A Roadmap to Climate-Friendly Cars: 2013

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CLIMATE CENTRAL

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Executive Summary

An electric car is only as good for the climate as the electricity used to power it. And in states that rely heavily on fossil fuels like coal and natural gas for their electricity there are many conventional and plug-in hybrid electric vehicles that are better for the climate than all-electric cars today.

But that is just part of the story. Another critical factor is the carbon emissions generated when a car is manufactured. Emissions from producing the battery and other electrical components create a 10,000 to 40,000-pound carbon debt for electric cars that can only be overcome after tens, or even hundreds of thousands of miles of driving and recharging from clean energy sources.

This comprehensive state-by-state analysis of the climate impacts of the electric car, plug-in hybrid electrics, and high-mileage, gas-powered hybrid cars takes both of these factors into account – the source of energy used to power the car and carbon emissions from vehicle manufacturing.

We found:

- In 40 states, a high-efficiency, conventional gas-powered hybrid, like the Toyota Prius, is better for the climate (produces fewer total "lifecycle" carbon emissions) than the least-polluting, all-electric vehicle, the Honda Fit, over the first 50,000 miles the car is driven.

- In 26 states, an efficient plug-in hybrid is the most climate-friendly option (narrowly outperforming all-electrics in 10 states, assuming a 50:50 split between driving on gas and electric for the plug-in hybrid), and in the other 24 states, a gas-powered car is the best. All-electrics and plug-in hybrids are best in states with green electrical grids with substantial amounts of hydro, nuclear and wind power that produce essentially no carbon emissions. Conventional hybrids are best in states where electricity comes primarily from coal and natural gas.

- For luxury sedans, in 46 states, the gas-powered Lexus ES hybrid is better for the climate than the electric Tesla Model S, over the first 100,000 miles the car is driven.

Greener Grid Needed to Reap Benefits of Electric Cars

In just two years, from 2010 to 2012, a greener grid from more natural gas and wind-generated electricity led to an 8 percent reduction in carbon emissions per kilowatt-hour generated nationally. Combined with more efficient electric cars:

- This reduction in carbon emissions from electric power generation more than doubled the number of states where *driving and charging* a high-efficiency all-electric vehicle (but not counting any vehicle manufacturing emissions) is better for the climate than a gasoline-powered Toyota Prius hybrid; from 13 in 2010, to 32 states in 2012. (The Prius is the most climate friendly conventional hybrid/gasoline powered vehicle on the market.)

But when all the carbon emissions associated with building and driving electric and high-mileage gasoline cars are included in the analysis, the all-electric advantage goes up in smoke. In the vast majority of states, the significant carbon debt associated with the production of electric car batteries outweighs recent reductions in carbon emissions from power generation and efficiency improvements of some electric vehicles.

State By State Summary

Swing states. In many states the rapid substitution of coal with natural gas and the adoption of substantial amounts of wind power have measurably decarbonized the grid from 2010 to 2012. These changes have shifted the balance of carbon emissions in favor of recharging electrics vs. burning gasoline in high-mileage hybrids like the Prius, if car manufacturing emissions are excluded.

In Pennsylvania, Virginia, and Alabama, the share of electricity generated with natural gas increased by about 10 percentage points while coal's share dropped an equivalent amount. In Texas, natural gas generated electricity is up about 5 percentage points, with coal down the same, and wind now accounts for 9 percent of the state's power. In Iowa, coal use dropped 10 percentage points and wind power jumped 8 percentage points, while in Nevada coal fell 10 percentage points, natural gas was up 5 percentage points and solar was up 3 percentage points.

In all these states, a relatively modest shift to less carbon intensive electricity generation – generally around a 10 percent shift from coal to gas or an equivalent increase in the percentage of wind or solar – pushed all-electric vehicles ahead of conventional hybrids in terms of climate benefits associated with driving and recharging (but not including manufacturing emissions).

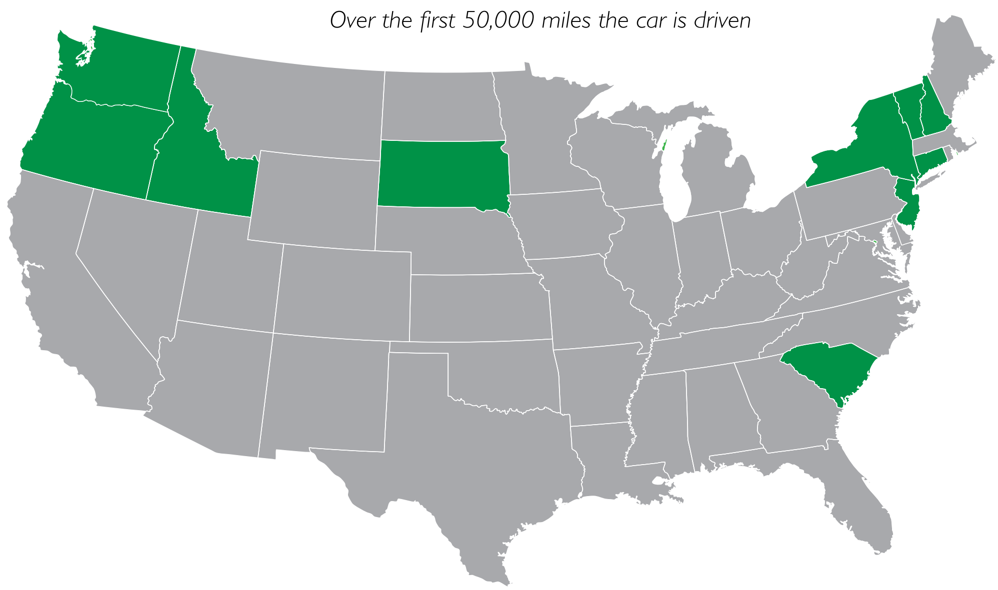
But when manufacturing emissions are included, gas-powered hybrids, or plug-in hybrids, which run on mix of gas and electricity, are the most climate-friendly choice.

Dirty Energy States. Eighteen states, including Colorado, Missouri, New Mexico, Michigan, and Ohio, still heavily depend on coal, or have virtually no renewables and little nuclear power in their electricity mixes. Driving and recharging an electric car in these states is worse for the climate than burning gasoline in a conventional hybrid or high-mileage car. Including manufacturing emissions in the calculations makes the electric car even less climate friendly.

Climate Friendly Electricity States. In 10 states (Washington, Oregon, Connecticut, Idaho, Vermont, New York, New Jersey, New Hampshire, South Carolina, and South Dakota), the best electrics are better for the climate than any gasoline car even when manufacturing emissions are included. Washington, Oregon, Idaho and Vermont have the cleanest grids, producing few carbon emissions, primarily through reliance on hydropower, nuclear, and small percentages of wind and solar. In these states, the mpg equivalents of the best electric vehicle are dazzling, ranging from more than 2,600 mpg in Vermont, to 380 mpg in Washington, 280 mpg in Idaho, and 200 mpg in Oregon.

The Best All-Electric Vehicle Is Better For the Climate Than the Best High-Efficiency, Conventional Gasoline-Powered Hybrid Vehicle In Only 10 States

Over the first 50,000 miles the car is driven



States where an all-electric car is more climate friendly than the best hybrid based on lifecycle emissions per mile

States where a hybrid is more climate friendly than any electric car based on lifecycle emissions per mile

1. Introduction

In April 2012, Climate Central released its first Roadmap to Climate Friendly Cars, a state-by-state analysis of greenhouse gas emissions from electric and gasoline vehicles (Larson and Kenward, 2012). Our analysis showed that the electricity used to charge a 2012 Nissan Leaf – advertised as a "zero-emissions" car — actually resulted in more greenhouse gas emissions per mile driven than driving an equivalent high-efficiency gas-powered vehicle in 32 states because of the carbon intensity of the electrical grid.

Last year, our analysis of electric vehicles focused on the new 2012 model-year Leaf and plug-in hybrid Chevrolet Volt. This year, with many more electric and plug-in hybrid cars on the market and some dramatic changes in our nation's electricity generation mix, our analysis reveals a changing landscape for consumers looking to make climate-friendly car choices. Moreover, the carbon accounting in last year's analysis did not include emissions associated with manufacturing cars. This turns out to be a significant factor, as this year's analysis reveals.

In recent years, about one third of U.S. greenhouse gas emissions have come from the transportation sector and pollution from cars, pickups, SUVs and minivans make up the majority of transportation emissions (Bureau of Transportation Statistics, 2012). While electric vehicles can help play a role in reducing transportation emissions, our analysis finds that they may not be the most climate-friendly option today for many drivers in the U.S.

The total greenhouse gas emissions per mile driven for an electric car depend on:

1. *Where you live*. Since electric cars draw their power by charging from the electric grid, the carbon-intensity of the source of the electricity, which varies from state to state, has a big impact.

2. *How far you drive*. The process of manufacturing an electric vehicle or a gas-powered car produces greenhouse gas emissions. Adding these manufacturing emissions to the total driving-related emissions (emissions per mile multiplied by the car's lifetime mileage) gives the total "lifecycle" emissions for a car. The further a car is driven over its lifetime, the lower will be the manufacturing emissions per mile driven, so how far a car is driven affects its lifecycle emissions per mile.

3. *What car you drive*. Some cars are more efficient than others at turning energy into miles driven. That's true for both gas-powered and all-electric vehicles. Improving a car's mpg or kilowatt-hours per mile (kWh/mi) rating can have a big effect on its emissions on a lifecycle basis in each of the 50 states.

In our new *Roadmap to Climate Friendly Cars*, we've updated last year's analysis and extended it to examine all three factors to show what the most climate-friendly options are, state-by-state.

2. Where You Live

How climate friendly an electric car is depends to a large extent on where you live and how electricity is generated in your state. The emissions from battery manufacturing also play an important role, as discussed in Section 3. In some states, where low-emission forms of electricity predominate, electric cars emit less climate pollution than conventional gas-powered cars during driving and charging. In states that depend heavily on fossil fuels like coal and natural gas for electricity, there are gas-powered cars that are more climate friendly during driving and charging than electric cars.

When we refer to driving and charging emissions in this section of this report, we are excluding emissions associated with manufacturing the car, but we are including emissions associated with production of the fossil fuels from which gasoline or electricity are produced as well as with combustion of the fuels. (See Methodology section.) Manufacturing emissions are brought into the analysis in Section 3.

Our analysis pertains only to charging of car batteries with electricity from the grid, which is the way most electric cars are charged today. Charging batteries from another source, such as a roof-top solar panel, would require a separate analysis from that presented here.

As it was in 2012, the 2013 Nissan Leaf is still the most efficient electric car on the market (tied

Table 1. State-by-state driving emissions of the Nissan Leaf (excluding manufacturing emissions). The Prius emits 0.52lbs CO_2e/mile. Compared to the Leaf, the Prius is the more climate-friendly option in 18 states when driving emissions are compared.

Rank	State	lbs. CO_2e/mile
1	Kentucky	0.76
2	Indiana	0.73
3	Wyoming	0.70
4	West Virginia	0.66
5	New Mexico	0.66
6	Utah	0.65
7	Missouri	0.64
8	North Dakota	0.63
9	Colorado	0.61
10	Delaware	0.61
11	Ohio	0.61
12	Hawaii	0.60
13	Nebraska	0.57
14	Oklahoma	0.57
15	Kansas	0.56
16	Alaska	0.54
17	Louisiana	0.53
18	Michigan	0.52
	Prius	**0.52**
19	Florida	0.52
20	Wisconsin	0.51
21	Iowa	0.51
22	Arkansas	0.50
23	Texas	0.50
24	Maine	0.49
25	Rhode Island	0.47
26	Maryland	0.47
27	Minnesota	0.46
	USA Average	**0.46**
28	Massachusetts	0.45
29	Georgia	0.45
30	Nevada	0.44
31	Montana	0.44
32	Mississippi	0.44
33	Pennsylvania	0.43
34	North Carolina	0.43
35	Alabama	0.42
36	Arizona	0.41
37	Tennessee	0.41
38	Virginia	0.37
39	Illinios	0.37
40	California	0.34
41	South Carolina	0.32
42	New York	0.29
43	New Hampshire	0.28
44	New Jersey	0.26
45	Connecticut	0.24
46	South Dakota	0.22
47	Oregon	0.13
48	Idaho	0.09
49	Washington	0.07
50	Vermont	0.01

Driving Emissions For An Electric Leaf Are Lower Than For A Gas-Powered Prius in 32 States

(Car Manufacturing Emissions Excluded Here)

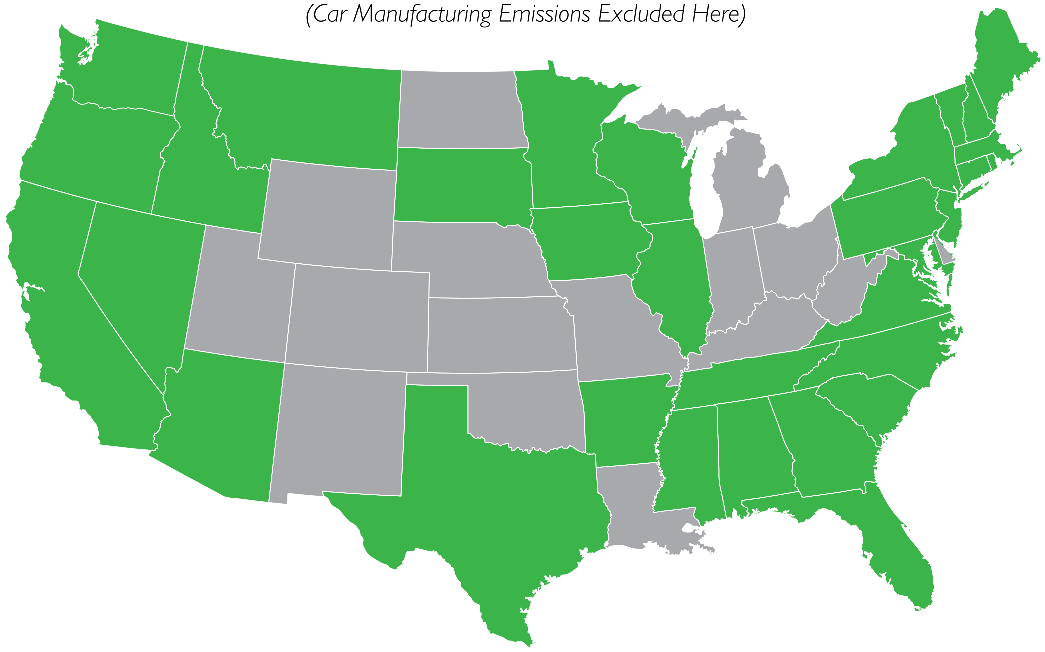


***Figure 1**. As of 2012, driving the Nissan Leaf in 32 states produces fewer emissions than the gas-powered Toyota Prius. This comparison includes emissions associated with fuel production and combustion (for the Prius) and all emissions associated with electricity generation and charging (for the Leaf). Emissions from manufacturing of the vehicles is not included here, but is discussed in Section 3.*

with the Honda Fit Electric, excluding two-passenger subcompact cars.) Table 1 lists the calculated emissions associated with the electricity used to charge the battery of a 2013 all-electric Nissan Leaf in each of the 50 states for the electricity generating mixes in 2012, as well as the emissions when the national average electricity generation mix is used. Also shown are the emissions for a 2013 (non plug-in) Toyota Prius, the most fuel-efficient gas-powered car comparable in size to the Leaf. The total emissions, including those from vehicle manufacturing, will be shown in Section 3.

Charging and driving a Nissan Leaf produces fewer greenhouse gas emissions than driving a Toyota Prius in 32 states (Figure 1), when manufacturing emissions are not included. In 18 states, making electricity generates enough climate pollution that charging and driving a "zero-emissions" Nissan Leaf in those states is worse for the climate than driving a gasoline-powered Prius.

Driving a Prius produces about 0.52 pounds of carbon dioxide equivalents[1] (CO_2e) every mile.

The largest state-to-state differences in emissions for electric vehicles are due to the large differences in carbon-intensity of electricity production that arise from the different mix of electricity generation sources from state-to-state. In states where electricity generation is much more carbon intensive than the national average, the Leaf can produce as much as 0.76 pounds of CO_2e per mile (in Kentucky). And in states with much cleaner electricity than on average in the U.S. the emissions produced per mile are comparably smaller.

While there are 18 states where charging and driving the gas-powered Prius produces fewer emissions than the electric Leaf, the Leaf is still far more climate friendly than the average new gas-powered car in any state. The average new vehicle in 2012 got about 25 miles per gallon and produced more than 1 pound of CO_2e for every mile driven, or twice the emissions of a Prius.

[1] Carbon dioxide equivalents (CO_2e) expressess the combined global warming impact of different greenhouse gases in terms of the amount of CO_2 alone that would give the same warming. See *Methodology* section for details.

In 10 States Gas Powered Cars Need Fuel Economies Of At Least 80 Miles Per Gallon to Produce Fewer Emissions Than the Electric Leaf (Excluding Manufacturing Emissions)

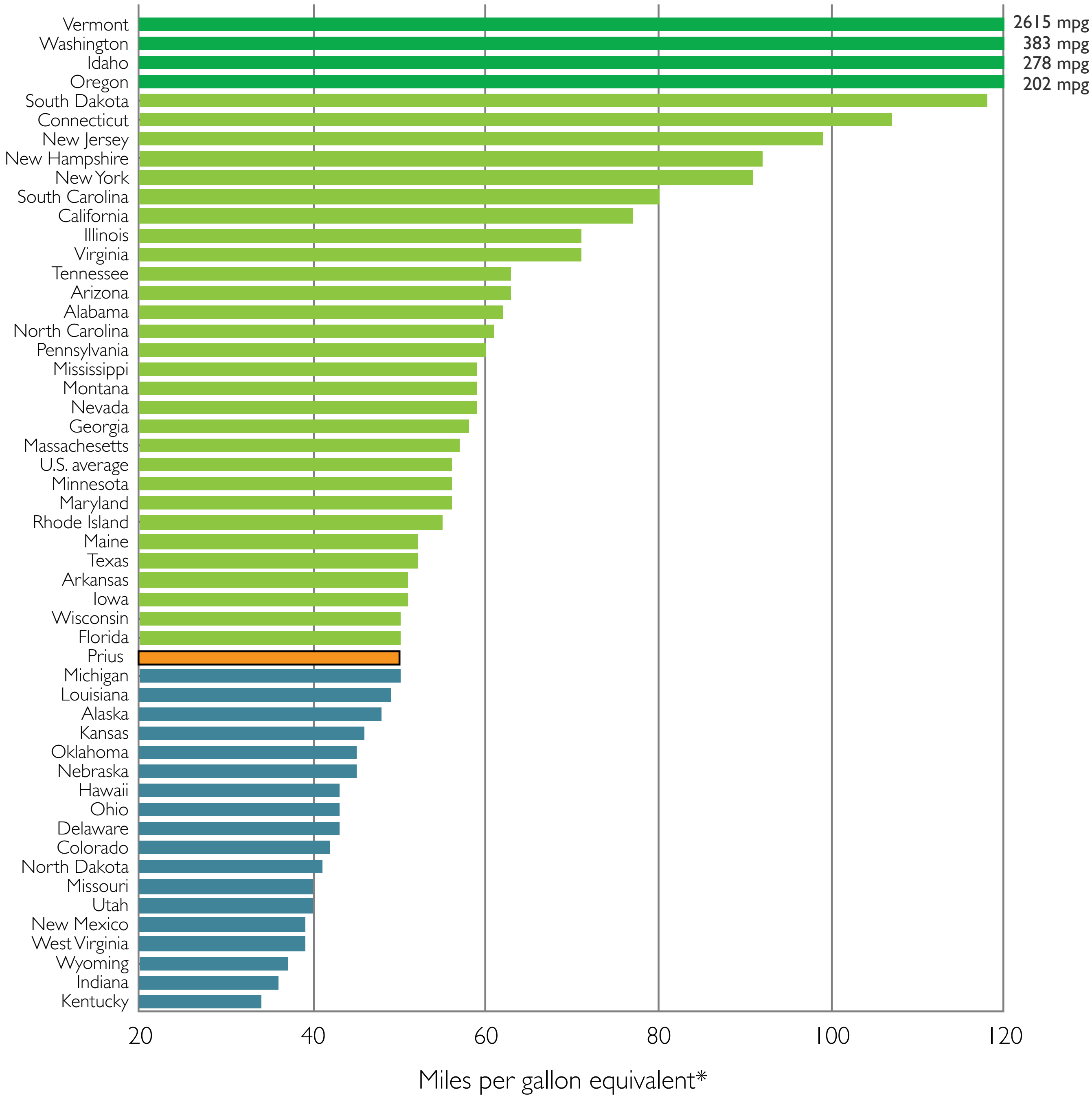


***Figure 2**. The equivalent mpg fuel economy of a Nissan Leaf in each state. (*) The equivalent mpg is the fuel economy that a gas-powered vehicle would need to have in order to be more climate friendly than the Nissan Leaf. Values for Vermont, Washington, Idaho and Oregon are off the scale. These mpg-equivalents are based on emissions from driving and do not incorporate manufacturing emissions.*

Table 2. *A gas-powered car needs to get at least 56 miles per gallon to have lower driving emissions (excluding manufacturing emissions) than a Leaf on average in the U.S.*

Rank	State	MPG Needed to Produce Fewer Emissions than Leaf
1	Kentucky	34
2	Indiana	36
3	Wyoming	37
4	West Virginia	39
5	New Mexico	39
6	Utah	40
7	Missouri	40
8	North Dakota	41
9	Colorado	42
10	Delaware	43
11	Ohio	43
12	Hawaii	43
13	Nebraska	45
14	Oklahoma	45
15	Kansas	46
16	Alaska	48
17	Louisiana	49
18	Michigan	50
	Prius	**50**
19	Florida	50
20	Wisconsin	50
21	Iowa	51
22	Arkansas	51
23	Texas	52
24	Maine	52
25	Rhode Island	55

Rank	State	MPG Needed to Produce Fewer Emissions than Leaf
26	Maryland	56
27	Minnesota	56
	USA Average	**56**
28	Massachusetts	57
29	Georgia	58
30	Nevada	59
31	Montana	59
32	Mississippi	59
33	Pennsylvania	60
34	North Carolina	61
35	Alabama	62
36	Arizona	63
37	Tennessee	63
38	Virginia	71
39	Illinios	71
40	California	77
41	South Carolina	80
42	New York	91
43	New Hampshire	92
44	New Jersey	99
45	Connecticut	107
46	South Dakota	118
47	Oregon	202
48	Idaho	278
49	Washington	383
50	Vermont	2615

Another way to compare emissions of electric and gas-power cars is to calculate the mpg fuel economy that a gas-powered car would need to have in order to be more climate friendly than a particular electric car. This could be called the equivalent MPG fuel economy for the electric car in question, and it would change with the carbon-intensity of the electricity used by the electric car. Figure 2 and Table 2 illustrate this calculation for the Nissan Leaf in each state.

Where the electrical grid is the least carbon intensive, including Washington, Idaho, and Oregon, a gas-powered vehicle would need fuel efficiencies of at least 200 miles per gallon to beat the Leaf. In Vermont, a conventional car would need to get over 2,600 miles per gallon to be more climate-friendly than the Leaf.

In states where electricity generation relies primarily on coal, or on a majority of coal and natural gas, several fuel-efficient gasoline-powered cars are better for the climate than electrics or plug-in hybrids. In states like Kentucky, Indiana, and Wyoming, for example, gas-powered cars only need to have fuel efficiencies of 34-37 miles per gallon to be the most climate-friendly options for drivers. In those states, there are many cars on the market that would be a better choice for the climate than an electric car.

Plug-in hybrid vehicles can also be a climate-friendly vehicle choice. These cars can be charged and run exclusively on electricity, so in states with low carbon intensity electricity generation, can be a cleaner option than the most fuel-efficient gas-powered cars. However, the distance that plug-in hybrids can travel solely on electricity before gasoline assist is needed tends to be short, at around 10-40 miles.

Where electricity generation is not carbon intensive, a plug-in hybrid in our analysis will produce fewer emissions from driving than a non plug-in hybrid, but the plug-in hybrid will produce more emissions from driving than most cars that run exclusively on electricity. On the other hand, where electricity generation is very carbon intensive plug-in hybrids may produce fewer emissions than an all-electric car, but more emissions than a fuel-efficient gas-powered car. Because a plug-in hybrid runs partially on electricity and partially on gasoline, its greenhouse gas emissions depend on the mix of miles driven using electricity versus miles driven using gasoline. For our analysis we assume half the miles are driven on electricity and half on gasoline. For an analysis of how the mix of driving on electricity versus gasoline affects driving emissions of plug-in hybrid electric cars, see our 2012 *Roadmap to Climate Friendly Cars*.

Fossil Fuels Make Up the Majority of Electricity Generation In Most States

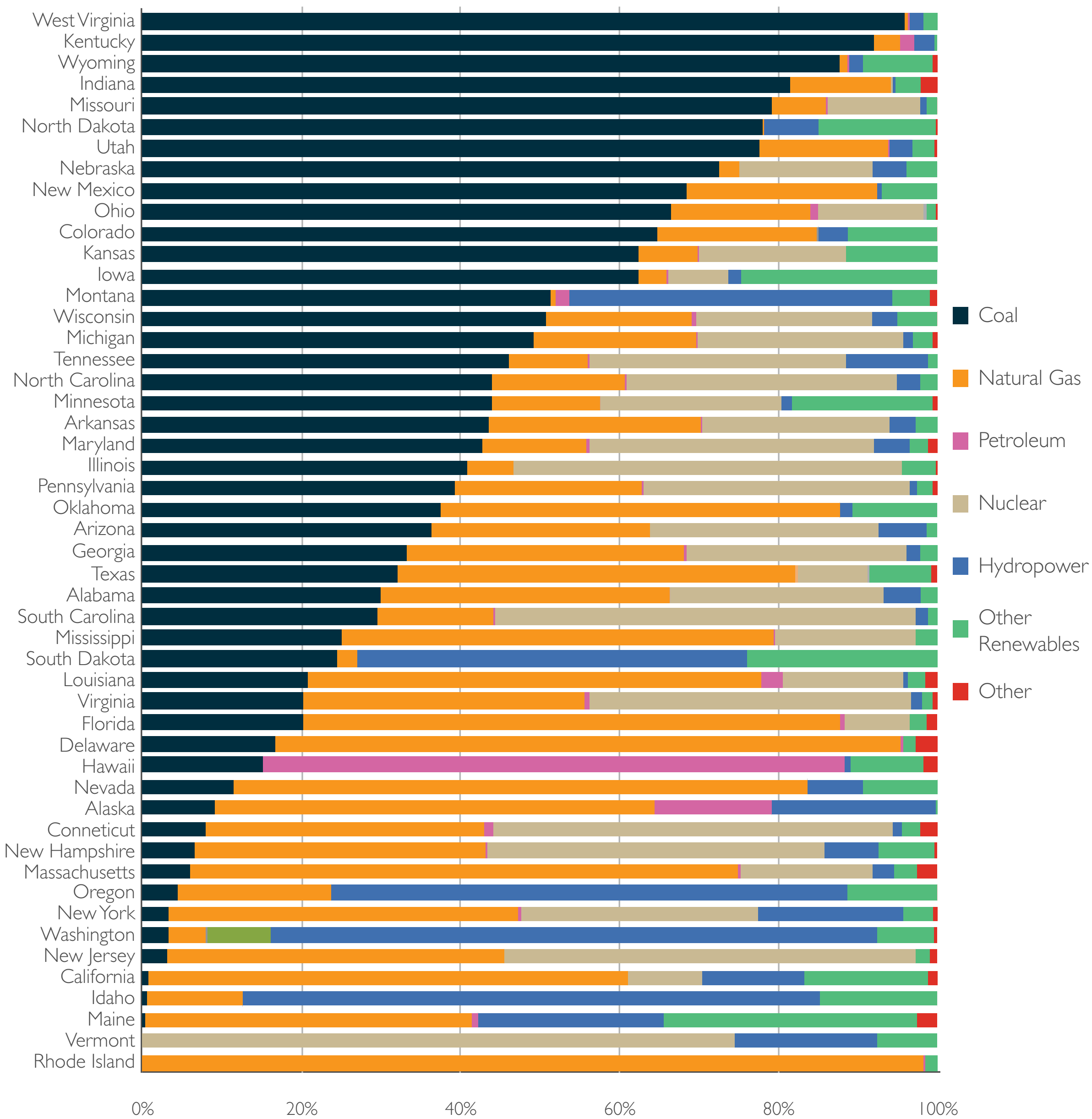


Figure 3. There were large variations in the mix of electricity generation in each state in 2012. All but one state, Vermont, relied on some amount of coal or natural gas.

Electricity Generation, State-by-State

The variations in electric vehicle driving emissions between states come from the large differences in how electricity is produced from state to state. As illustrated in Figure 3, each state has a unique mix of electricity generation, which means electricity in each state also has a different average carbon emissions intensity. Fossil fuels used for generating electricity, and especially coal, play a key role. In 2012, coal was used to generate the largest share of electricity in the U.S. as a whole, followed by natural gas.

To make the calculations tractable, our analysis assumes that charging a car battery in a given state uses electricity with a carbon intensity equal to the annual average carbon emissions intensity of electricity generated in that state. There are uncertainties associated with this assumption, because it is difficult to determine with accuracy where an electron goes once it enters the grid (e.g., it may cross a state line) and because the carbon intensity of electricity generation within a state changes on an hourly or shorter basis as the level of electricity demand changes and different power generating sources start up or shut down to accommodate the changes. These issues are discussed further in the Methodology section.

With our assumptions, if an electric car charges in a state like West Virginia (96 percent coal) or Kentucky (92 percent coal), the greenhouse gas emissions from driving will be higher than driving the car in a state with little-to-no coal and natural gas. In a state that instead relies heavily on nuclear power, hydropower, and renewables like wind and solar power, there are very few emissions during electricity generation. Vermont, for example, generated nearly 75 percent of its electricity from nuclear power, and Washington made 76 percent of its electricity at hydroelectric dams, and these are the top states in which electric cars are the most climate-friendly options.

For the U.S. as a whole from 2010 to 2012, the fraction of electricity generated from coal dropped to 37 percent from 45 percent (Figure 4). Electricity from natural gas increased by more than 6 percentage points to 30.5 percent, driven by natural gas prices that reached a 10-year low in 2012. Wind and solar power growth accounted for the rest of the coal power reduction over this period.

In some states, changes in coal and natural gas-powered electricity generation were much more pronounced than at the national level. For example, Delaware saw its share of electricity coming from coal drop by 30 percentage points while the share coming from natural gas rose by 27 percentage points. Alabama, Massachusetts, Maryland, Montana, North Carolina, Ohio, Virginia, and Wisconsin all saw coal power drop by at least 10 percentage points (Table 3).

In most states, the decrease in coal consumption

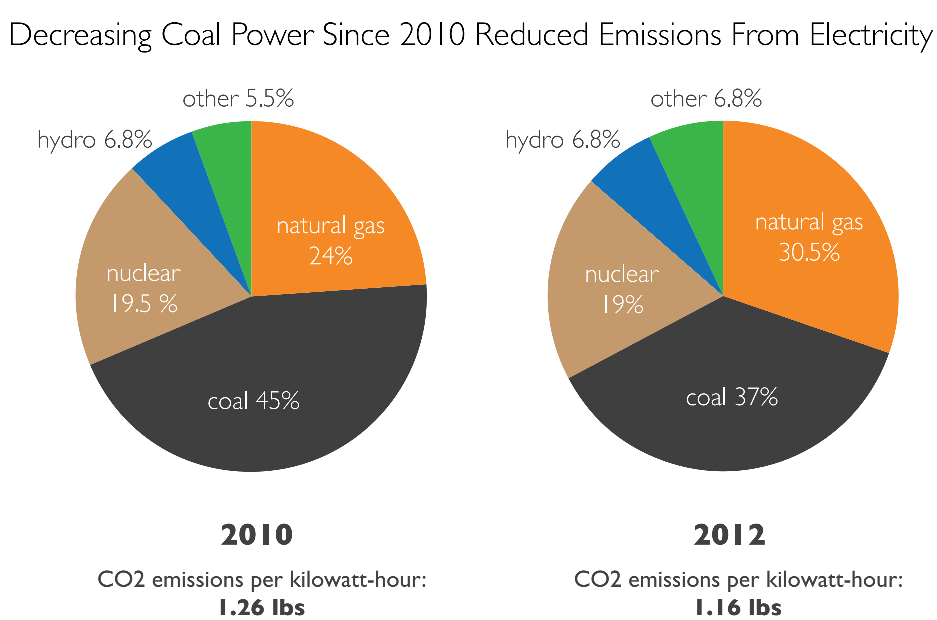


Figure 4. The carbon emissions intensity of the electricity grid (lbs per kWh) from 2010 to 2012 dropped about 8 percent due to reduced coal use and increased natural gas use.

Table 3. *Changes in share of electricity from coal between 2010 and 2012. The top 10 states with the largest shifts away from coal are highlighted.*

State	% Coal 2010	% Coal 2012
USA Average	45	37
Alabama	41	30
Alaska	9	9
Arizona	39	36
Arkansas	46	43
California	1	1
Colorado	68	65
Connecticut	8	8
Delaware	46	17
Florida	26	20
Georgia	53	33
Hawaii	14	15
Idaho	1	0
Illinois	46	41
Indiana	90	81
Iowa	72	62
Kansas	68	62
Kentucky	93	92
Louisiana	23	21
Maine	1	0
Maryland	54	43
Massachusetts	19	6
Michigan	59	49
Minnesota	52	44
Mississippi	25	25
Missouri	81	79
Montana	62	51
Nebraska	64	72
Nevada	20	11
New Hampshire	14	7
New Jersey	10	3
New Mexico	71	68
New York	10	3
North Carolina	56	44
North Dakota	82	78
Ohio	82	67
Oklahoma	44	37
Oregon	7	4
Pennsylvania	48	39
Rhode Island	0	0
South Carolina	36	30
South Dakota	33	24
Tennessee	53	46
Texas	36	32
Utah	81	78
Vermont	0	0
Virginia	35	20
Washington	8	3
West Virginia	97	96
Wisconsin	62	51
Wyoming	89	88

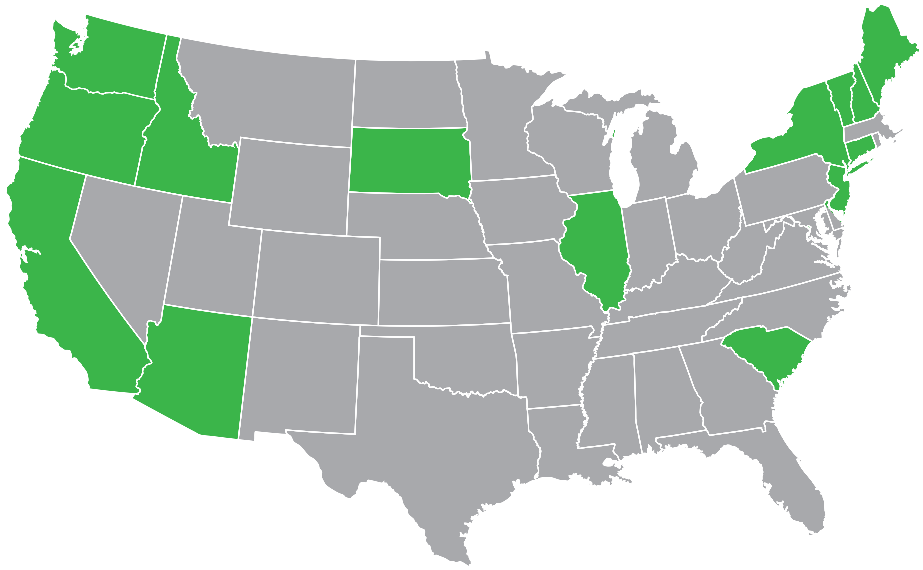
was largely met with increased use of natural gas, but increasing renewable energy, including hydro, wind and solar power, also helped make up the difference. Washington, Oregon, and Montana each saw the share of hydropower increase by about 10 percent, and South Dakota and Iowa both saw the share of electricity from wind power increase by at least 8 percent.

Our 2012 report *A Roadmap to Climate-Friendly Cars*, which was based on 2010 electricity generation data, showed that in 36 states, the high mileage gas-powered Toyota Prius (2012 model) produced fewer overall driving emissions than the all-electric 2012 Nissan Leaf. As noted above, this year the trend has essentially reversed; in 32 states, the all-electric 2013 Leaf is more climate friendly than the 2013 Prius (Figure 5) considering only the driving and charging emissions. Our analysis represents only a snapshot of the grid in time. As the carbon intensity of the grid changes in the future, the per-mile emissions calculated for all-electric and plug-in electric hybrid will change.

In the next section, we highlight the added emissions impact on the state-by-state analysis when manufacturing emissions are also considered.

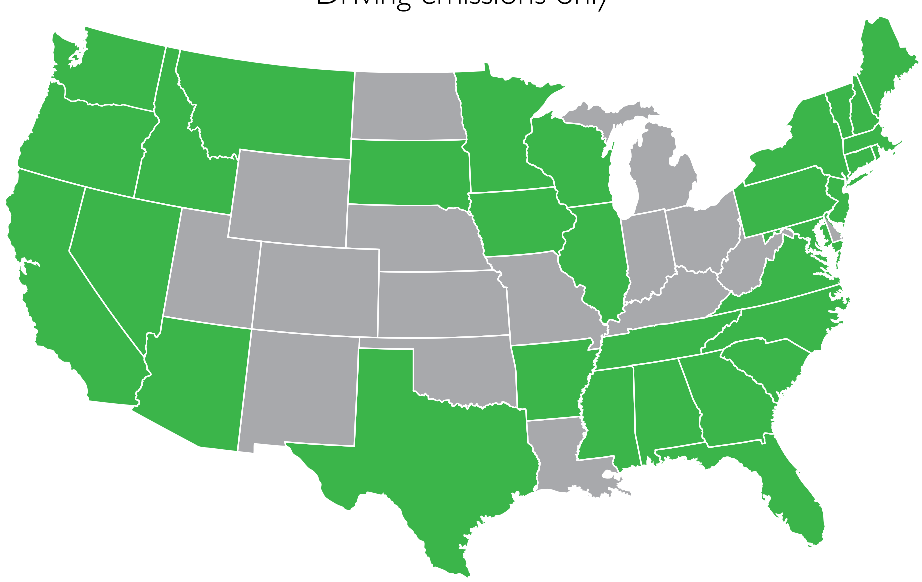
2010 Grid

Driving emissions only



2012 Grid

Driving emissions only



States where the Leaf is more climate friendly than the Prius

***Figure 5**. Changes to the electrical grid from 2010 to 2012 have helped increase the number of states where the Leaf has lower driving emissions than the Prius.*

3. How Far You Drive

Our above analysis of vehicle emissions per mile focused on greenhouse gas emissions that come from charging or driving cars, including emissions from electricity generation, fuel combustion, and fuel extraction, refining, and transportation. But the total carbon footprint ("lifecycle emissions") of any vehicle also includes the emissions generated in manufacturing the car.

The manufacturing emissions per mile for a car depend on how far the car is driven over its lifetime. Since manufacturing emissions all occur before a car is driven at all, to put the emissions on a per-mile basis, they are divided by the estimated total lifetime miles that will be driven. The further a car will be driven over its lifetime, the lower the manufacturing emissions per mile driven will be.

To estimate the "lifecycle" GHG emissions per mile for a car, its per-mile manufacturing emissions are added to its per-mile emissions associated with driving or recharging.

Manufacturing electric vehicles generates more carbon emissions than manufacturing comparable gas-powered cars (EPA, 2013; Hawkins, 2012). Most of the extra emissions are due to the battery in the electric vehicle (see Methodology section.) In particular, smelting aluminum, mining and refining copper, and the chemical processing of other battery components collectively generate substantial greenhouse gases. It is uncertain precisely how much higher electric vehicle manufacturing emissions are because to date there have been only a limited number of detailed analyses (EPA, 2013). Here we base our results on recent work of Hawkins *et. al.* (2013; 2012).

For purposes of comparing lifecycle emissions of electric cars and gas-powered cars, the higher manufacturing emissions for the electric car can be thought of as a "carbon debt" carried by the car before it is driven off a dealer's lot: in the extreme case that the electric car is driven using carbon-free electricity, it would still have some level of lifecycle emission per mile, but this would decrease as more and more miles are driven. On the other hand, the gas-powered car would always produce some emissions while driving, and its manufacturing-related emissions per mile would also fall as it drives more and more miles. After some

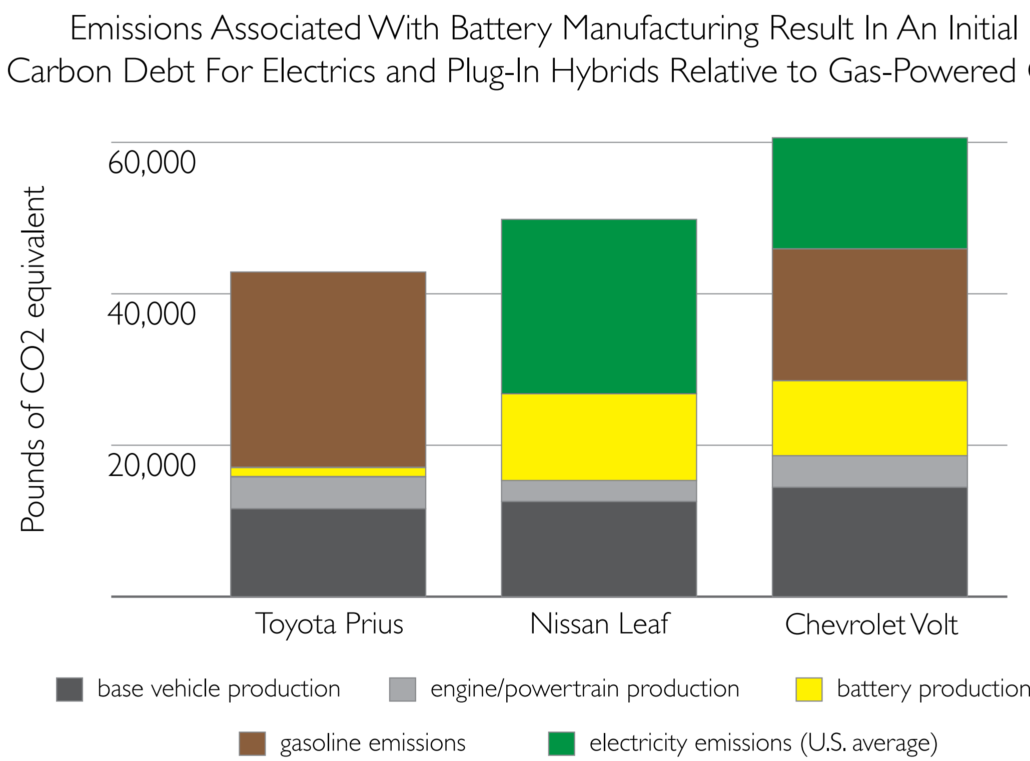


Figure 6. *Lifecycle emissions for the Toyota Prius, Nissan Leaf and Chevrolet Volt, based on 50,000 miles of driving and the U.S. average mix of electricity generation. For the Volt, half the miles were assumed to be driven using electricity and half using gasoline. While driving emissions - those from gasoline or electricity - are comparable for the Prius and Leaf, emissions from battery production in the Leaf put it at an overall emissions disadvantage.*

number of miles driven the total lifecycle emissions per mile for the electric car would come down to that of the gas-powered car. The "carbon debt" would be paid off after driving that many miles.

Figure 6 illustrates the breakdown of lifecycle emissions for a Toyota Prius (gasoline-powered hybrid), a Nissan Leaf (electricity powered) and a Chevrolet Volt (plug-in hybrid electric) if driven 50,000 miles (based on the U.S. average mix of electricity generation). While the Prius has a similar share of emissions coming from driving as the Leaf (gasoline emissions for Prius compared to electricity emissions for the Leaf), the Leaf has the added emissions from battery production, and driving 50,000 miles is not enough distance to offset this initial carbon debt. In this case, the vehicles would need to be driven over 205,000 miles before total lifecycle emissions for the Prius would surpass those for the Leaf.

If you drive an electric car in a state with a low carbon electricity mix, it may not take very many miles of driving before the carbon debt is paid. On the other hand, in states where the electricity generation is carbon intensive, electricity-related emissions from charging the electric vehicle may be larger than the driving emissions of the gas-powered car. In this case, the electric car's carbon debt could never be paid off.

Estimating manufacturing emissions of each car on the market is difficult because each car's weight, component specifications, and supply chain are unique.

Table 4. *Total lifecylce emissions (tons CO_2e) after driving the Leaf 100,000 miles.*

State	Tons CO_2e
Vermont	14.0
Washington	16.8
Idaho	18.1
Oregon	19.9
South Dakota	24.4
Connecticut	25.5
New Jersey	26.6
New Hampshire	27.6
New York	27.7
South Carolina	29.7
California	30.4
Illinois	31.8
Virginia	31.8
Prius	**33.7**
Tennessee	33.9
Arizona	34.1
Alabama	34.3
North Carolina	34.8
Pennsylvania	35.0
Mississippi	35.3
Montana	35.4
Nevada	35.4
Georgia	35.9
Massachusetts	36.0
USA Average Electricity Mix	**36.6**
Minnesota	36.6

State	Tons CO_2e
Maryland	36.8
Rhode Island	37.2
Maine	38.2
Texas	38.5
Arkansas	38.7
Iowa	39.0
Wisconsin	39.1
Florida	39.3
Michigan	39.4
Louisiana	39.8
Alaska	40.7
Kansas	41.5
Oklahoma	42.2
Nebraska	42.2
Hawaii	43.3
Ohio	43.8
Delaware	43.9
Colorado	44.2
North Dakota	45.2
Missouri	45.6
Utah	46.1
New Mexico	46.5
West Virginia	46.6
Wyoming	48.6
Indiana	49.9
Kentucky	51.3
24.8 MPG Car	60.4

Emissions From Manufacturing Electric Cars Reduces Their Climate Friendliness

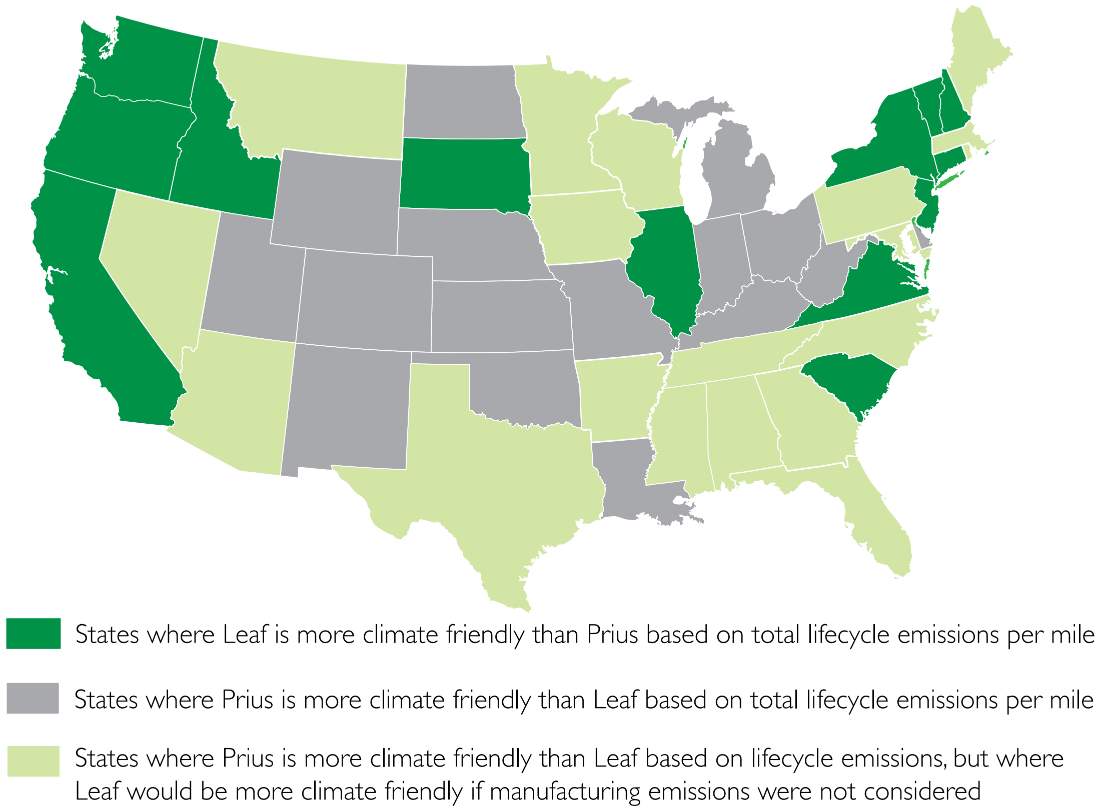


***Figure 7**. Considering the full lifecycle emissions for cars driven 100,000 miles, there are only 13 states where the electric Leaf is more climate friendly than the gas-powered Prius.*

However, some detailed estimates of manufacturing emissions for several specific electric and gas vehicles have been published (Hawkins, 2013; Hawkins, 2012; Samaras, 2008; Hawkins, 2012b; Notter, 2010). Building from Hawkins *et. al.*'s work (2013, 2012), as described in the methodology section of this report, we have estimated emissions produced during the manufacture of commercially available electric cars, plug-in hybrid electrics, and conventional hybrid electric cars.

When manufacturing emissions are expressed on a per-mile basis and added to the per-mile emissions from driving, we find that the rank ordering by climate-friendliness of electric versus gasoline cars is reversed in many states compared with rank ordering on the basis of driving emissions only (excluding manufacturing emissions).

To begin with, consider the Leaf and the gasoline-powered Prius, for which earlier comparisons were made for driving emissions alone. Table 4 shows the full lifecycle emissions (including manufacturing emissions) for a Leaf in each state, as well as for the Prius, for 100,000 miles of driving. There are only 13 states where the Leaf is more climate friendly than the Prius – less than half the number of states when the comparison included only driving emissions (Figure 1). Figure 7 illustrates the states where the Leaf is more climate friendly than the Prius on the basis of driving emissions after 100,000 miles, and also outlines states where, when manufacturing emissions are included, the Leaf is no longer the most climate friendly car.

It is worth pointing out, however, that in every state, the Leaf is still more climate friendly than the average new car purchased in the U.S. today; the average fuel economy of new cars bought last year was about 25 miles per gallon.

As noted earlier, how far a car is driven over its lifetime affects its climate-friendliness ranking on a per-mile basis when manufacturing emissions are included.

In Vermont, for example, where less than 1 percent of the electricity is made from fossil fuels, a brand new Leaf needs to be driven only 22,000 miles before its total lifecycle emissions per mile are less than those of a Prius.

On the other hand, Montana gets about 60 percent of its electricity from coal, and the rest from renewable sources, like hydropower. On a per-mile basis, the Leaf outperforms the Prius when manufacturing emissions are not included. However, when manufacturing emissions are included, the Leaf would need to be driven more than 140,000 miles before its emissions per mile are less than for a Prius.

To compare cars, we have considered the emissions generated over both 100,000 miles and 50,000 miles of driving. Traditionally, cars easily last well beyond the 100,000-mile driving mark (although this may be spread over multiple owners for any given car), but electric cars have not yet been on the market long enough to firmly establish battery lifetimes. (Replacing the battery would effectively increase the manufacturing emissions for a vehicle). For this reason, we have calculated the emissions impact of only 50,000 miles of driving, in addition to 100,000 miles.[2]

There are nine states where lifecycle emissions per mile for the Leaf are less than for a hybrid after 50,000 miles of driving (Figure 8). There are an additional 4 states where you have to drive the Leaf at least 100,000 miles to reach this threshold. Even if you drive your electric car 200,000 miles, there are only 23 states where the Leaf emits less GHG than a car like the Prius.

In Florida, where the Leaf just barely outperforms the Prius on a per-mile basis when manufacturing emissions are not considered, you would need to drive close to 7 million miles to reach the same emissions per mile with manufacturing emissions included.

There are some states where it is impossible for the electric car to pay off its carbon debt no matter how far it is driven. In the 18 states where the electricity mix is so carbon heavy that the Leaf emits more GHG per mile than the Prius does just in charging and driving, then driving an electric car for longer only emits more total lifecycle greenhouse gases (See Table 1). It is worth reiterating, however, that in these states, the Leaf is still a better option than the average new gasoline car getting 25 MPG.

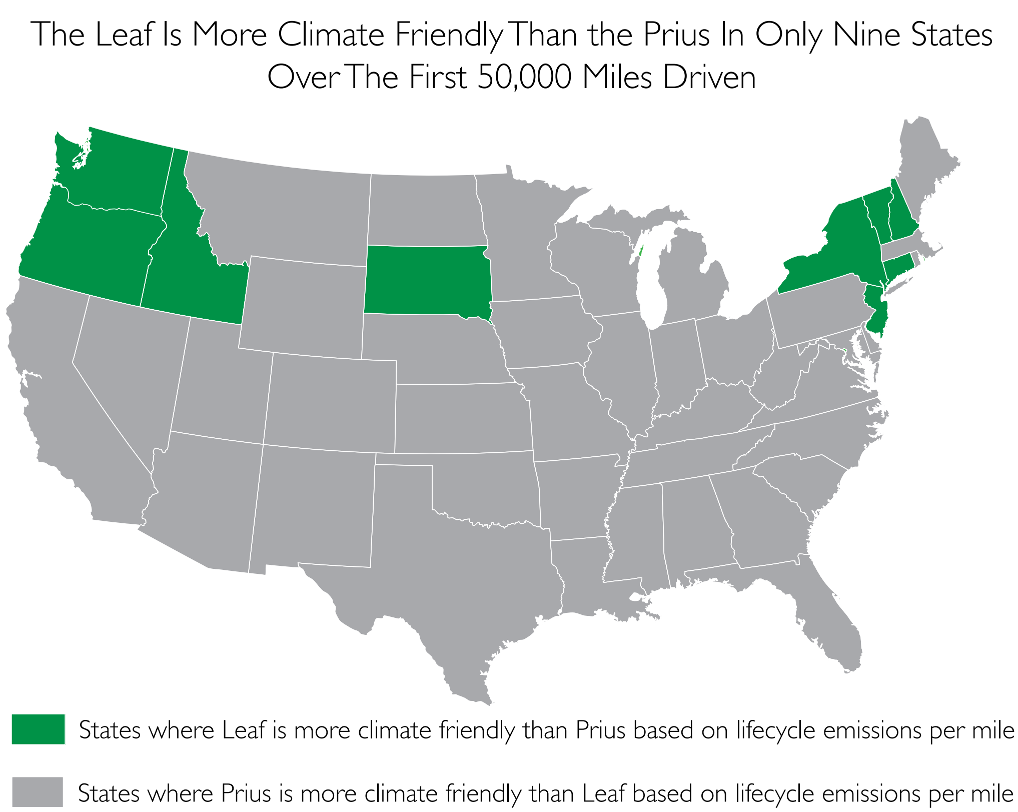


Figure 8. *Considering the full lifecycle emissions for cars driven 50,000 miles, there are only 9 states where the electric Leaf is more climate-friendly than the gas-powered Prius.*

[2] Interestingly, the Nissan Leaf has a battery warranty that covers "flaws and defects" up to 100,000 miles, suggesting the vehicle manufacturer expects at least a 100,000 mile lifetime. However, it also provides an additional 60,000 mile battery replacement warranty, for batteries that lose more than 30 percent of their charging capacity before 60,000 miles.

4. The Car You Drive

As shown in the previous sections, how climate friendly your car is depends on both where you live and how far you drive. But of course, the car itself also matters. The specific components and overall efficiency of each car influence its lifecycle greenhouse gas emissions.

For example, according to the EPA, the first generation model of the Leaf (2012) required 34 kWh of electricity to travel 100 miles, or 0.34 kWh per mile. The 2013 model Leaf is more efficient, consuming only 29 kWh of electricity over 100 miles, or 0.29 kWh per mile. This 15 percent improvement in the Leaf's efficiency (with no change in the Prius's efficiency) has helped make the Leaf more climate friendly than the Prius in several states last year. Two states, Rhode Island and Missouri, saw no significant change in how electricity was generated between 2010 and 2012, but the Leaf is now ranked as more climate friendly than the Prius in these states, considering driving and charging emissions, where we found the opposite result for the 2012 model-year vehicle efficiencies.

This substantial efficiency increase for the Leaf within just one year suggests that electric and plug-in hybrid electric vehicles are on a steep improvement curve, and additional climate-benefitting improvements may materialize in the future.

Importantly, the selection of different electric vehicles available for purchase has also grown rapidly in the past year. In order to compare climate-friendly electric, plug-in hybrid, and conventional hybrid cars, we have estimated the lifecycle emissions of a large number of commercially available 2013 model cars, including manufacturing emissions over both 50,000 mile and 100,000 mile driving lifetimes (see *Methodology* for details on how manufacturing emissions were estimated for different vehicle models). Table 5 and Table 6 list the 2013 model-year all-electric, plug-in electric, and regular hybrid cars, in terms of total lifecycle emissions per mile for driving the car either 100,000 miles (Table 5) or 50,000 miles (Table 6).[3]

Our analysis includes a small but distinct "luxury sedan" class of electric and hybrid cars. This includes the electric Tesla Model S, the hybrid BMW Active 3 and hybrid Lexus ES. When their full lifecycle emissions are accounted for, they are less climate friendly than most other electric, plug-in hybrid and conventional hybrid electric cars.

The Tesla Model S is one of the newest electric cars on the market, and has attracted attention for having a longer range on a single charge than other electric cars (LeBeau, 2013). One model of the Tesla, thanks to its large, 85 kilowatt-hour battery, can reportedly travel up to 265 miles on a single charge (EPA, 2013b).

However, considering the lifecycle emissions over 100,000 miles of driving, there is only one state, Vermont, where the largest Tesla Model S (with a 85 kWh battery) is more climate friendly than the Lexus ES and the BMW Active 3 hybrids. In fact, in 24 states, both models of the Tesla Model S are less climate friendly than the two luxury sedan hybrids.

When the lifecycle emissions over 50,000 miles of driving are considered, the BMW and Lexus hybrids are more climate friendly than the Tesla in 46 states.

Conventional (non-hybrid) gas-powered cars are also undergoing dramatic efficiency improvements. This year, there are more than 20 conventional gas-powered cars that boast fuel economies of at least 30 miles per gallon. We have not included these conventional gas-powered cars in our rankings because there are more than 10 hybrid cars that produce fewer lifecycle emissions, and are thus more climate-friendly options.

Taking this full list of cars, and the state-by-state mix of electricity generation into account, we've ranked the most climate-friendly cars on a full lifecycle basis.

Considering a 100,000-mile driving lifetime (Table 7), the gas-powered Toyota Prius is the most-climate friendly car in 22 states. The Prius Plug-In is the most climate friendly car in 24 states.[3] Only in four states is an electric car, the Honda Fit Electric, the most climate-friendly option. In fact, in 25 states, an electric car is not even ranked among the top 5 most climate-friendly cars.

Over a 50,000-mile driving lifetime (Table 8), there are no states where an electric car is the most climate friendly car. In 26 states, the Prius Plug-In Hybrid produces the fewest emissions, leaving the fully gas-powered Toyota Prius the best car for the climate in 24 states.

[3] The driving emissions of plug-in hybrid cars depends on the percentage of driving done on electricity versus driving done on gasoline. We have assumed plug-in cars drive half their miles on electricity and half on gas. For a more complete discussion of how the split between gas and electric miles affects emissions, see our 2012 Roadmap to Climate Friendly Cars report (Larson and Kenward, 2012).

Table 5. *Ranked lifecycle emissions for electic, plug-in hybrid and conventional hybrid cars based on 100,000 miles of driving and the average U.S. mix of electricity.*

Vehicle	lbs. CO_2e/mile
Toyota Prius Plug-In	0.64
Toyota Prius Hybrid	0.67
Toyota Prius v Hybrid	0.68
Honda Fit Electric	0.71
Honda Civic Hybrid	0.72
Honda Insight Hybrid	0.72
Volkswagen Jetta Hybrid	0.73
Nissan Leaf Electric	0.73
Ford Fusion Hybrid	0.74
Ford C-Max Hybrid	0.74
Lincoln MKZ Hybrid	0.77
Lexus CT 200h Hybrid	0.77
Ford C-Max Plug-In	0.78
Ford Fusion Plug-In	0.78
Ford Focus Electric	0.79
Acura ILX Hybrid	0.82
Toyota Camry Hybrid	0.82
Honda CRZ Hybrid	0.82
Lexus ES 300h Hybrid	0.84
Toyota Avalon Hybrid	0.85
Hyundai Sonata Hybrid	0.85
Kia Optima Hybrid	0.85
Chevrolet Volt Plug-In	0.87
Toyota RAV4 Electric	1.09
BMW Active 3 Hybrid	1.13
Tesla S (60kWh) Electric	1.14
Tesla S (85kWh) Electric	1.34

Table 6. *Ranked lifecycle emissions for electic, plug-in hybrid and conventional hybrid cars based on 50,000 miles of driving and the average U.S. mix of electricity.*

Vehicle	lbs. CO_2e/mile
Toyota Prius Plug-In	0.81
Toyota Prius Hybrid	0.83
Toyota Prius v Hybrid	0.84
Honda Civic Hybrid	0.84
Honda Insight Hybrid	0.85
Volkswagen Jetta Hybrid	0.89
Ford Fusion Hybrid	0.92
Ford C-Max Hybrid	0.92
Lexus CT 200h Hybrid	0.93
Honda CRZ Hybrid	0.95
Acura ILX Hybrid	0.95
Honda Fit Electric	0.96
Lincoln MKZ Hybrid	0.96
Nissan Leaf Electric	1.00
Ford C-Max Plug-In	1.01
Ford Fusion Plug-In	1.01
Toyota Camry Hybrid	1.01
Hyundai Sonata Hybrid	1.02
Kia Optima Hybrid	1.02
Lexus ES 300h Hybrid	1.04
Toyota Avalon Hybrid	1.04
Ford Focus Electric	1.08
Chevrolet Volt Plug-In	1.15
BMW Active 3 Hybrid	1.33
Toyota RAV4 EV Electric	1.48
Tesla S (60kWh) Electric	1.72
Tesla S (85kWh) Electric	2.07

electric vehicle

plug-in hybrid vehicle

hybrid electric (gasoline-powered)

Table 7. The top five most climate-friendly cars in each state, based on lifecycle emissions from 100,000 miles of driving. (*) denotes an electric vehicle, and (**) denotes a plug-in hybrid vehicle.

State	First	Second	Third	Fourth	Fifth
Alaska	Toyota Prius	Toyota Prius v	Toyota Prius Plug-In**	Honda Civic Hybrid	Honda Insight Hybrid
Alabama	Toyota Prius Plug-In**	Honda Fit*	Toyota Prius	Toyota Prius v Hybrid	Nissan Leaf*
Arkansas	Toyota Prius	Toyota Prius Plug-In**	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Arizona	Toyota Prius Plug-In**	Honda Fit*	Toyota Prius	Toyota Prius v	Nissan Leaf*
California	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Colorado	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Connecticut	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Delaware	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Florida	Toyota Prius	Toyota Prius v	Toyota Prius Plug-In**	Honda Civic Hybrid	Honda Insight Hybrid
Georgia	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Honda Civic Hybrid
Hawaii	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Iowa	Toyota Prius	Toyota Prius v	Toyota Prius Plug-In**	Honda Civic Hybrid	Honda Insight Hybrid
Idaho	Honda Fit*	Toyota Prius Plug-In**	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Illinois	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Toyota Prius	Toyota Prius v Hybrid
Indiana	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Kansas	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Kentucky	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Louisiana	Toyota Prius	Toyota Prius v	Toyota Prius Plug-In**	Honda Civic Hybrid	Honda Insight Hybrid
Massachusetts	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Honda Civic Hybrid
Maryland	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Honda Civic Hybrid
Maine	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Michigan	Toyota Prius	Toyota Prius v	Toyota Prius Plug-In**	Honda Civic Hybrid	Honda Insight Hybrid
Minnesota	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Honda Civic Hybrid
Missouri	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Mississippi	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Nissan Leaf*
Montana	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Nissan Leaf*
North Carolina	Toyota Prius Plug-In**	Toyota Prius	Honda Fit*	Toyota Prius v	Nissan Leaf*
North Dakota	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Nebraska	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
New Hampshire	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
New Jersey	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
New Mexico	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Nevada	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Nissan Leaf*
New York	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Ohio	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Oklahoma	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Oregon	Honda Fit*	Toyota Prius Plug-In**	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Pennsylvania	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Fit*	Nissan Leaf*
Rhode Island	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
South Carolina	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
South Dakota	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**

Table 7 (continued). *The top five most climate-friendly cars in each state, based on lifecycle emissions from 100,000 miles of driving. (*) denotes an electric vehicle, and (**) denotes a plug-in hybrid vehicle.*

State	First	Second	Third	Fourth	Fifth
Tennessee	Toyota Prius Plug-In**	Honda Fit*	Toyota Prius	Toyota Prius v	Nissan Leaf*
Texas	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Utah	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Virginia	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Toyota Prius	Toyota Prius v Hybrid
Vermont	Honda Fit*	Nissan Leaf*	Toyota Prius Plug-In**	Ford Focus Electric*	Ford C-Max Energi**
Washington	Honda Fit*	Toyota Prius Plug-In**	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Wisconsin	Toyota Prius	Toyota Prius v	Toyota Prius Plug-In**	Honda Civic Hybrid	Honda Insight Hybrid
West Virginia	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Wyoming	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid

Table 8. *The top five most climate-friendly cars in each state, based on lifecycle emissions from 50,000 miles of driving. (*) denotes an electric vehicle, and (**) denotes a plug-in hybrid vehicle.*

State	First	Second	Third	Fourth	Fifth
Alaska	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Alabama	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Arkansas	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Arizona	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
California	Toyota Prius Plug-In**	Toyota Prius	Honda Fit*	Toyota Prius v	Honda Civic Hybrid
Colorado	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Connecticut	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford C-Max Energi**	Ford Fusion Energi**
Delaware	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Florida	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Georgia	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Hawaii	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Iowa	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Idaho	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford C-Max Energi**	Ford Focus Electric*
Illinois	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Indiana	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Kansas	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Kentucky	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Louisiana	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
Massachusetts	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
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New Jersey	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford C-Max Energi**	Ford Fusion Energi**
New Mexico	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Nevada	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
New York	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Toyota Prius	Toyota Prius v
Ohio	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
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Pennsylvania	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Rhode Island	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
South Carolina	Toyota Prius Plug-In**	Honda Fit*	Toyota Prius	Toyota Prius v	Honda Civic Hybrid
South Dakota	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford C-Max Energi**	Ford Fusion Energi**

Table 8 (continued). *The top five most climate-friendly cars in each state, based on lifecycle emissions from 50,000 miles of driving. (*) denotes an electric vehicle, and (**) denotes a plug-in hybrid vehicle.*

State	First	Second	Third	Fourth	Fifth
Tennessee	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
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Virginia	Toyota Prius Plug-In**	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid
Vermont	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Washington	Toyota Prius Plug-In**	Honda Fit*	Nissan Leaf*	Ford Focus Electric*	Ford C-Max Energi**
Wisconsin	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Toyota Prius Plug-In**
West Virginia	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid
Wyoming	Toyota Prius	Toyota Prius v	Honda Civic Hybrid	Honda Insight Hybrid	Volkswagen Jetta Hybrid

5. Conclusion

Our state-by-state analysis reveals that because the manufacturing of an electric car causes more greenhouse gas emissions than manufacturing a comparable gasoline-powered car, an electric car must be driven sufficiently long distances using sufficiently low-carbon electricity for it to have lower total lifecycle greenhouse gas emissions than the gasoline-fueled car.

Over 50,000 miles of driving, no electric car is more climate-friendly than the most climate-friendly gasoline car or plug-in hybrid car when operating on electricity with the carbon intensity of electricity generated in any state today. Over 100,000 miles of driving, an electric car is the lowest-emissions choice today in only four states: Idaho, Oregon, Vermont and Washington.

In the rest of the states, for up to at least 100,000 miles (and much longer driving lifetimes than this in many states) a plug-in hybrid car or a fully gas-powered car is the most climate-friendly choice today. In states with sizeable portions of nuclear power, hydropower, or wind and solar power, plug-in hybrids that draw on a mixture of gasoline and electricity offer the lowest emission choice (assuming half of their miles are driven using electricity and half are driven using gasoline). But in states that rely heavily on fossil fuels like coal and natural gas, fuel-efficient, gas-powered hybrid cars are still the most climate-friendly car.

In 18 states with the highest carbon-intensities of electricity generation, efficient gasoline cars are more climate friendly than the best electric cars, even without counting manufacturing emissions. In these states, driving the electric car for more lifetime miles cannot overcome the initial difference in emissions from manufacturing the cars due to the high carbon-intensity of the electricity used to charge the electric car.

Our analysis represents a snapshot in time. As the carbon intensity of the grid changes, the climate-friendliness of electric vehicles will also change. The shift from 2010 to 2012 in electricity generation away from coal and toward natural gas and renewable technologies resulted in a modest decrease in carbon intensity of electricity. If this trend continues, electric cars will become the most climate-friendly option in an increasing number of states.

It is worth noting, however, that in the first five months of 2013, coal use for power generation was on the increase across the U.S., which reverses some of the decrease in carbon intensity achieved in the prior two years.

Our analysis highlights the importance of considering the emissions associated with manufacturing a vehicle, in addition to emissions from driving the cars. When considered together, the initial carbon debt of electric cars from manufacturing emissions is difficult to overcome, but electric cars can be the most climate-friendly vehicle options when the electricity they use is sufficiently decarbonized.

6. Methodology

We separately describe our estimates of greenhouse gas (GHG) emissions associated with driving a car and those associated with manufacturing a car. As discussed earlier, the sum of these is the total lifecycle emissions for the car.

Driving Emissions

Our calculations of what we call driving emissions start with the EPA's combined highway/city drive-cycle fuel economy of cars: miles per gallon for gasoline cars, and kilowatt-hours per mile for electric cars (EPA, 2013c). For a gasoline car, the bulk of these driving emissions (also sometimes called fuel-cycle emissions) are made up by the CO_2 emitted during combustion of the fuel in the car's engine. A gallon of gasoline releases about 19 lbs of CO_2 when burned. To these CO_2 emissions we must add the GHG emissions associated with extracting, transporting, and refining the crude oil used to make that gallon of gasoline. When these are included, the total GHG emissions for using gasoline in a car come to 25.9 lbs of CO_2-equivalent per gallon.[4]

In this report, the term CO_2-equivalent (or CO_2e) is used to refer to GHG emissions. This measure expresses the combined global warming impact of several different gases in terms of the amount of CO_2 alone that would give the same warming. (GHGs in addition to CO_2, such as methane (CH_4) and nitrous oxide (N_2O) are emitted over the fuel cycles considered here.) Since different gases have different lifetimes in the atmosphere, the relative warming impact of the non-CO_2 molecules depends on the time frame under consideration. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) gives global warming potentials (GWPs) relative to CO_2 for a large number of gases considering 20-year, 100-year, and 500-year time frames. For the results reported in this report, we have used the 20-year GWP values since 20 years in closer to the typical lifetime of a car than either 100 years or 500 years.[5] (For a gasoline car, the driving emissions assuming 100-year GWP are 24.3 lbs CO2e/gallon instead of 25.9 for a 20-year GWP.[4])

Estimating GHG emissions associated with electricity use by an electric car is more difficult than estimating emissions for a gasoline car, because it is essentially impossible to say with certainty that an electron generated at a particular power plant is the same electron that ends up in the battery of a particular vehicle. The uncertainties arise because of the nature of electricity flow and the interconnectedness of electricity grids. Additional uncertainty is introduced by the time-varying nature of electricity demand and supply. For example, if an electric vehicle plugs in to charge during a period of peak electricity demand, the mix of power plants generating electricity (and hence the average GHG emissions per kWh of electricity) will be different from the mix of plants during periods of lower electricity use. In general, the greater the temporal or geographic specificity with which we wish to determine the emissions associated with electricity use, the greater will be the uncertainty around whether the emissions accurately represent actual use.

To make our analysis tractable, we chose to use annual average emissions per megawatt-hour generated from power plants by state. We also assume electricity generated in a state is consumed in that state. A study by the Union of Concerned Scientists also uses annual emissions per megawatt hour, but chooses to divide the U.S. into 26 electricity-generating/consuming sub-regions defined by the EPA (Anari, 2012). Another study in 2007 by the Electric Power Research Institute and the Natural Resources Defense Council divided the U.S. into 13 sub-regions (EPRI, 2007).

The larger the geographic region selected, the more certain one can be of the average emissions associated with each kilowatt-hour used in that region – for example, the average emissions per kilowatt-hour consumed for the entire U.S. can be known with considerable certainty. The drawback of averaging over larger and larger areas in that less and less insight can be gained into the impact of geographic distribution of different electricity generating sources. In an effort to balance these competing considerations, we have chosen to average emissions at the state level. For large states, or for states of any size that have similar electricity generating fuel mixes as neighboring states, the uncertainty introduced by this assumption is small. The uncertainties are larger for smaller states.

[4] This estimate is for gasoline from conventional crude oil, as calculated by the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, version 1_2011. (See Figure 2 in A. Burnham, J. Han, C.E. Clark, M.Wang, J.B. Dunn, and I. Palou-Rivera, "Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal and Petroleum," ***Environ. Sci. Technol.***, 46:619-627, 2012).

[5] For a quantitative discussion of the 20-year versus 100-year GWP, see the appendix to our 2012 report, *A Roadmap to Climate-Friendly Cars.*

To estimate state-level GHG emissions associated with electricity, the following method was adopted. Our starting point was preliminary data published by the Energy Information Administration (EIA) about the amount of electricity generated in each state in 2012, and the fuel that was used to generate it. These are reported on EIA form EIA-923 2012m, which can be downloaded from the EIA website.[6] We then determined the mass of CO_2 that would be emitted from each fuel source when it burns.[7]

But CO_2 emissions at a power plant alone are not the full emissions story because there are also emissions associated with supplying fuel to the plant (e.g. emissions that occur during coal mining or natural gas extraction). Accurately estimating those emission on a state-by-state basis requires detailed calculations.

These calculations were undertaken using the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions and Energy Use in Transportation (GREET) Model, version 1_2012, the same model used to estimate the fuel-cycle GHG emissions for gasoline mentioned above. We ran GREET for each state's electricity system by specifying in GREET the mix of fuels used for electricity generation in the state (as calculated from EIA data). The main sources of electricity in any given state in the U.S. are coal, natural gas, nuclear, or hydro. (Renewables other than hydro play small roles in most states today). In the case of natural gas, the power plant technologies used (and associated power plant efficiencies) vary significantly from state to state. (This is not the case for coal, nuclear, or hydro plants.) Efficiency directly impacts the GHG emissions per unit of electricity produced, so we provided the mix of natural gas power plant technologies in each state as an input to GREET. The mix of natural gas power plant technologies (combined cycle, simple cycle, or steam cycle) in each state was obtained from EIA data.[8]

The outputs from running the GREET model for each state include **A**, the average CO_2 emissions at power plants per kWh generated, and **B**, the average total fuel cycle GHG emissions in CO_2-equivalents per kWh delivered to the end user.[9] (The transmission and distribution losses assumed by the GREET model are 8% of generated electricity.) For each state, the ratio **B/A** was calculated and multiplied by the average CO_2 emissions per kWh of electricity generated (derived from EIA data, described above) to arrive at the fuel cycle GHG emissions associated with electricity used in each state in 2012.

Vehicle Manufacturing Emissions

To calculate the emissions associated with vehicle manufacturing, we looked to the growing body of literature on full lifecycle assessments of electric vehicles (Hawkins, 2012b). In the manufacturing of two similar-sized cars the battery is responsible for almost all of the difference in emissions between an electric car and a gas-powered car. Based on several studies for smaller vehicles, the battery takes roughly 50 percent more GHGs to manufacture than the rest of the vehicle (Hawkings 2013; Hawkins, 2012; Hawkins, 2012b; Samaras, 2008, Majeau-Battez, 2011; Notter, 2010), but the exact difference depends on the types of cars being considered, the type of battery and on a range of other assumptions made in the analysis.

The range of literature on the global warming impacts of electric vehicles is still small (EPA, 2013). To date, the most detailed analyses of the lifecycle impacts of all-electric vehicles focus on small cars like the Leaf, or cars sold only in Europe. Since a comprehensive analysis of different classes of electric, hybrid and plug-in vehicles has not previously been done, we extrapolated from a published detailed lifecycle analysis of two specific vehicles (one all-electric and one conventional gasoline-fueled) to make preliminary

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6 In Climate Central's 2012 study (Larson and Kenward, 2012), we used finalized data published by the EIA for CO2 emitted and kilowatt-hours (kWh) of electricity generated in each state in 2010. As of the time the current study was being prepared, the EIA had not yet released final data for 2012, so we have utilized preliminary EIA data, which is based on reporting by individual power plants, with some edits made by EIA. The EIA spends about a year reviewing the preliminary data and revising as needed before publishing final numbers. Historically, differences between the preliminary and final numbers are small. The amount of electricity generated in each state in 2012 broken down by type of power plant technology are collected by the EIA on form EIA-923 2012m and published in spreadsheet form. This form also includes the amount of each type of fuel that went into generating that electricity, in both physical units (e.g., tons) and in energy units (e.g., MMBtu).

7 A full table of our emissions factors can be found in the Appendix. We used emission factors published by the EIA, in kg CO2 / MMBtu. Where the EIA did not publish an emissions factor for a fuel source (such as for blast furnace gas), we turned to a report published by The Climate Registry. That report can be found at: http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/

8 These are included in the EIA-923 2012m. For input to GREET, the natural gas generating technologies were categorized as combined cycle, simple cycle, or steam cycle.

9 The GREET model assumes that 2.38 percent of methane extracted from gas formations leaks from the natural gas production and supply system. This is consistent with Climate Central's findings that leak rates range from 2 to 8 percent across the United States (See, Larson, E., "Natural Gas and Climate Change." Climate Central, June 2013.). A leak rate higher than 2.38% would give emissions estimates for electric cars that are higher than those in this report.

estimates of the manufacturing-related emissions for a variety of cars currently on the market. Combining these estimates with our estimates of emissions from driving/recharging, we produced the preliminary estimates of the full lifecycle emissions for a large number of vehicles reported in Section 4.

We based our assessment of the global warming impact of manufacturing on a study by Hawkins, *et al.* (Hawkins, 2013; Hawkins, 2012) who estimated the global warming impact of producing an electric car like a Nissan Leaf and a similarly-sized gasoline fueled car. We used the detailed information provided in the supporting information that accompanied the article to estimate, as described next, the global warming impacts of other all-electric cars, as well as hybrid and plug-in hybrid electric vehicles. Among the handful of studies that have looked at lifecycle emissions of electric vehicles (Hawkins 2012; Hawkins 2012b, Dunn, 2012, Notter, 2010; Majeau-Bettez, 2011), Hawkins *et al.*'s estimates for battery manufacturing are among the most detailed and well-documented, which is why we chose to base our analysis on these. Hawkins *et al.*'s estimates are also on the high end of the few published assessments we have found. However, using a lower estimate, eg. EPA (2013) would result in only minor changes to the ranking of cars discussed in Section 4, since battery manufacturing emissions are only a fraction of the total manufacturing emissions.

Table 9, based on Hawkins *et al.* (2013; 2012), shows estimates of GHG emissions associated with producing an Electric Car and a Gasoline Car, broken down into base vehicle, engine, motor, powertrain, and battery.[10] The CO_2e values in the table use a 20 year GWP for methane rather than Hawkin *et al.*'s original 100 yr GWP.[11] Also shown are scale factors that we discuss below. The gasoline hybrid numbers in Table 9 are also discussed below.

Table 9. Estimated greenhouse gas emissions for vehicle manufacturing (in lbs of CO_2e per vehicle). The electric vehicle emissions are based on Hawkins et al. (2013, 2012) for manufacturing a 2012 Nissan Leaf. The gasoline vehicle is derived from the same analysis based on a combination of the 2008 Mercedes A-series and Volkswagen A4. The estimate for the hybrid vehicle is Climate Central's estimate extrapolated from the Electric Car and Gasoline Car estimates in this table, as discussed in the text. Estimates of lbs CO_2e emissions per vehicle assume a 20-year GWP value for methane.

	Electric Car		**Gas Car**		**Gasoline Hybrid (Prius)**	
Component	*lbs. CO_2e*	*Scale* (**a**)	*lbs. CO_2e*	*Scale* (**a**)	*lbs. CO_2e*	*Scale* (**a**)
Base Vehicle	12,631	3,291lbs	12,631	3,291 lbs	11,675	3,042lbs
Electric Motor	1,003	107 hp	-	-	1,519	80 hp
Gas Engine	-	-	1,486	189 hp		98 hp
Other power-train	1,783	-	2,043	-	1,195	-
Battery (**b**)	11,516	24 kWh	215	-	1,238	1.4 kWh
Total	**26,933**		**16,375**		**15,627**	

*(a) Values in the "scale" column are used in estimating manufacturing emissions for vehicles with different curb weights (lbs), gasoline engine and electric motor horsepowers (hp), and battery storage capacities (kWh) from the Electric Car and Gasoline Car values in this table. The text discusses how the "scale" values are used. (**b**) Electric car represents a Nissan Leaf, with Li-NCM battery. The battery in all cars evaluated in this report are assumed to be Li-NCM batteries, except for the following: Chevrolet Volt and BMW Active 3 use a Li-FePO4 battery; the Toyota Prius, Camry, and Avalon and Honda Insight hybrids all use a NiMH battery. Manufacturing emissions for a 24 kWh capacity Li-FePO4 (estimated based on Hawkins et al. and consistent with the Li-NCM estimate in this table) are 14,488 lbs CO_2e per battery. Manufacturing emissions for a NiMH battery are assumed to be 1.8 times these for an equivalent capacity Li-NCM (Majeau-Bettez et al., 2011).*

[10] Hawkins et al. did not have a full range of information from the manufacturers about the type and exact amount of materials that went into producing every part of each car, so they made informed estimates based on published information (such as the curb weight, battery type, engine horsepower, and other characteristics). These assumptions introduce some uncertainty in the emissions estimates, but since Hawkins et al. use a consistent framework and database for both the electric and gas car, estimated manufacturing-related emissions for the two vehicles relative to each other are probably reasonable.

[11] All of the literature studies of car manufacturing emissions that we reviewed, including Hawkins et al., use a GWP of 100 years for non-CO2 greenhouse gas emissions, rather than the 20-yr GWP we have used in this report. According to Hawkins (personal communication with D. Yawitz, July 9, 2013) CO2 accounts for 90.4% of the total CO2-equivalent manufacturing emissions considering a 100-year GWP, with methane accounting for most of the rest (7.6%). With the same physical amount of emissions of CO2 and methane, using the 20-year GWP to evaluate the climate-warming impact of methane results in total CO2e emissions about 12% higher than when using the 100-year GWP. We have made this adjustment to Hawkins et al.'s original estimates, so that the manufacturing emissions estimates we use reflect a 20-yr GWP for methane and are thus consistent with the rest of our analysis.

We extrapolated results based on Hawkins *et al.* in Table 9 for the Electric Car to estimate the manufacturing emissions for nine 2013 model year electric vehicles rated by the EPA (see Table A2). We scaled the lbs of CO2e emissions in Table 9 for the base vehicle, electric motor, and power train components for the Electric Car by the ratio of the published vehicle curb weight for the car of interest divided by the curb weight shown for the Electric Car in Table 9. We scaled the battery manufacturing emissions in Table 9 by the ratio of the battery capacity of the car of interest divided by the Electric Car battery capacity in Table 9. For all the cars we analyzed, Table 10 gives vehicle curb weights, engine and motor sizes, and battery capacities that we have used in our scaling calculations.

We used a similar method in our analysis of the gas-powered hybrid-electric and plug-in hybrid electric vehicles. We began by imagining a simplified construction of a hybrid car. We assumed that all four of the components in Table 9 are present in a hybrid. We scaled the estimates in Table 9 for the base vehicle and for the battery in the same way we did with the electric vehicles, using curb weight and battery capacity, respectively, as scaling factors.

For the engine/motor and the powertrain we modified the approach, since hybrid vehicles have both an electric motor and an internal combustion engine. We assumed that the manufacturing emissions for these components scale with rated horsepower. We calculated the emissions for manufacturing the engine/motor as follows:

$$\text{lbs } CO_2\text{e for Car X engine/motor} = \frac{\text{HP of Car X engine}}{\text{HP of a Gasoline Car engine}} * \text{lbs } CO_2\text{e for Gasoline Car engine} + \frac{\text{HP of Car X motor}}{\text{HP of Electric Car motor}} * \text{lbs } CO_2\text{e for Electric Car motor}$$

where Car X is the car of interest. The HP values in the denominator in both terms and the lbs CO_2e multipliers are from Table 9. For the powertrain, we averaged the manufacturing emissions for a scaled Electric Car powertrain and a scaled Gasoline Car powertrain:

$$\text{lbs } CO_2\text{e for Car X powertrain} = 1/2 * \left\{ \frac{\text{HP of Car X engine}}{\text{HP of a Gasoline Car engine}} * \text{lbs } CO_2\text{e for Gas Car powertrain} + \frac{\text{HP of Car X motor}}{\text{HP of Electric Car motor}} * \text{lbs } CO_2\text{e for Electric Car powertrain} \right\}$$

where Car X is the car of interest. The HP values in the denominator in both terms and the lbs CO2e multipliers are from Table 9.

The last two columns in Table 9 show the detailed results of our calculations for the gasoline-powered hybrid Toyota Prius based on published curb weights and engine/motor and battery capacities.[12]

In extrapolating the results of Hawkins, *et al.*, we have assumed that the GHG emissions for each part of a car scales linearly with curb weight, battery capacity, or engine power. This is a simplistic assumption. Nevertheless, for vehicles with component capacities relatively close to those used by Hawkins *et al*, there should be relatively little uncertainty about the accuracy of our estimates relative to those of Hawkins *et al.* There is more uncertainty when vehicles vary more significantly in capacities from the vehicles analyzed by Hawkins *et al*., particularly those for which the base vehicle weight or the vehicle battery size vary significantly, since these two components contribute the lion's share to the manufacturing emissions (Table 9). Further research would help reduce the uncertainty in all of our estimates.

As a final note, since the technology that goes into producing electric cars is still evolving Hawkins, *et al.* made assumptions about battery mass, vehicle lifetime, and vehicle efficiency, that may change as sales of electric cars grow. In this regard, the estimates that have been used in the analysis in this report represent merely a snapshot taken from a moving uncertain picture. In the future, as more studies are done to quantify emissions associated with manufacturing electric vehicles, the overall uncertainty in these estimates will decrease.

[12] See: http://www.toyota.com/content/ebrochure/2013/prius_ebrochure.pdf

Table 10. *Climate Central estimates, based on published information, of vehicle characteristics for all-electric, plug-in hybrid electric and gasoline hybrid-electric cars evaluated in this report.*

	Curb weight (lbs)	Engine size (hp)	Motor size (hp)	Battery size (kWh)
All-Electric Cars				
Smart Fortwo	1,808			17.6
Fiat 500e	2,987			24.0
Scion IQ	2,127			12.0
Mitsubishi i-MiEV	2,400			16.0
Ford Focus Electric	3,691			23.0
Nissan Leaf	3,291		107	24.0
Tesla S (85 kWh)	4,647			85.0
Tesla S (60 kWh)	4,647			60.0
Honda Fit Electric	3,252			20.0
Toyota RAV4 Electric	4,032			41.8
Plug-In Hybrid Electric Cars				16.5
Chevrolet Volt	3,781	84	149	7.6
Ford Fusion Plug-In	3,913	141	118	4.4
Toyota Prius Plug-In	3,165	98	80	7.6
Ford C-Max Energi	3,899	141	118	
Gasoline Hybrid Electric Cars				0.6
Honda CRZ	2,657	113	23	1.0
Honda Civic Hybrid	2,740	100	23	1.0
Acura ILX	2,959	100	23	1.0
BMW Active 3	3,814	306	55	1.0
Honda Insight	2,747	88	13	1.3
Lexus CT 200h	3,130	98	80	1.4
Toyota Prius	3,042	98	80	1.0
Volkswagen Jetta Hybrid	3,311	150	27	1.4
Toyota Prius V	3,274	98	80	1.4
Lincoln MKZ	3,828	141	118	1.4
Ford Fusion Hybrid	3,615	141	118	1.4
Ford C-Max	3,640	141	118	1.4
Hyundai Sonata Hybrid	3,457	159	47	1.4
Kia Optima Hybrid	3,496	159	47	1.4
Toyota Camry Hybrid	3,435	155	50	1.6
Lexus ES 300h	3,660	156	50	1.6
Toyota Avalon Hybrid	3,594	156	141	

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8. Appendix

Table A1. Carbon Dioxide Emission Coefficients by Fuel. Adapted from U.S. Energy Information Administration.

Fuel Type	**Pounds of CO2 per Million Btu**
Coal by type	
Coal (All types)	210.2
Bituminous	205.7
Lignite	215.4
Anthractie	228.6
Subbituminous	214.3
Waste/Other Coal	207.2
Coke	251.6
Petroleum Products	
Middle Distillate Fuels (No.1, No. 2, No. 4 fuel oil, diesel, home heating oil	161.3
Jet Fuel	156.3
Kerosene	159.4
Petroleum coke	225.1
Residual Heating Fuel (No. 5, 6 fuel oil), bunker fuel	173.7
Other petroleum & miscellaneous	160.1
Natural and other gases	
Natural Gas	117.0
Blast Furnace Gas	604.8
Other Gas	117.0
Propane gas	139.0
Other Renewables	
Municipal Solid Waste (biogenic)	91.9
Wood and wood waste	206.8
Black Liquor	208.2
Landfill Gas	114.8
Sludge Waste	231.5
Agricultural Byproducts	260.5
Other Biomass (gas)	114.8
Other biomass (liquid)	165.3
other biomass (solid)	231.5
Other	
Municipal Solid Waste (non-biogenic)	199.9
Tire Derived Fuels	189.5

* *additional information from The Climate Registry. "U.S. Default Factors for Calculationg CO2 Emissions from Fossil Fuel and Biomass Combusion." January, 2012.*

Table A2. *2013 Model Electric Vehicles Available in the U.S. (statistics from EPA, 2013).*

Vehicle	Vehicle Class	Efficiency (kWh/mile)	Miles per charge
smart fortwo	Two seater	0.32	68
Fiat 500e	Minicompact	0.29	87
Mitsubishi i-MiEV	Compact	0.30	62
Ford Focus Energi	Subcompact	0.32	76
Nissan Leaf	Compact	0.29	75
Tesla S (85kWh)	Large car	0.38	265
Tesla S (60kWh)	Large Car	0.35	208
Honda Fit	Small station wagon	0.29	82
Toyota RAV4 EV	Small SUV	0.44	103

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