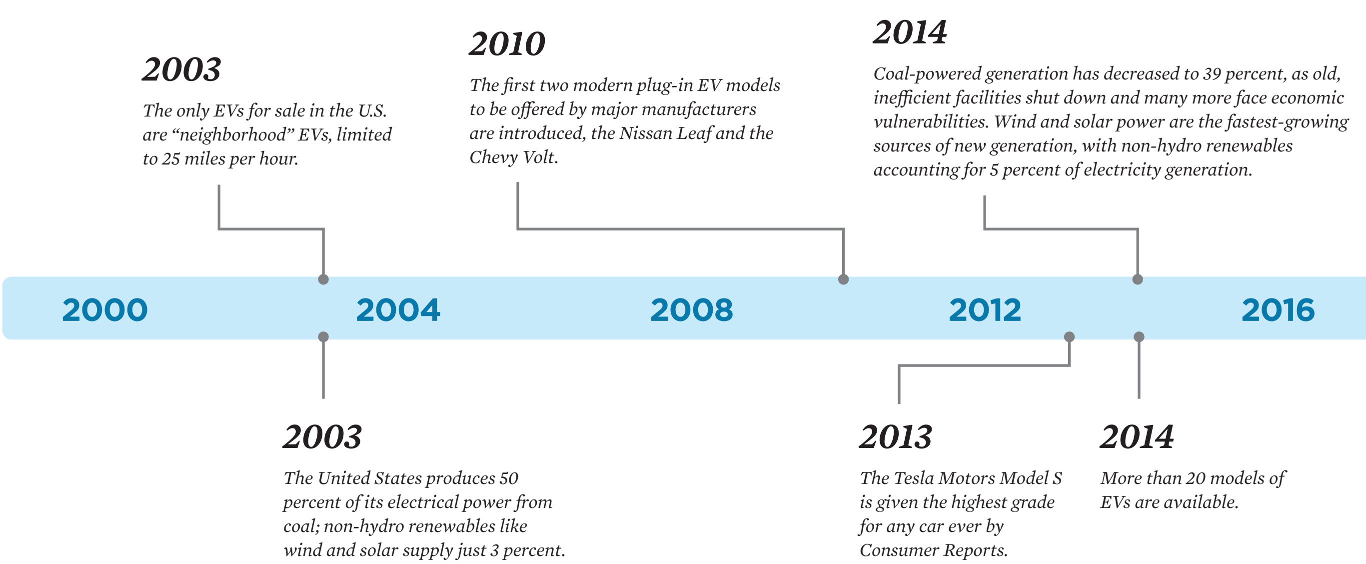
2 *We have not considered credits for carbon sequestration in soil carbon, biochar, or geologic sequestration in our forecast. These strategies can lead to dramatically lower or even negative lifecycle emissions. Carbon sequestration has potential application not just in conjunction with biofuels but for electricity and oil as well. Carbon sequestration is potentially very significant, but it raises complex accounting questions that are beyond the scope of this report.*

Electricity

The clean transportation system of the future will be powered significantly by electricity. Major studies have found that a large-scale transition to EVs powered by batteries or fuel cells is required to achieve the deep emissions reductions necessary by mid-century to avoid the worst effects of climate change (Williams et al. 2014; Yang et al. 2014; NRC 2013). Battery EVs have no tailpipe emissions; instead the emissions associated with using them come primarily from the source of power used to charge the batteries. EVs powered by renewable sources of energy provide major reductions in global warming emissions as well as benefits to air quality and public health. EVs are on the road now, delivering climate benefits today, but moving to cleaner sources of electricity is needed to deliver the full promise of transportation electrification.

In this chapter, we discuss the use of electricity as a transportation fuel, how electricity is produced today around the country, and how the global warming emissions of charging an EV in different parts of the country compare to fueling a car with gasoline. We consider the future of

TIMELINE 3. Changes in the Electricity Industry



Vehicles powered by electricity produce no tailpipe emissions, but many sources of electricity do create global warming pollution at the power plant. Replacing coal-fired electricity generation with renewable energy cuts the emissions associated with charging an EV significantly.

electricity generation, highlighting the importance of renewable energy to maximize the benefits of electric transportation. UCS has published extensively on EVs and electricity generation, and we highlight key conclusions of that work in Boxes 12 (p. 40) and 13 (p. 43), where interested readers can find more in-depth analysis.

The Use of Electricity as a Transportation Fuel

Sales of modern plug-in on-road passenger vehicles only really started at the end of 2010, with the introduction of the 2011 models of the Nissan Leaf and the Chevy Volt (a plug-in hybrid capable of running solely on electricity for 35 miles and then running on gasoline until it can be recharged). Since then, EV sales have been growing rapidly, with more than 340,000 vehicles sold between December 2010 and June 2015, and more than 20 models offered by more than a dozen different brands (InsideEVs.com 2015).

Electricity has been used to power vehicles of various types for a long time in applications where electric power was available (such as subways and some rail lines) or weight and range were not a constraint (such as forklifts and golf carts). But electric passenger vehicles have been held back by the poor performance of available battery technology. Recent technical progress with lithium batteries has allowed the development of plug-in electric automobiles (both battery electric and plug-in hybrids) that compete very favorably against gasoline vehicles, epitomized by the Tesla Model S, which in 2013 received the highest score for a car ever by Consumer Reports, a well-regarded independent consumer testing and rating service that has been testing cars since 1936 (Consumer Reports 2013).

> ***Recent technical progress with lithium batteries has allowed the development of plug-in electric automobiles that compete very favorably against gasoline vehicles.***

Lithium batteries are still relatively expensive, and long-range EVs like the Tesla Model S compete only in the luxury segment of the car marketplace. Less expensive vehicles with more limited ranges, like the battery electric Nissan Leaf and BMW i3 and plug-in HEVs like the Chevy Volt, are available across a broad price range, and technical progress and large-scale manufacturing experience with batteries and electronics are bringing costs down quickly. In particular, a 2015 study found that between 2007 and 2014, costs per kilowatt-hour of batteries have fallen from above $1,000 to around $410, with leading automotive battery manufactures producing batteries with costs as low as $300 (a Nissan Leaf has a 24-kilowatt-hour battery) (Nykvist and Nilsson 2015).

The Emissions of Electricity Production

Driving an EV releases no tailpipe emissions and consumes no gasoline, but this does not mean these cars are responsible for zero carbon emissions. To understand the climate impact of EVs, the source of the electricity used to charge the batteries must be considered as well.

> ***When the electricity used to power an EV comes from renewable resources such as wind or solar, the vehicle can operate nearly emissions-free.***

Sources of electricity vary in their global warming emissions. When the electricity used to power an EV comes from renewable resources such as wind or solar power, the vehicle

BOX 12.

The Inherent Efficiency of Electric Transportation

Comparing electricity to a fuel used in an internal combustion engine (like gasoline or ethanol) on the basis of energy content is potentially misleading. Electric drive is inherently very efficient; therefore, EVs go much farther on a given amount of energy than cars powered by internal combustion engines. For example, a relatively efficient full-sized gasoline-powered vehicle gets about 30 mpg of gasoline. Using the same amount of energy (that of one gallon of gasoline), a Tesla Model S can drive 95 miles and a Nissan Leaf can drive 114 miles (DOE 2015). Based on a comparison of gasoline-powered vehicles and EVs, CARB determined that, on average, EVs can travel more than three times farther using the same amount of energy than a comparable gasoline-powered vehicle, and it adopted an energy-economy ratio of 3.4 for light-duty EVs to allow an appropriate comparison of these different fuels as part of its Low Carbon Fuel Standard (CARB 2015c; CARB 2011; CARB 2009). The same approach and energy-economy ratio of 3.4 has been applied to emissions calculations for various sources of electricity in this report.

The progress of electrification in the U.S. vehicle fleet is more significant than the number of EVs on the road would suggest. Gasoline-powered vehicles are also becoming steadily more electrified—quite visibly in the case of HEVs and in more subtle ways in conventional gasoline-powered vehicles. Even though these vehicles are never plugged in, electrification is bringing significant efficiency gains. Hybrid vehicles like the Toyota Prius use a combination of gasoline and electricity generated on board the vehicle to achieve much greater efficiency than that of conventional vehicles. In the 2015 Honda Accord hybrid, the propulsion system has been largely replaced with a pair of electric motors, one of which propels the car while the other acts as a generator making electricity from a gasoline engine. The hybrid version of the Accord is still powered entirely with gasoline and has no plug to supply electric power from the grid, yet by dispensing with the complex mechanical transmission and relying on electric drive more heavily, the hybrid version goes more than 30 percent farther on a gallon of gas than the non-hybrid versions (DOE 2015).

The improved efficiency of these hybrid systems demonstrates that even when the fuel source is the same gasoline as usual, running the car on electric power dramatically improves efficiency, cuts oil use, and in so doing reduces global warming pollution.

Even within the workings of more conventional gasoline-powered vehicles, functions that were previously provided by mechanical linkages are being replaced by electric motors, reducing associated drivetrain losses and contributing incremental improvements in fuel efficiency. For example, components such as power steering systems and air-conditioning pumps are switching from being mechanically driven to electrically driven. Mild hybrids, which add stop-start function and regenerative braking, improve efficiency by around 10 percent (Bilgin et al. 2015). This inherent efficiency of electric versus mechanical systems is a fundamental reason that clean transportation is increasingly electric. But while greater electrification of gasoline-powered vehicles is reducing gasoline use and pollution, the replacement of the internal combustion engine with an electric motor—especially if powered by clean electricity—offers much larger gains.

can operate nearly emissions free. This potential is demonstrated today by some individuals who are pairing rooftop solar electricity systems with their EV ownership. For most EV owners, however, their cars will be charged using electricity from their region's electricity grid.

In the United States as a whole, coal is the largest source of electricity generation. But its share has been falling steadily from a high of 57 percent in the late 1980s to less than 40 percent in 2014. Coal's share of CO_2 emissions is much higher than its share of generation, because electricity generated with coal produces about twice as much carbon pollution per unit of energy generation as electricity generated with natural gas. Coal is being replaced by natural gas and also renewable energy sources. Emissions from natural gas, while lower than coal, are still significant. Most renewable sources of energy emit no global warming gases at all when producing electricity. Currently, renewables account for a small share of the U.S. power supply (non-hydro renewables accounted for about 5 percent in 2014), but their share is growing rapidly.

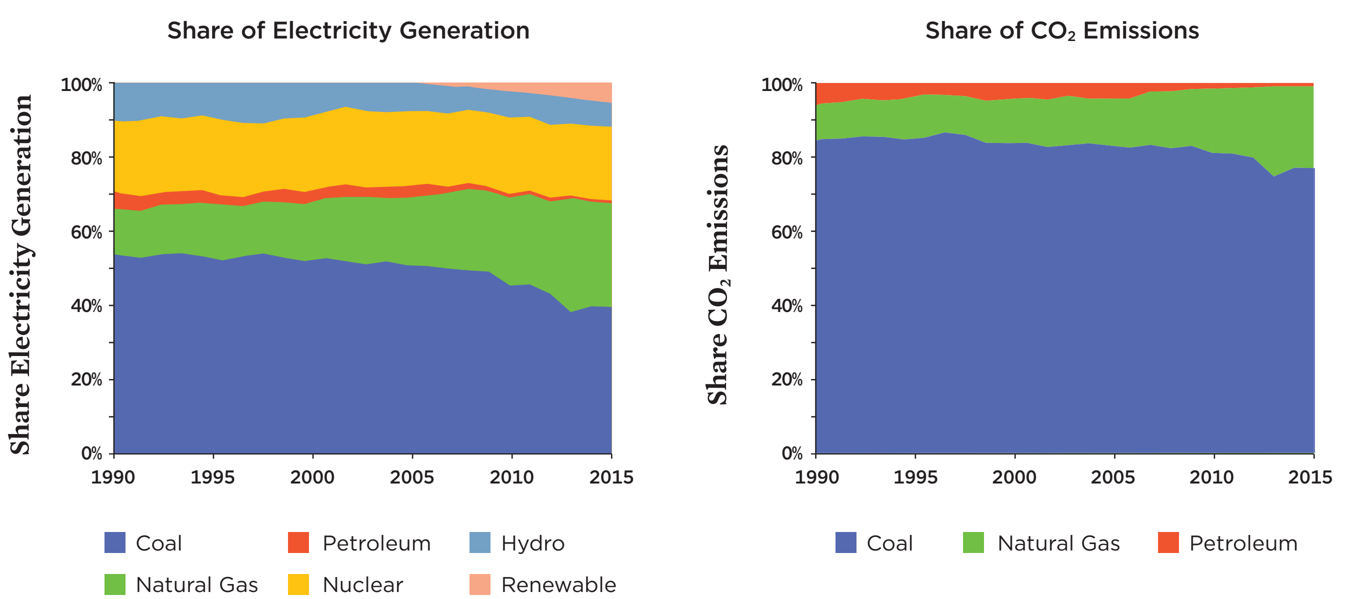
National totals, however, mask regional differences in the mix of fuels used to generate electricity, and these differences result in significant variations in global warming emissions per unit of electricity. Correspondingly, the global warming emissions of driving an EV varies according to the region's power plants' mix of fuels.

Some regions rely on coal for the lion's share of their electricity generation and therefore have higher-than-average emissions per unit of electricity generation. For example, in the grid region called the Western Electricity Coordinating Council (WECC)/Rockies, which covers Colorado and parts of several neighboring states, coal provides 70 percent of the power, 17 percent comes from natural gas, and 13 percent comes from wind and hydropower; as a result, emissions per unit of electricity generation are 60 percent higher than the national average.

Other regions have a cleaner mix and lower emissions. Two western regions have emissions per unit of generation about 40 percent cleaner than the national average, but they achieve these results with very different mix of energy sources. The Pacific Northwest, with its massive dams supplying hydropower, gets more than 60 percent of its power from low-carbon sources, principally hydro at 52 percent, with the remainder coming from coal (25 percent), natural gas (11 percent), wind (7 percent), and other sources. California has similar emissions per unit of energy as the Northwest, but a very different grid mix, with less hydropower but also less coal. Where an EV gets charged makes a big difference (see Figure 18, p. 42).

These different regional grid mixes have a significant impact on the emissions associated with driving an EV. Figure 19 (p. 43) compares the global warming emissions from driving a

FIGURE 17. Coal Dominates Emissions from Electricity



Coal is the largest source of electricity generation, and produces more emissions than any other source, almost twice as much as natural gas per unit of energy generation.

SOURCE: EIA 2015B.

25 mpg car 12,000 miles to driving the same distance in a battery EV that is charged in the different grid regions. Charging an EV on the average U.S. grid has emissions of about half those of a gasoline-powered car, while in regions with relatively cleaner grids, the emissions are just one-third of those of a gasoline-powered car. Even in regions with a relatively dirty grid, like Colorado, charging an electric car is cleaner than fueling a typical gasoline-powered car.

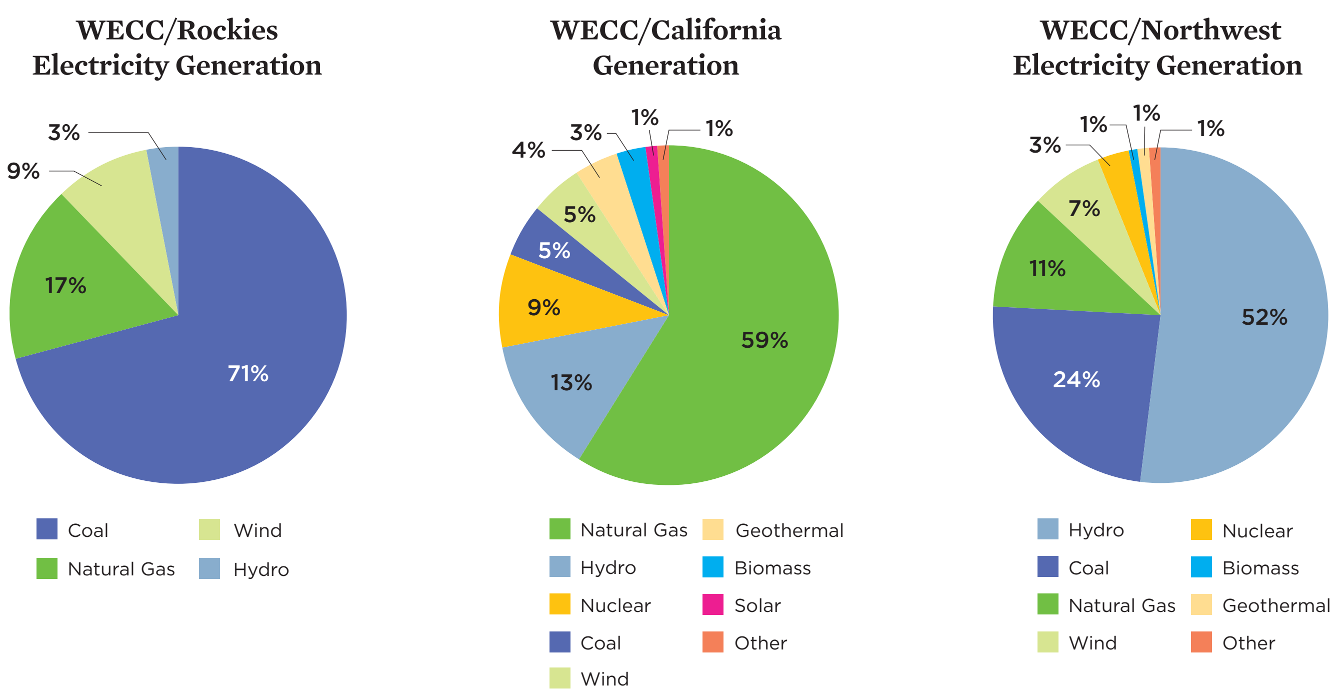
A recent UCS study of the lifecycle emissions of an EV, described in Box 13, highlights the regional variation and also considers the emissions differences associated with the production of battery EVs compared to gasoline-powered cars.

The Future of Electricity

While electricity is overall cleaner than oil, the emissions produced by electricity can be lessened further by shifting electricity generation from fossil fuel sources, such as coal, to renewable sources, such as wind.

> ***Charging an EV on the average U.S. grid has emissions of about half those of a gasoline-powered car, while in regions with relatively cleaner grids, the emissions are just one-third of those of a gasoline-powered car.***

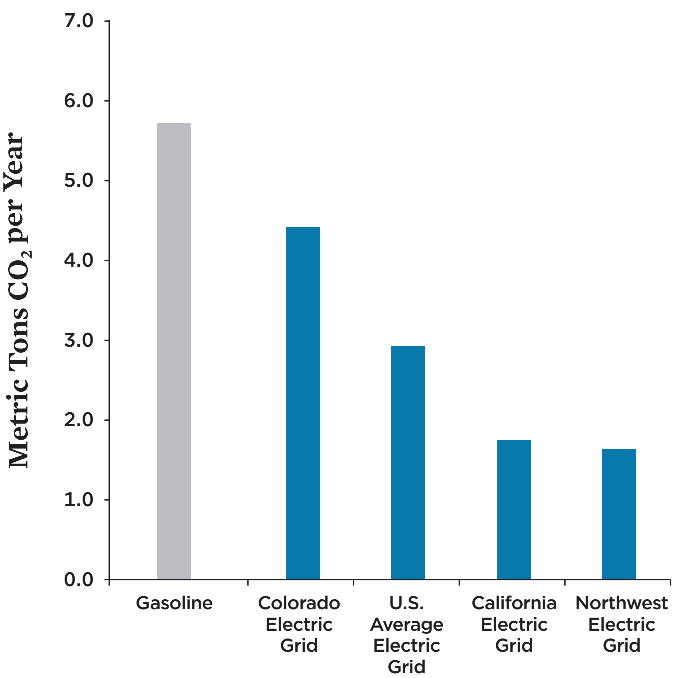
FIGURE 18. Regional Electricity Grid Energy Sources



Electricity is created from a variety of energy sources—including coal, natural gas, and renewable energy—and the mix of sources varies in different regions of the United States. This means that an electric vehicle charged in a region using a greater share of renewable energy to create electricity is cleaner than one charged in a region where the electricity is generated primarily from burning coal.

SOURCE: NEALER, REICHMUTH, AND ANAIR 2015.

FIGURE 19. Electricity Is Cleaner than Gasoline



Cars that run on gasoline put out more emissions than even electric cars charged in areas where coal is the biggest source of electricity. When electricity is created from cleaner sources, emissions are reduced further.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). For electricity the emissions represent the production of fuel (e.g., coal, natural gas) and consumption by power plants to generate a quantity of electricity needed for a similar vehicle traveling the same distance adjusted for electric drive efficiency.

SOURCE: CARB 2015A; NEALER, REICHMUTH, AND ANAIR 2015.

BOX 13.

Lifetime Global Warming Emissions of Electric Vehicles

UCS recently compared the global warming emissions associated with charging an EV in different regions of the country to driving a gasoline-powered car. We estimated the global warming emissions from electricity consumption in the 26 "grid regions" of the United States—representing the groups of power plants that together serve as each region's primary source of electricity—and we rated each region based on how charging and using an EV there compared with driving a gasoline-powered vehicle. We also estimated, based on recent sales data, the average efficiency of new EVs (battery electric and plug-in EVs combined) sold in the United States in 2015. We found that: 1) driving the average EV in any region of the country produces lower global warming emissions than the average new gasoline car (achieving 29 mpg); 2) our ratings of 20 out of 26 regions have improved since 2009; and 3) more than 66 percent of Americans—up from 45 percent just three years ago—live in regions where powering an EV on the regional electricity grid produces lower global warming emissions than driving a 50 mpg gasoline-powered car.

Comparisons between EVs and gasoline-powered cars look even more attractive when one considers that many EVs are currently being sold and driven in areas where the electricity grid is cleaner than the U.S. average. As a result, based on calculations that weighted where EVs were sold in 2014, driving an EV in the United States produced global warming emissions equal to those of a gasoline vehicle getting 68 mpg.

Our analysis also examined emissions associated with manufacturing different types of cars. We found that, on average, battery EVs representative of those sold today produce less than half the global warming emissions of comparable gasoline-powered vehicles, even when the higher emissions associated with the manufacturing of battery EVs are taken into consideration. Based on modeling of the two most popular battery electric vehicles available today and the regions where they are currently being sold, excess manufacturing emissions are offset within 6 to 16 months of driving (Nealer, Reichmuth, and Anair 2015).

The mix of electricity sources not only varies by region; it is also changing over time. These changes are affecting the entire electricity sector, not just the small share currently used for transportation. After considering how these changes are affecting the grid in general, we will explore the implications for the transportation sector in more detail.

The U.S. electricity sector is in the midst of a major transformation driven by the need to reduce air pollution and reduce the heat-trapping gases responsible for climate change, as well as by the lower price of natural gas and the steadily falling price of wind and solar energy. A complex interplay of policy, technology, and economics are shaping the energy system, and the implications go beyond the future of clean transportation. Taken together, transportation and electricity generation account for more than half of U.S. global warming pollution and a large share of other air pollutants; therefore, the way we generate electricity is critical for public health, climate stability, and our economic well-being. As electricity becomes a more important transportation fuel, the electricity generation and transportation sectors will become increasingly intertwined.

DAVID ILIF/Creative Commons (Wikimedia Commons)

While electricity is overall cleaner than oil, the emissions produced by electricity can be lessened further by shifting electricity generation from fossil fuel sources, such as coal, to renewable sources, such as wind.

CHANGE IS UNDER WAY: COAL'S SHARE IS FALLING, NATURAL GAS AND RENEWABLES ARE GROWING

From 2007 to 2014, coal's share of the U.S. electricity mix declined from almost 50 percent to just 39 percent, while natural gas generation's share grew from 22 percent to 27 percent (EIA 2015b). Utilities are increasingly choosing natural gas over coal for meeting electricity demand because of higher coal prices, standards aimed at limiting harmful pollution from coal-fired power plants, and sharp declines in natural gas prices driven primarily by U.S. shale gas production (Fleischman et al. 2014).

One of the more visible ways that this transition is playing out is in the form of coal plant retirements. Since 2009, plans have been announced to retire—or convert to natural gas—more than 450 coal-powered generators in 39 states, equal to about 20 percent of the total U.S. coal-fired plants. However, there are still many more uncompetitive coal generators that should also be considered for closure. A 2013 UCS analysis of the economic viability of our nation's remaining coal generators found that at least another 360 coal generators are not cost-competitive when compared with natural gas and wind power in the today's power market environment (Fleischman et al. 2014).

This transition away from coal has reduced the emissions associated with operating an EV, which is cleaner today than it was just a few years ago. But there is a lot of room to build on that important progress by reducing the share of coal-fired electricity generation yet further.

One important driver of continued progress in cleaning up electricity generation is the EPA's Clean Power Plan. Finalized in August 2015, the Clean Power Plan is the first-ever national standard for cutting carbon emissions in the power sector. Under the plan, states are collectively required to reduce power plants' carbon emissions to 32 percent below 2005 levels by

As electricity is used more and more for transportation, reducing emissions caused by its generation will be critical for public health, climate stability, and our economic well-being.

2030. The Clean Power Plan provides for a number of options to cut carbon emissions, including increasing energy efficiency, utilizing natural gas and nuclear power, and shifting generation toward renewable energy and away from coal-fired power. States have until September 2016 to submit a final compliance plan, and emission reductions must begin in 2022 (EPA 2015b).

MOVING FROM COAL TO NATURAL GAS IS NOT ENOUGH

Burning natural gas instead of coal to generate electricity offers important and immediate benefits, including reduced air and water pollutants emanating from power plants, fewer smokestack carbon emissions, lower power plant water use, and greater flexibility of the power grid. These advantages, along with the current economic favorability of natural gas, have led some states to rapidly increase their dependence on natural gas. In just five years, Florida has increased the share of its electricity generated from natural gas from 44 percent to 62 percent. Many other states, including Virginia, Delaware, Ohio, and Pennsylvania, are following a similar path (Deyette et al. 2015).

However, despite the important benefits of natural gas compared to coal, a natural gas–dominated electricity generation system would still generate substantial global warming emissions—and fail to effectively address the growing dangers of climate change.

The electric power sector is the largest contributor to U.S. global warming emissions and currently accounts for approximately one-third of the nation's total emissions. Increasing the use of electricity to power transportation will increase the demands on this sector. To limit the worst consequences of climate change, the United States needs to make very deep cuts to emissions from the power sector by 2050. Overreliance on natural gas is risky, both because it fails to adequately mitigate the risks from climate change, but also for other economic and environmental reasons evaluated in detail in a recent UCS analysis, described in Box 14 (Deyette et al. 2015).

Toward a Focus on Renewable Energy

UCS analysis of the electricity sector, like analyses from the National Renewable Energy Laboratory and others, have targeted producing 80 percent of electricity generation from renewable resources as part of overall efforts to avoid the risk of catastrophic climate change. These renewable energy technologies are already ramping up quickly across the country and demonstrating that they can deliver affordable, reliable, and low-carbon power. According to an analysis of the National Renewable Energy Laboratory, an 80-percent reduction of carbon pollution from electricity generation compared to the study's baseline can be achieved in 2050 by relying on renewables for 80 percent of generation (Fields, Luckow, and Vitolo 2015; Rogers et al. 2013; Hand et al. 2012).[4]

Transforming the entire U.S. electricity grid to 80 percent renewable sources will take many years, but some states, regions, and even individuals are moving forward much more

> ***[The electric power sector is the largest contributor to U.S. global warming emissions.]***

BOX 14.

The Natural Gas Gamble: A Risky Bet on America's Clean Energy Future

The U.S. electricity sector is in the midst of a major change. As power producers retire aging coal plants, they are turning to natural gas to generate electricity at an unprecedented rate.

While this rapid shift is providing important near-term environmental and economic benefits, strong evidence suggests that becoming too reliant on natural gas poses numerous and complex risks, including persistent price volatility and rising global warming emissions.

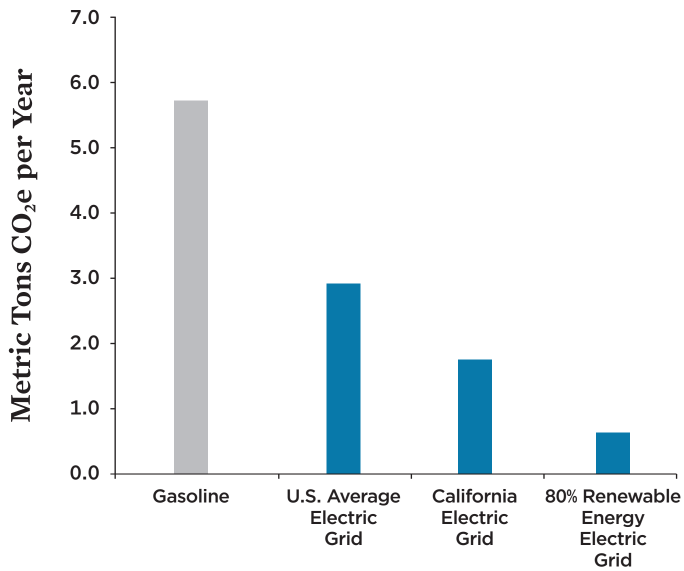
UCS analysis shows, however, that the dangers of an overreliance on natural gas can be overcome by greatly expanding the use of renewable energy and energy efficiency in our power supply. These technologies are already ramping up quickly across the country, demonstrating that they can deliver affordable, reliable, and low-carbon power. With sensible policies in place, these technologies can flourish, and natural gas would play a useful—though more limited—role in a clean energy system (Deyette et al. 2015).

4 *Many studies of the electricity sector's emissions, including the two referenced in this chapter, are based on combustion emissions from electricity generation rather than full lifecycle emissions that are the focus of this report. They do not consider emissions from mining coal or extracting natural gas, for example. However, the analysis by the National Renewable Energy Laboratory included an appendix that also considered the full lifecycle emissions reductions of their renewable scenario. While these emissions are harder to predict precisely, their analysis found that the level of emissions reductions on a full lifecycle basis were very similar or even slightly higher than emissions from generation (Hand et al. 2012).*

quickly, illustrating what is possible. The state of California is already well on its way to meeting a 2020 renewable portfolio standard that requires one-third of retail electricity sales come from renewable energy sources by 2020. In 2015, it increased this target to 50 percent renewable energy by 2030. This transition will build valuable experience that will reduce costs and solve technical challenges, helping to facilitate a national transition to renewable energy by mid-century.

The progress of the electricity sector toward renewables amplifies the benefits of shifting transportation toward electricity. Charging an EV from an 80-percent renewable grid will cut emissions compared to gasoline-powered vehicles by more than 80 percent, to about 0.7 metric ton of CO_2e global warming emissions per year for a typical vehicle. And many drivers of EVs are not waiting until their grid is cleaner to start powering EVs with renewable energy. A survey in 2013 of new EV owners in California, which represents more than 40 percent of the market for EVs, found that 32 percent of respondents had solar photovoltaic systems in their homes. An additional 16 percent indicated that they planned to install a photovoltaic system in the future (CCSE 2013).

FIGURE 20. Renewable Energy Electricity Is Almost 90 Percent Cleaner than Gasoline



Electricity is cleaner than gasoline, but when the electric grid is powered by 80% renewable energy, the reductions in emissions are even more evident. A car charged from an 80% renewable grid produces only 11% of the emissions a gasoline car produces.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 mpg) for a year (driving 12,000 miles). For electricity the emissions represent the production of fuel (e.g., coal, natural gas) and consumption by power plants to generate a quantity of electricity needed for a similar vehicle traveling the same distance adjusted for electric drive efficiency.

SOURCE: CARB 2015A; NEALER, REICHMUTH, AND ANAIR 2015; HAND ET AL. 2012.

RENEWABLE ENERGY AND ELECTRIC TRANSPORTATION COMPLEMENT EACH OTHER

EVs and renewable energy are two critical technologies for making the deep emissions reductions that are required if the United States is to avoid the worst consequences of climate change. While much of this chapter has highlighted the benefits of renewable energy in general and the benefits it offers to EVs in particular, EVs also have unique features that improve electric utilities' ability to integrate high levels of renewable sources of energy into the grid.

Unlike televisions, lights, and many other grid-connected users of electricity, battery EVs have energy storage built in. This provides potential scheduling flexibility for the demand they place on the grid when charging. Using information technology to coordinate the charging of battery EVs at periods when renewable energy generation is abundant, for example, at the mid-day when solar panels are generating at peak capacity, EVs can help balance the load on the grid. This "smart charging" is one of a broader set of "demand flexibility" measures required to facilitate high levels of renewable energy onto the grid (Dyson et al. 2015). Taking this further, future EVs could provide power in a vehicle-to-grid arrangement, compensating for short-term drop-offs in wind or solar power production (CAISO 2014; Kempton and Tomić 2005). Further opportunities for synergy arise from using surplus renewable energy to generate hydrogen to power fuel cell vehicles. This sort of coordination between renewable generation and charging or fueling EVs will not just make things easier for grid managers, but can further reduce the already low cost to power an EV, improving the economics of operating an EV for consumers.

Conclusions and Recommendations

Realizing the full potential of electric transportation to lower emissions from the transportation sector will require large changes in the way electricity is produced and how it is used. An EV charged by a grid with power produced primarily from fossil fuels already offers significant carbon pollution reductions compared to a typical gasoline-powered vehicle. However, EVs charged by a grid powered by 80 percent renewable energy can cut emissions by more than 80 percent compared to today's vehicles—they are one of the core strategies identified by experts to avoid the worst effects of climate change. This calls for investments in a cleaner, more renewable grid and accelerating the deployment of EVs.

BOX 15.

Hydrogen Fuel Cell Vehicles

While battery EVs are the focus of this chapter, hydrogen fuel cell EVs are also an important technology to cut carbon emissions and oil use from transportation. Hydrogen fuel cells produce electricity on board the vehicle from hydrogen rather than relying on energy stored in batteries. This gives them unique attributes, producing only water vapor, benefiting from the attractive properties of electric drive, and resembling battery EVs in that they release no carbon pollution from their tailpipes. Hydrogen fuel cell EVs, like battery EVs, see increased climate benefits when renewable sources of hydrogen or electricity are used.

Vehicles using hydrogen fuel cells also have some key differences from battery EVs. While EVs offer the convenience of home recharging and allow the use of existing electricity infrastructure, hydrogen fuel cell EVs allow fast central refueling similar to that of current gasoline-powered vehicles, once the necessary infrastructure is in place. Fuel cell vehicles are much more efficient than internal combustion engines, but not quite as efficient as battery EVs. CARB computed an energy economy ratio for hydrogen fuel cell powered passenger cars as 2.5, which means they can go 2.5 times as far as gasoline-powered cars on the same amount of energy, while battery EVs have an energy economy ratio of 3.4. However, hydrogen fuel cells offer the highest energy storage capacity for electric drive, facilitating scalability to larger and heavier vehicles. Hydrogen fuel cell technology complements batteries, rather than competing with them, and both technologies can help to cut the United States' oil use and global warming emissions from transportation (NRC 2013; CARB 2012).

A series of three UCS fact sheets describes in more detail how these two EV technologies complement one another (UCS 2014c), how clean they are based on the source of the hydrogen available today (UCS 2014b), and the importance of low-carbon hydrogen production to fulfilling their potential (UCS 2015c).

THE TRANSITION FROM COAL TO CLEAN, RENEWABLE ELECTRICITY MUST BE ACCELERATED

The first step toward cleaning up the grid is to replace coal-fired power plants with cleaner sources of electricity, which is already underway. The next step is for states to implement the Clean Power Plan.

UCS analysis using the Clean Power Plan's rate-based approach for setting emissions goals shows that:

- 31 states are already on track to be more than halfway to meeting their 2022 Clean Power Plan benchmarks, with 21 of them set to surpass them.
- 20 states are already on track to be more than halfway to meeting their 2030 Clean Power Plan target, with 16 set to surpass it (Richardson 2015).

Many states are exceeding the requirements of the Clean Power Plan, supporting more renewable energy and setting a course for even deeper reductions in emissions. California passed legislation in 2015 requiring 50 percent renewable electricity generation by 2030. Other states have formed regional partnerships, such as the Northeast Regional Greenhouse Gas Initiative, to collectively cap carbon emissions from power plants. Together, the nine northeastern states in this partnership have cut emissions by 40 percent since 2005 and have used auction proceeds of $1.4 billion to invest in energy efficiency, renewable energy, and other measures that will support continued emissions reductions over time (Cleetus 2015).

THE DEPLOYMENT OF EVS NEEDS TO RAMP UP

While EV technology has proven its ability to produce great vehicles, car makers are still developing experience with the large-scale manufacturing needed to bring down costs. As a result, tax credits and other types of support are vital to bring EVs within reach of drivers at all income levels. In addition to direct sales support, a variety of policies are needed to help build out the charging infrastructure in homes, apartment buildings, workplaces, and other locations that will make EVs an even more attractive choice for car-buyers.

Delivering clean power and clean transportation will require transformative changes in both sectors, but thoughtful coordination of the two sectors can deliver synergistic benefits for both. As new technologies are deployed to coordinate battery charging and hydrogen fuel production with periods of high availability of renewable sources of energy, EVs can increase the reliability of the grid while reducing the cost of power for their owners and the global warming emissions of the country's transportation sector overall.

Conclusion

Reducing global warming emissions from transportation is an essential element of a comprehensive strategy to avoid the worst impacts of climate change. The key first step is to cut oil use. With more efficient vehicles, better alternatives to driving, and cleaner fuels like electricity and biofuels, we can cut projected oil use by 50 percent by 2035.

However, even a clean transportation system requires a great deal of fuel, and all major transportation fuels have at least some emissions. Therefore, realizing the potential climate benefits of an oil savings plan requires that all of our transportation fuels be as clean as possible. Cleaner fuels like electricity and biofuels have lower emissions than gasoline, and, as we continue to move to cleaner sources of electricity and biofuels and more efficient production processes, these fuels have the potential to get much cleaner over time. But while clean fuels are getting cleaner, oil is getting dirtier as production moves to harder-to-access, more polluting sources, and more intensive methods of extraction and refining. It will take several decades to transition away from gasoline and other fuels made from oil, and in the meantime oil producers must be held accountable to minimize avoidable emissions and avoid the dirtiest sources of oil.

[*Oil producers must be held accountable to minimize avoidable emissions and avoid the dirtiest sources of oil.*]

Fuel Producers' Choices

All fuel producers have important choices to make—about the resources they develop to produce fuel and about the production processes themselves.

- Oil sources are increasingly diverse, and some sources are much more polluting than others. Oil companies have choices to make about which sources of oil to develop, and how to extract and refine them. By reducing avoidable emissions from wasteful practices such as flaring and avoiding the dirtiest sources of oil such as tar sands, they can prevent oil from getting any more polluting than it already is.
- The use of biofuels has expanded dramatically, making significant inroads into the transportation fuel mix, cutting oil use, and reducing emissions. But if biofuels are to expand further without unacceptable trade-offs in the food system and forests, they must shift from food-based fuels to fuels made from wastes and environmentally friendly crops that play a complementary role in the food system and landscape.
- Electricity shows the greatest promise as a future clean transportation fuel. Even with today's average grid mix, EVs are cleaner than gasoline-powered cars. But realizing the potential for electric transportation depends upon cleaning up the grid: moving away from coal and shifting to a grid powered primarily by renewable sources like wind and solar power.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Not all oil is created equal. The emissions caused by producing gasoline can vary greatly, depending on the methods used to extract and refine oil. While reducing our oil consumption is the most important strategy to reduce emissions, it's also essential to hold oil companies accountable to minimize emissions from their operations.

Key Steps Toward Cleaning Up Transportation Fuels

Cleaning up transportation fuels is a major effort that extends beyond the transportation sector to a large share of our economy, including agriculture and the electricity grid. A successful transition to clean transportation will take several decades and will require a wide range of actions by government at the state, regional, national, and international levels, as well as the private sector.

Key steps include the following:

- Policy makers and investors need access to comprehensive data on petroleum-based fuels in order to track emissions accurately. Transparency is the goal.
- All transportation fuel producers must be held accountable to reduce emissions from their fuel production processes.
    - Existing policies that support reducing emissions from the production of biofuels and electricity should be strengthened.
    - New policies are needed to hold oil companies accountable to minimize their production emissions.
- Policy makers should pursue a combination of narrowly tailored policies to address specific challenges and sector-wide performance standards like California's Low Carbon Fuel Standard.
- Infrastructure investment should be targeted to support a clean fuel future and minimize infrastructure lock-in of the most polluting fuels.

POLICY MAKERS AND INVESTORS NEED ACCESS TO COMPREHENSIVE DATA

After the oil shocks of the 1970s, the federal government increased the collection and dissemination of information and projections on energy, including creating the Energy Information Administration (EIA) within the Department of Energy, charged with the collection, analysis, and dissemination of independent and impartial energy information. However, while the EIA and other government and private entities collect and disseminate a great deal of information about energy production, they do not devote the same level of attention to the global warming emissions from the production and use of our major fuels, in particular, of oil. The focus on supply reflects the primary concern of the 1970s—that access to oil was the most fundamental challenge to the U.S. economy and interests. But scarcity is no longer the primary risk posed by oil; rather, it is the mounting damage that this fuel does to our climate. Mitigating the economic, environmental, health, and social harms of climate change requires all energy producers to minimize their emissions, and achieving these emissions reductions requires data on these emissions, for all fuels.

> ***In contrast to policies governing biofuels and electricity, policies governing the oil sector place little emphasis on reducing emissions from the fuel production process.***

The EPA collects and evaluates emissions data from electricity and biofuels production as part of the implementation of Clean Air Act provisions. The EPA also evaluates the global warming emissions from the use of gasoline and diesel as part of emissions standards for vehicles. These regulatory processes and others in California and the European Union have fostered a great deal of analysis and debate about the present performance and future potential for emissions mitigation from biofuels, renewable electricity generation, vehicle efficiency, and EVs. By contrast, U.S. government agencies have devoted relatively little focus to the potential for emissions mitigation or emissions increases in the oil sector beyond determining a baseline against which other fuels can be compared (NETL 2009; NETL 2008). Only in the last few years have the first detailed open-source lifecycle models of the oil supply chain been developed to characterize emissions from oil extraction, including unconventional sources, and different methods of crude oil refining (El-Houjeiri, Brandt, and Duffy 2013; Abella and Bergerson 2012; Bergerson et al. 2012). Moreover, the application of these models to evaluate the oil industry is currently constrained by the lack of available data. Given the magnitude of emissions from oil production, policy makers should require more complete disclosure of the information needed to assess the climate implications of the oil industry's activity.

Oil industry investment in new oil fields or technologies is shaped by what investors understand about the future prospects for different fuels and the firms that produce them. In a carbon-constrained world, the relative emissions of these choices are a key element of this understanding. But the complexity of the oil supply chain renders companies' current level of disclosure inadequate for detailed comparisons of firms' climate performance. Investors may choose to avoid investments in especially polluting fuels as a matter of conscience, or, as a risk mitigation strategy they may discount the value of reserves that are at risk of becoming incompatible with future climate regulations. In either case, investors will be able to make better-informed decisions if fuel producers are required to provide more meaningful information about the relative emissions profile of their portfolio of current products, future prospects, and proven reserves.

ALL FUEL PRODUCERS, INCLUDING OIL COMPANIES, MUST BE HELD ACCOUNTABLE TO REDUCE EMISSIONS

As transportation fuels get more diverse, the sources of emissions associated with their production and use get more complex. Policies to reduce emissions from transportation must focus on using fuel efficiently, shifting to cleaner fuels, and ensuring that all fuel producers take action to minimize emissions from fuel production. A number of policies are already in place to expand the use of clean fuels including electricity and biofuels and to ensure that these fuels get cleaner over time. These policies need to be strengthened, augmented, and refined to effectively minimize oil use and global warming emissions.

In contrast to policies governing biofuels and electricity, policies governing the oil sector place little emphasis on reducing emissions from the fuel production process. Given the enormous scale of current and future emissions from oil production, this is a serious omission in fuels policy. The transition to unconventional resources and methods is increasing emissions from oil production, and decisions made by the oil industry in the next few decades about which resources to develop and how to manage global warming emissions from these processes will materially affect climate change. While reducing emissions from oil production is no substitute for cutting oil use itself, both strategies must be pursued in parallel to reduce the harm caused by climate change.

NARROWLY TAILORED AS WELL AS SECTOR-WIDE POLICIES ARE NEEDED

There are major differences in the physical, economic, and regulatory structure of the electricity grid that charges EVs, the agricultural system that produces feedstocks for biofuels, and the global oil industry that produces gasoline, diesel, and jet fuel. Each of these industries is facing critical decisions that will affect the carbon pollution from our future transportation fuels, but the factors influencing these decisions in each sector are quite different. Therefore, the policy approaches most suitable to shape these decisions will be different as well. Policies to remove barriers to electric transportation or increase renewable energy on the grid will be different from the policies required to support investment in advanced biofuels and ensure that the scale of biofuel production does not cause conflicts in food markets or exacerbate water pollution or deforestation. A variety of federal, regional, and state policies are already in place addressing these challenges in different ways, and smart implementation of these existing polices together with additional, targeted policies will be needed to realize the full potential of these clean fuels.

Policies to encourage or require the oil industry to reduce emissions from the supply chain for fossil fuels are at an earlier stage of development. Examples of early efforts in this area include the federal regulation of methane emissions from oil and gas wells, and provisions of the California Low Carbon Fuel Standard that support innovative practices to reduce emissions from oil production. However, much more needs to be done.

INFRASTRUCTURE INVESTMENT MUST BE TARGETED TOWARD CLEANER FUELS

The fuel system is complex and capital-intensive, and the current transportation system centered on oil is shielded from competition by other, cleaner fuels by a complex network of infrastructure ranging from pipelines and gasoline fueling stations to the building codes designed to accommodate parking gasoline-powered cars but lacking facilities for electric vehicle charging. The transformation of these systems will require large investments over several decades. It is critical to formulate policies that support investments to build out clean-fuel production and the associated infrastructure, while investments in the production, distribution, and use of dirty, high-emissions fuel must be greatly reduced. Investments in long-lived infrastructure that support a transition to a clean fuel future will become more valuable over time, paying dividends as they accelerate the transition to clean fuels and reduce the harm caused by climate change. Investments in dirty fuels, by contrast, will either become stranded assets or, worse yet, lock in highly polluting fuels and increase the mounting harm of climate change for decades to come.

Fueling a Clean Transportation Future

The clean transportation future we need is within reach, with more efficient vehicles, smarter choices for moving ourselves and our goods, cleaner fuels, and steadily falling oil use. Realizing the potential of this future requires everyone to do their part, including all fuel producers. Cleaning up the electricity grid will cut emissions from operating EVs. Producing biofuels from wastes and environmentally friendly crops at a scale that complements food production and protects forests will avoid harsh trade-offs while cutting oil use and dramatically cutting emissions. And, even as oil use declines, it is critical that we manage oil production responsibly. Oil producers must reduce avoidable emissions and avoid the dirtiest sources of oil to ensure that the oil we do use is as clean as possible. The transition to clean transportation will take time, investment, hard work, technological innovation, and smart policy, but the benefits of a stable climate and healthier world are well worth the effort.

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Fueling a Clean Transportation Future

Smart Fuel Choices for a Warming World

[Cutting oil use dramatically is essential to avoiding the worst impacts of climate change, but to achieve a clean transportation future, we must ensure that all of our fuels are as clean as possible.]

Cutting oil use dramatically is essential to the comprehensive transformation of the U.S. energy system that is required to avoid the worst impacts of climate change. In 2012, the Union of Concerned Scientists (UCS) unveiled a practical plan to cut projected U.S. oil use in half by 2035 through improvements in vehicle efficiency and by accelerating the use of innovative clean fuels. The good news is that we are off to a solid start. Cars are getting more efficient, and the use of clean transportation fuels like electricity and biofuels is growing.

But there is a largely unrecognized problem undermining these efforts: the oil we use is getting dirtier. The resources broadly described as oil are changing, with major climate implications. Because we use so much oil, even a relatively small rise in emissions per barrel adds up to a very large increase in pollution over time.

It doesn't have to be this way.

This report points the way to a cleaner transportation future by describing key ways we can clean up our transportation fuels. It builds on the UCS Half the Oil plan by describing how our major transportation fuels are changing and how we can reduce emissions from the production of these fuels. Oil is getting steadily more polluting, but by holding oil companies accountable to reduce avoidable emissions and avoid the dirtiest sources of oil, we can slow that mounting climate damage and make sure that the oil we do continue to use has the lowest global warming emissions possible. Our clean fuels—electricity and biofuels—are already helping us cut oil use and reduce emissions from the transportation sector, but to deliver on their potential we need to shift toward renewable sources of electricity and sustainable non-food sources of biofuels.

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