

Key Investments in Greenhouse Gas Mitigation Technologies

From 2000 Through 2016 by Oil and Gas Companies,
Other Industry and the Federal Government

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April 2018



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Undertaken for API

Revised May 17, 2018

Preface

Glossary of Terms (for extended discussion see page 25)

Technology Categories

Fuel substitution technologies include liquefied natural gas (LNG), shale gas, nuclear, and landfill gas.

End-use technologies include efficiency improvements, such as cogeneration (CHP), improved lighting, and carbon capture and storage (CCS).

Non-hydrocarbon technologies include any energy form that is not a hydrocarbon energy source, such as wind, solar and biomass.

Enabling technologies are necessary and often basic technologies that allow other technologies' use and include various consortia that are researching and developing a wide variety of technologies, and include several university programs.

Alternative Fuel Vehicles and Advanced Technology Vehicles use both petroleum and nonpetroleum based fuels (or mixtures) or fuel-cell technologies.

Biomass uses plant materials, animal fats and wastes, or woody material to produce energy.

Biorefineries produce a broad slate of products from plant materials and/or animal fats.

Biodiesel generally refers only to diesel substitutes produced from vegetable oils and/or animal fats. However, this study includes other bio-derivatives including those produced as refinery products, such as certain higher alcohols and alkanes.

Carbon Capture and Storage (CCS) is the capture and long term storage of carbon dioxide emissions from combustion processes.

Cogeneration, or combined heat and power (CHP), is the simultaneous production of both electricity and thermal energy (steam, hot water, hot air).

Ethanol is a liquid fuel, currently produced by the fermentation of various sugars, primarily from corn and sugar cane. Sugar cane is not a significant source in the North American market.

Gasification is a thermal process for converting solid materials (e.g. biomass, coal or petroleum coke) into a synthetic gas. The gas may be used directly, or converted to hydrogen or liquid fuels.

Gas Flaring occurs when crude oil is extracted and natural gas associated with the oil is produced to the surface as well. In areas lacking natural gas infrastructure and markets, this associated gas is flared (burned) or vented (emitted as un-burnt gas).

Liquefied natural gas (LNG) is natural gas that has been super-cooled to a liquid for transport. This dramatically reduces the volume for cost-effective transport over longer distances.

Landfill gas (LFG) is methane that is produced anaerobically in landfills from the decomposition of waste material.

SF6 (sulfur hexafluoride) is used in the electrical industry as a dielectric and within the magnesium production industry.

Fluorocarbons and halogenated fluorocarbons are various chemicals used as either refrigerants or industrial cleaning agents. Several of them are greenhouse gases, while others can deplete ozone.

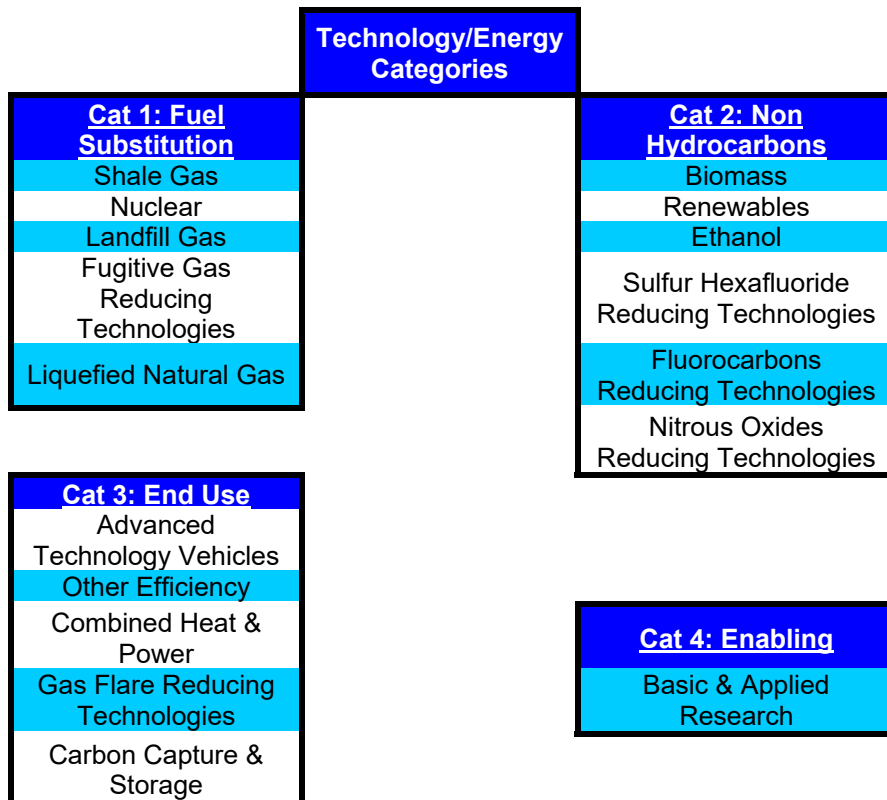
Nitrous Oxides (N₂O) are produced by both biogenic and anthropogenic sources. Primary anthropogenic sources of N₂O are agricultural practices related to the use of fertilizer. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests.

Shale Gas is an important source of expanded supply of natural gas in the U.S., typically produced through a well-tested process known as hydraulic fracturing. As a greenhouse gas emission reduction technology, shale gas increases the supply of natural gas to the North American market that may substitute for coal, and to a lesser extent for petroleum fuels.

A *Disruptive Technology* is a new technological innovation, product, or service that overturns the existing dominant technology in the market, despite the fact that the disruptive technology is radically different from the leading technology and requires fundamental infrastructure and support changes.

Figure P-1

Categorization of GHG Mitigating Technologies



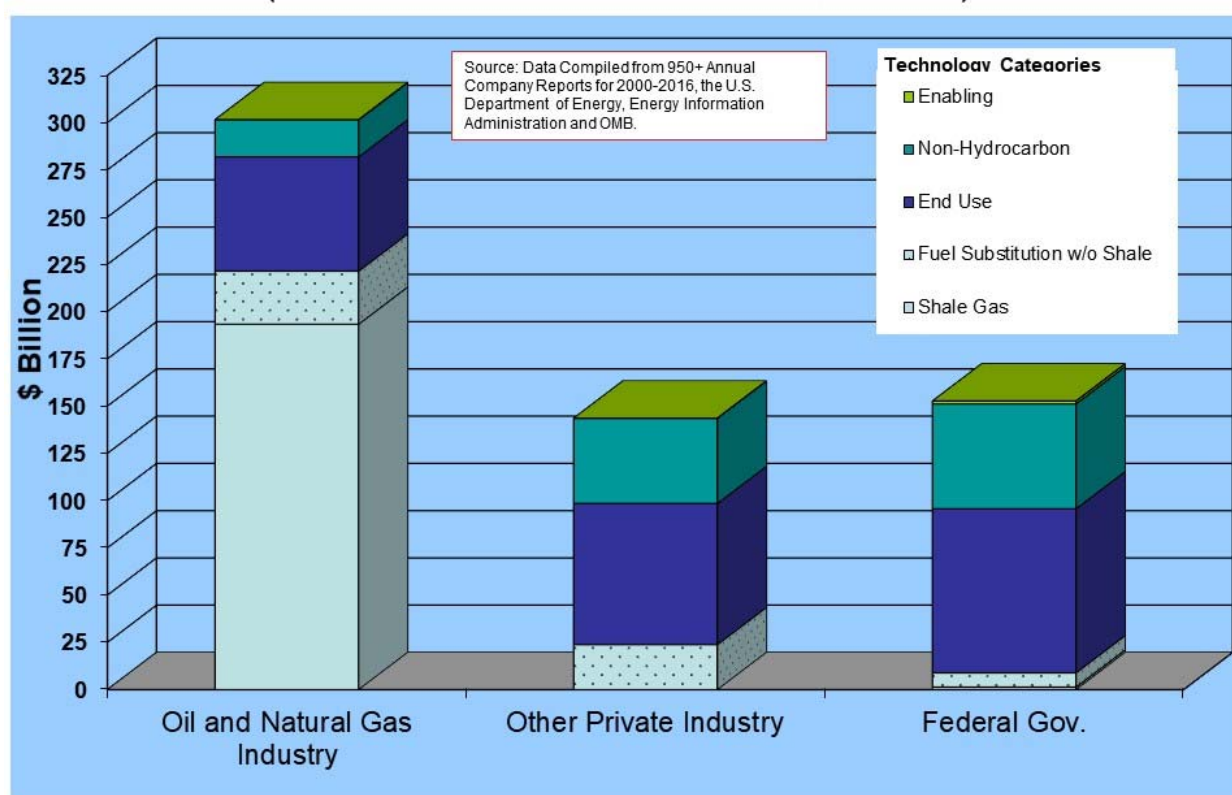
Executive Summary

This report provides estimates of the investments made from 2000 through 2016 in various greenhouse gas emission reduction technologies. Estimates are provided for the oil and gas industry, other private sector industries, and the Federal Government.

North American investments in GHG mitigating technologies are estimated to have totaled \$597.8 billion (2016 dollars) between 2000 and 2016.¹ **Figure ES-1** summarizes these greenhouse gas mitigation investments by investor type and by technology category. Over the 2000 – 2016 period, the U.S. based oil and natural gas industry invested an estimated \$301.5 billion in GHG mitigating technologies including shale gas, or \$108.2 billion without shale gas investments, other U.S. based private industries invested an estimated \$143.6 billion, and the Federal Government invested an estimated \$152.7 billion, or \$151.4 billion without shale gas investments.

Figure ES-1

GHG Mitigation Investments in North America 2000-2016 (Total Investment=\$598 billion, 2016\$)



Major investments by the oil and natural gas industry included shale gas (especially over the 2009-2016 period), efficiency improvements including combined heat and power, and

¹ “North American market” is used herein to include Canada and the U.S. Percentages may not add to 100% due to rounding. All figures are provided in 2016 dollars.

advanced technology for vehicles. Investments in wind, biofuels and solar were also made. Other private industries' major investments included advanced technology vehicles, efficiency improvements and fuel substitution in electricity generation, biofuels, wind and solar. The Federal Government has spread investment across all technology categories with major investments in energy efficient lighting, wind, solar, biofuels and basic research. Significant investments in renewables and efficiency were made between 2009 and 2012 as part of the American Recovery and Reinvestment Act of 2009 (ARRA). In earlier periods, federal spending was more heavily focused on early-stage development investments, particularly at the basic research stage. Now it includes later stage and commercial plants, such as the Section 1603 direct grants to wind energy facilities in lieu of tax credits.

Overall, the surge in investments that began in 2009 has continued, albeit more modestly than in 2009-2011. In 2013 and 2014, investments had increased by about \$106.7 billion, or about \$59.1 billion not including shale gas, while in 2015 and 2016 the increase was about \$109.2 billion, or about \$55.9 billion not including shale gas.

Emission Reductions

The EIA² has reported that energy-related CO₂ emissions in the United States decreased in each of the last three years after a slight uptick in 2013. The total CO₂ emissions in 2016 were 14% or 820 million metric tons, below the peak of 2007. Energy-related carbon dioxide emissions have declined in seven of the past nine years.

In 2016 GDP grew by 1.6 percent (chained 2009 dollars)³ while energy related emissions decreased about 1.3 percent⁴, largely due to a continuing improvement in GHG emission intensity. Since 1990, GHG emissions in the United States have grown much more slowly than GDP; in 2007 emissions reached a peak of about 20 percent more than 1990 levels, while 2016 GHG emissions were less than 3 percent above 1990 levels. GDP has increased by 87 percent over that same time period, as measured in constant chained dollars⁵. At the same time the U.S. population has increased by about 73 million people or a little over 20 percent⁶.

² <http://www.eia.gov/totalenergy/data/monthly/#environment>

³ <http://bea.gov/national/index.htm#gdp> Table "gdplev" Current-Dollar and "Real" Gross Domestic Product release date Dec. 21, 2017

⁴ <http://www.eia.gov/totalenergy/data/monthly/#environment>

⁵ <http://bea.gov/national/index.htm#gdp>

⁶ <http://www.multpl.com/united-states-population/table>

The GHG mitigation investments catalogued in this report delivered greenhouse gas emission reductions either in absolute terms or relative to what would have otherwise occurred. No connection is made between specific investments and reduction amounts. Emission reductions reported by the oil and gas industry in the North American market are shown in Table ES-1. These are reductions that occur from the various companies' operations, such as improved efficiency in energy use in their facilities and improved fugitive emission control. Table ES-1 does not include reductions that were accomplished by other industries, like electric utilities, that were only made possible by investments by the oil and gas industry in shale gas and other fuel substitution technologies, allowing those electric utilities to switch from coal to natural gas. They also do not include the significant reductions from improved production technologies resulting in lower emission intensity of methane, which otherwise may have increased in aggregate with vastly expanded hydraulic fracturing related production.

Table ES-1
Reported Emission Reductions 2011 through 2016 versus Prior Year
Oil and Gas Industry in North America
Million Metric Tons CO₂e*

	Fuel Substitution	End Use	Nonhydrocarbon	Total
2011	19.8	24.3	9.0	53.1
2012	19.9	24.5	9.2	53.6
2013	20.4	24.8	9.2	54.4
2014	20.9	25.2	9.4	55.5
2015	21.1	24.7	9.1	54.9
2016	22.7	25.5	8.9	57.1

*Emissions reductions associated with fuel substitution do not include reductions from other industries, such as electric utilities, replacing coal with natural gas produced and sold by the oil and natural gas industry.

U.S. based oil and gas industry sources have reported direct emission reductions totaling 57.1 million metric tons CO₂ equivalent for 2016 compared to 2015. The reduction of 57.1 million metric tons is equivalent to taking 12.1 million cars and light trucks off the road,⁷ or retiring nine 1000MW coal fired power plants and putting one more on part time work.⁸ For comparison, there were 256 million cars and trucks in the US in 2013, according to the U.S. Department of Transportation.⁹

⁷ Passenger vehicles estimate derived from <http://www3.epa.gov/otaq/climate/documents/420f14040a.pdf>, by dividing total reductions by average passenger vehicle emissions

⁸ Average coal plant estimate derived from <http://www.epa.gov/cpd/pdf/brochure.pdf> and http://www.eia.gov/coal/production/quarterly/co2_article/co2.html by calculating total MWh/year, mmBTU/MWh and MMT CO₂/mmBTU.

⁹<http://www.fhwa.dot.gov/policyinformation/statistics/2013/mv1.cfm>

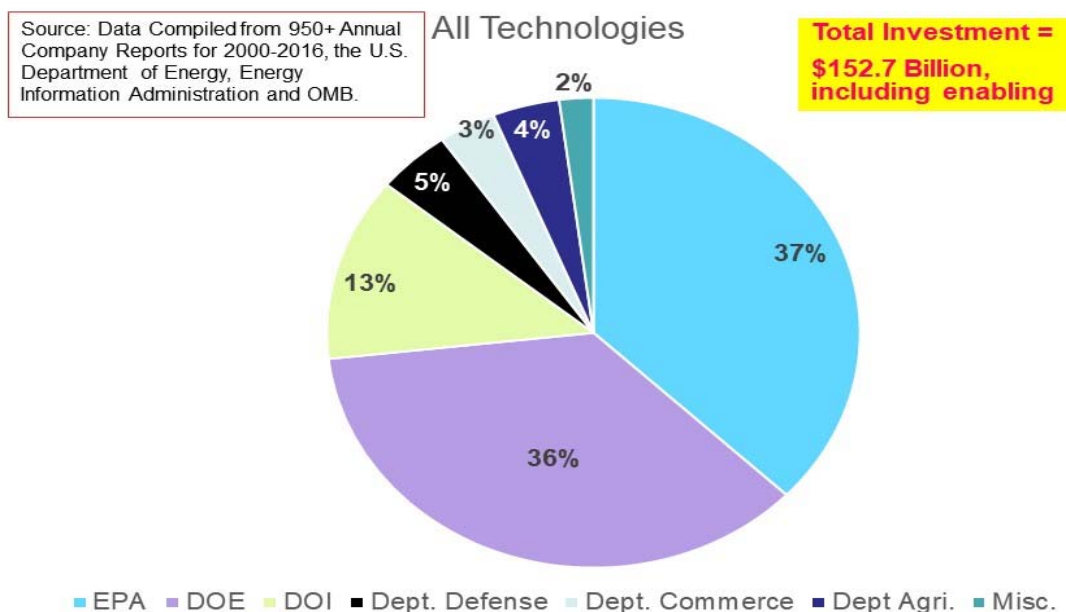
Major Changes In This Update

Oil and natural gas companies, other private sector companies, and the Federal government continue to invest in greenhouse gas mitigating technologies in the North American market. Since the last report that covered investment from 2000-2014¹⁰, total investment in these technologies has increased by approximately \$109.2 billion in the 2015-2016 period, or approximately 23 percent, from \$488 billion to \$597.8 billion¹¹.

In addition, the investments made by the federal government have been disaggregated into specific agencies. **Figure ES-2** shows the investments by the federal government including: The Environmental Protection Agency, Department of Energy, Department of Interior, Department of Defense, Department of Commerce, Department of Agriculture and, miscellaneous agencies.

Figure ES-2

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$



¹⁰ Thomas Tanton, *Key Investments in Greenhouse Gas Mitigation Technologies from 2000 Through 2012 by Energy Firms, Other Industry and the Federal Government*, October 2015

¹¹ Note that early reports in this series provided estimated investments in nominal dollars; these have been adjusted to constant 2016 dollars throughout here. In the last two reports they were provided in 2010 dollars. Figures showing nominal dollars are provided in Appendix A.

Chapter I: Investments From 2000-2016

Introduction

This report summarizes identified investment in GHG mitigation technologies in North America during the period 2000 through 2016.¹² Investments are reported for the private sector and the Federal government by technology or energy category. In the case of the private sector we delineate by industrial category and for the Federal Government by Cabinet agency. The data were compiled from a review of over 950 company annual reports, federal budget documents, and other public sources.¹³ It should be noted that most of the investments may provide benefits in addition to any reduction of greenhouse gas emissions, and were made for a variety of reasons, such as to increase or diversify energy supplies, or to improve efficiency.

Greenhouse gas emissions can be reduced by a variety of measures, such as improving energy efficiency and, in some applications, by developing alternative energy sources, like wind and solar power. Another way to reduce atmospheric emissions is to capture the CO₂ that is released from fossil fuel-fired power plants and store it underground, referred to as carbon capture and storage (CCS). Oil and natural gas companies continue to control the leakage of methane, a potent greenhouse gas, while at the same time greatly expanding energy supplies through various substitute fuels through hydraulic fracturing. Next to hydraulic fracturing, oil and gas companies have invested heavily in end use technologies to improve overall efficiency.

The GHG mitigating technologies examined in this report were placed into four categories: *fuel substitution*, *nonhydrocarbon*, *end-use* and *enabling* technologies as laid out in the organizational chart on page iv.

This report does not include investments made by individual consumers (e.g. for more efficient appliances or hybrid and flexible fuel vehicles), or tax policies by the government intended to encourage specific technologies, nor monies paid in various legal settlements. Direct cash grants, such as the Federal Section 1603 grants begun in 2009 to renewable energy generators were included. Finally, many of the project investments were made by partnerships and/or joint ventures. While all reasonable efforts were made to allocate those project expenditures to the entities involved, this was not always possible. In those instances, project level expenditures were assigned to the lead sponsor and the corresponding sector.

¹² No claim is made to have captured 100% of investments in each technology or for each GHG, but the author believes that further refinements to the database would change the relative distributions only at the margin.

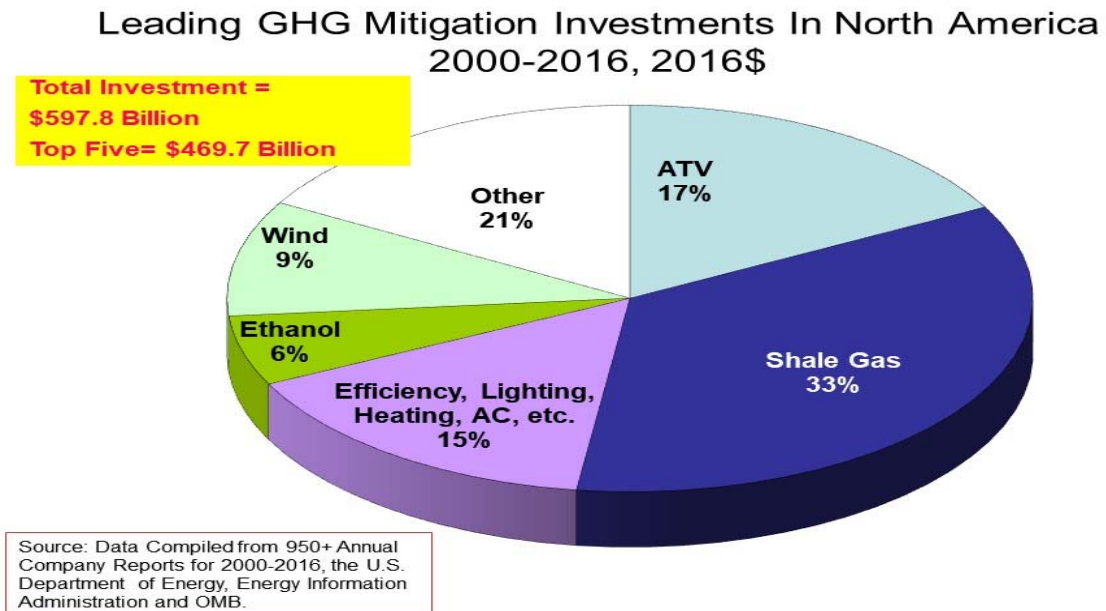
¹³ See bibliography for a list of data sources used in this study. Not all company reports reviewed provided data for the analysis undertaken in this report.

This report also does not include investments in battery and other energy storage technologies, other than the extent to which batteries and flywheels are subsumed in advanced technology vehicles. There are six main types of storage: Solid State Batteries , Flow Batteries, Flywheels, Compressed Air Energy Storage, Thermal, and Pumped Hydro-Power. Each has different application and different time horizon they provide storage for, and different costs and turn around efficiency. In themselves storage technologies do not reduce greenhouse gas emissions but may further enable technologies that can reduce emissions.

Five Leading Technology Investments

The five leading emission mitigation technologies for private and public-sector investment (**Figure 1**), as measured by expenditure share, are: shale gas, 33 percent (\$194.6 billion); advanced technology vehicles (ATV), 17 percent (\$100.0 billion); efficiency, 15 percent (\$86.9 billion)¹⁴; wind, 9 percent (\$53.4 billion); and ethanol, 6 percent (\$34.7 billion). These top five technologies commanded 79 percent of the estimated total investments, or \$469.7 billion over the 2000 – 2016 period in the North American market. All other technologies combined comprised 21 percent of the estimated total investments.¹⁵

Figure 1



¹⁴ “Efficiency” comprises all ‘other’ efficiency technologies except for combined heat and power (CHP) and vehicle efficiency, such as more efficient lighting, heating, ventilation, air conditioning, *etc.*

¹⁵ Percentages may not add to 100% due to rounding.

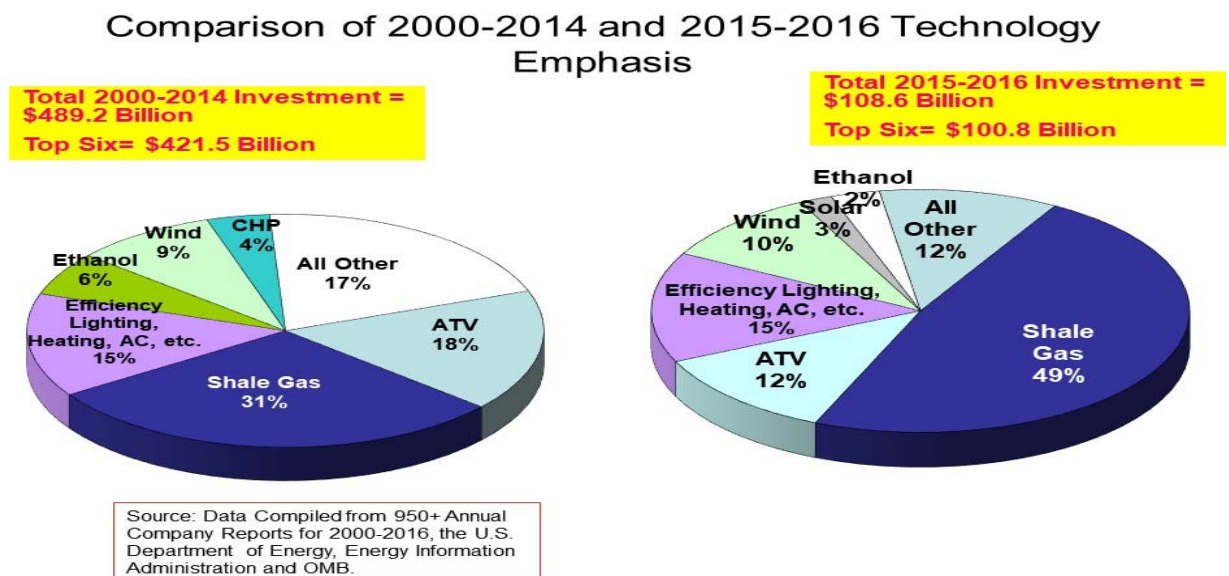
Major Movers

During the 2000 to 2016 period, different technologies captured attention in certain years, as opportunities and challenges developed or played out. Within the oil and gas industry, the most significant technology mover was shale gas. The EIA estimates that in 2016, proved reserves of natural gas increased by 5% from 324.3 trillion cubic feet (Tcf) to 341.1 Tcf—an increase of 16.8 Tcf. Proved reserves of U.S. crude oil and lease condensate rose 3% onshore in the Lower 48 states, while declines in oil reserves in Alaska and the Federal Offshore, led to virtually the same total U.S. crude oil and lease condensate at year-end 2016, at 35.2 billion barrels.¹⁶

During 2015 and 2016 the Federal Government continued to increase investments, although at a somewhat more modest pace than under the American Recovery and Reinvestment Act of 2009 (ARRA), now reaching a total of \$152.7 billion. Direct expenditures by the Federal Government helped drive an investment surge in solar (\$2.7 billion) and efficiency improvements (\$1.5 billion) in 2015 through 2016. The Federal Government continued investments in conventional technologies and fuels. Other private companies tempered their investments in renewables, compared to those driven by the Federal government's own direct expenditures under ARRA begun in 2009.

Figure 2 summarizes the major changes in technology focus, showing the percent of total investments in the 2000 to 2014 and 2015 to 2016 periods.

Figure 2



¹⁶ <http://www.eia.gov/naturalgas/crudeoilreserves/?src=home-b1>

Greenhouse Gas Mitigation Technology Investments

U.S. based companies¹⁷ and the Federal government invested approximately \$597.8 billion (2016 dollars) from 2000 to 2016 on greenhouse gas mitigating technologies in the North American market. The U.S. based oil and gas industry invested \$301.5 billion (\$108.2 billion without shale gas), 50 percent of the \$597.8 billion total, in end-use, fuel substitution, non-hydrocarbon, and enabling technologies. Other private companies invested an estimated \$143.6 billion or 24 percent of the total, predominantly in end-use and non-hydrocarbon technologies. During the same period, the Federal government invested in a wide array of greenhouse gas mitigation technologies, with expenditures of approximately \$152.7 billion (\$151.4 without shale gas), or 26 percent of the total North American investment (**Figure 3**). This does not include state and local expenditures nor investments.

Oil and Gas Industry Investments from 2000 through 2016

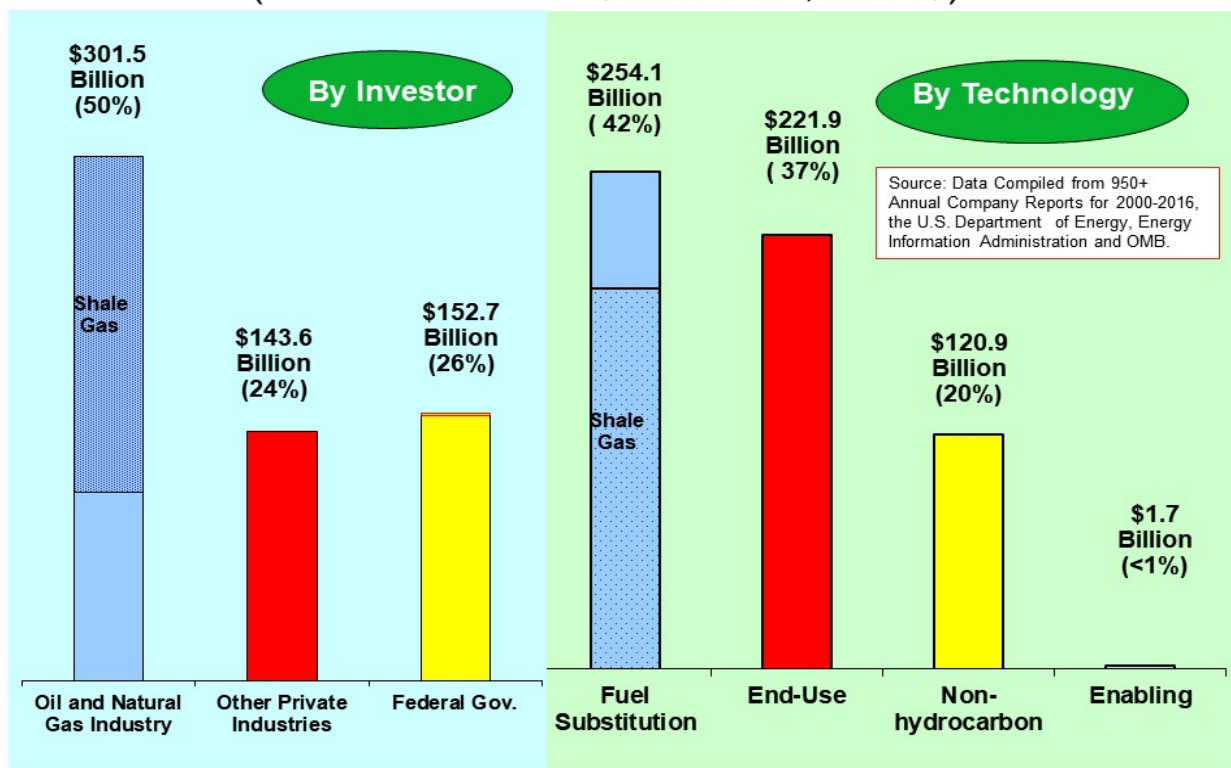
It is estimated that U.S. based oil and natural gas companies invested \$301.5 billion (\$108.2 billion without shale gas) from 2000 through 2016 in GHG mitigating technologies in the North American market.¹⁸ (**Figure 3**) This expenditure represents 50 percent of the estimated total of \$597.8 billion spent by U.S. companies and the Federal government. Publicly announced non-hydrocarbon investment by the U.S. based oil and gas industry in the North American market is estimated at just more than \$19.6 billion over the 2000 – 2016 period, or about 7 percent of the oil and natural gas industry's investments. This represents 16 percent of the total industry and Federal government investments of approximately \$120.1 billion in this technology class (**Figure 10**). The oil and gas industry's top publicly announced non-hydrocarbon investments continue to be in wind, biofuels, solar, geothermal, and landfill digester gas, although investments in those technologies each diminished in absolute amounts and in relation to shale gas investments.

¹⁷ U.S. based companies include both U.S. companies and foreign-owned companies operating in the U.S.

¹⁸ "North American market" is used herein to include Canada and the U.S.

Figure 3

GHG Mitigation Investments in North America 2000-2016 (Total Investment=\$598 billion, 2016\$)



The largest share of investments made by the oil and gas industry, roughly 73 percent or \$221 billion, was in the fuel substitution category (**Figure 4**). This \$221.4 billion investment in fuel substitution technologies represents 87 percent of the estimated \$254.1 billion invested in total in this technology class (**Figure 15**). Of this \$221.4 billion, \$193.3 billion, (87 percent of the oil and natural gas industry fuel substitution investment), was invested to expand shale gas development. The remaining fuel substitution technologies received \$28.1 billion from the oil and natural gas industry, or 13 percent of the \$221.4 billion oil and natural gas industry fuel substitution investment.

The oil and gas industry invested \$60.4 billion (or 20 percent of its \$301.5 billion total investments across technologies) for advanced end-use technologies, mostly for efficiency improvements including combined heat and power in the early part of the period, for carbon capture and storage¹⁹ and for advanced technology vehicles. Significantly, this \$60.4 billion

¹⁹ Carbon Capture and Storage was moved from “enabling” in the May 2008 Report to “end-use” in the 2011 report and here. As described on page 24, this technology has progressed beyond basic research, with demonstration plants now under construction.

investment in end-use technologies represents 27 percent of the estimated total amount (\$221.9billion) spent by all U.S. companies and the Federal government in this technology category (**Figure 16**).

Figure 5 shows the investment pattern over the 2000-2016 period for the oil and gas industry. Significant new levels of investment occurred starting in 2009 in the fuel substitution category. This surge was driven by investments for shale gas development, as advancing technology enabled companies to efficiently develop the very large US shale gas resources. These significant new investments were made in the face of a persistent recession and slow recovery. In late 2014, investments decelerated with drops in natural gas and crude oil prices.

Figure 4

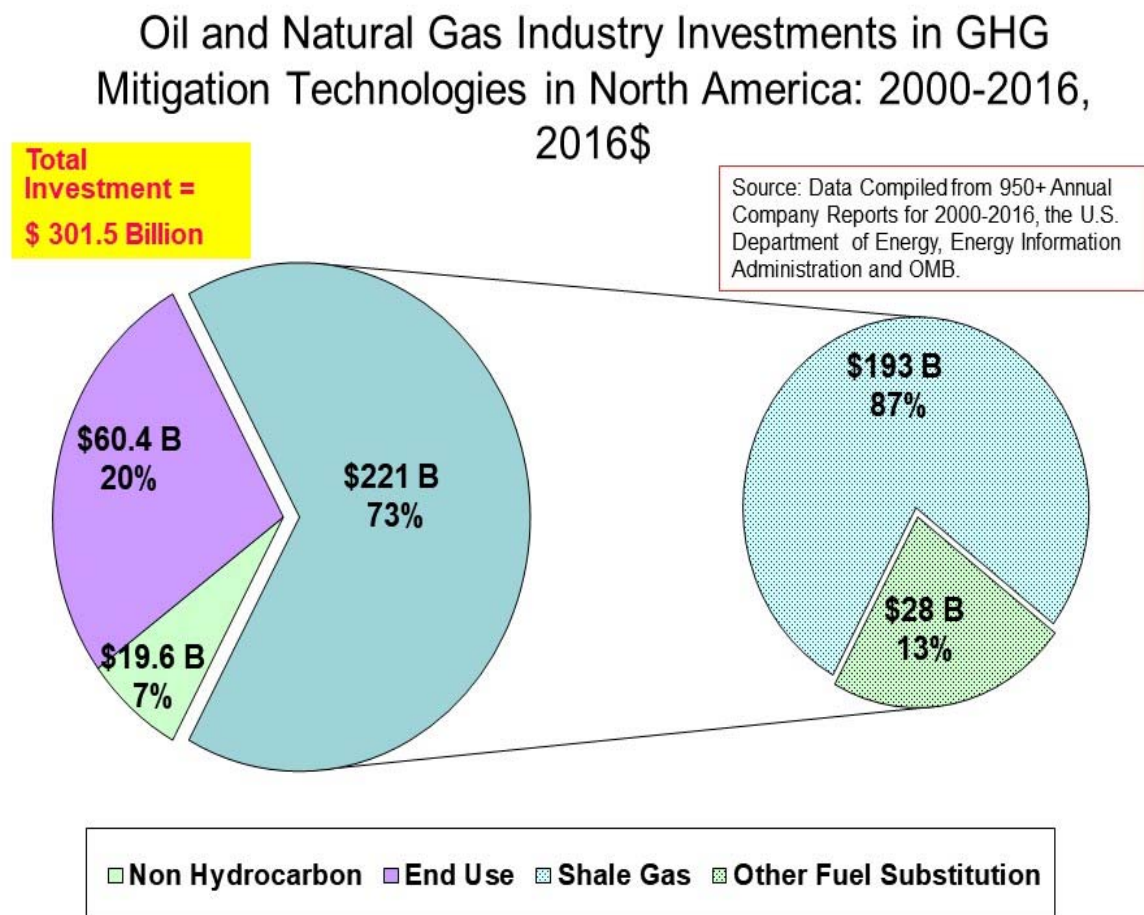
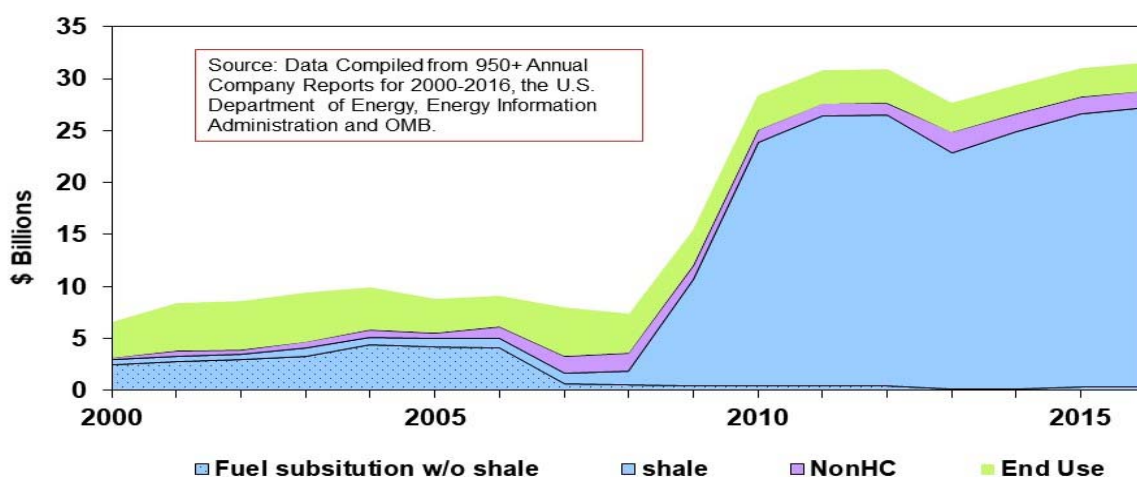


Figure 5

Oil and Natural Gas Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$



Other Private Industries' Investment from 2000 through 2016

In addition to the oil and gas industry, other significant technology investments were made by the motor-vehicle industry, agricultural industry, electric utilities, and the renewable-fuels industry. These other private industries are estimated to have invested \$143.6 billion (or 24 percent of the \$598.7 billion total) from 2000 to 2016 (**Figure 6**). Other private companies made significant investments in (1) the *end-use* market (mostly automotive companies investing in advanced technology vehicles), and (2) the *non-hydrocarbon* market (mostly agricultural firms and renewable fuel firms in the biofuel market, independent power producers in the electricity market, and manufacturing firms in the wind and solar markets).

Of the \$143.6 billion sector total, \$76.1 billion (52 percent) is associated with end-use technologies, \$44.4 billion (31 percent) with non-hydrocarbons and \$23.0 billion (17 percent) with fuel substitution technologies. End-use technologies include advanced technology vehicles, efficiency improvements and combined heat and power. Non-hydrocarbons include industrial gas replacements (e.g. for SF₆), and renewables such as wind, solar and ethanol. Fuel substitution technologies included a significant proportion in landfill gas recovery and in the mid to later years significant investment in nuclear. By technology class, other private industries'

investment share was 46 percent of the non-hydrocarbon investment, 9 percent of the fuel substitution category and 34 percent of the end-use category. (**Figures 18-20**).

Figure 6

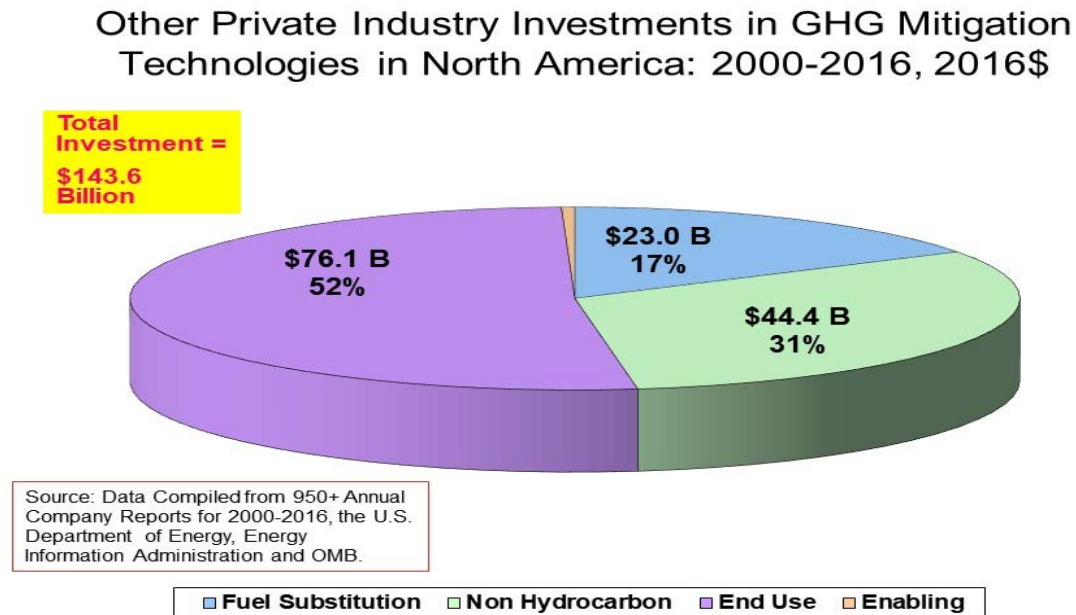


Figure 7 shows the investment pattern over the 2000-2016 period for other private companies. Significant new levels of investment occurred starting in 2009 in non-hydrocarbon technologies such as wind energy, largely driven by various states Renewable Portfolio Standards, favorable tax credits and the Federal Renewable Fuel Standard. Some of the investments were “matched” or otherwise encouraged by Federal expenditures under ARRA, further increasing activity by other private sector industries. In 2015 and 2016, the amount of investment by other private industry declined compared to the most recent peak in 2012.

Figures 8-11 show the investment by various sectors under the category of “other private industries” for fuel substitution technologies (**Figure 8**), end use technologies (**Figure 9**), nonhydrocarbon technologies (**Figure 10**) and for all technologies (**Figure 11**.)

Electric utilities and independent power producers invested approximately \$13.1 billion or 55% of the fuel substitution investments by other private industries, primarily in renewables and nuclear. Approximately 20% or \$4.8 billion was invested by automobile industry in alternative fuels. Investments made by automakers in alternative fuel vehicles and engines are included in the end use category.

Figure 7

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$

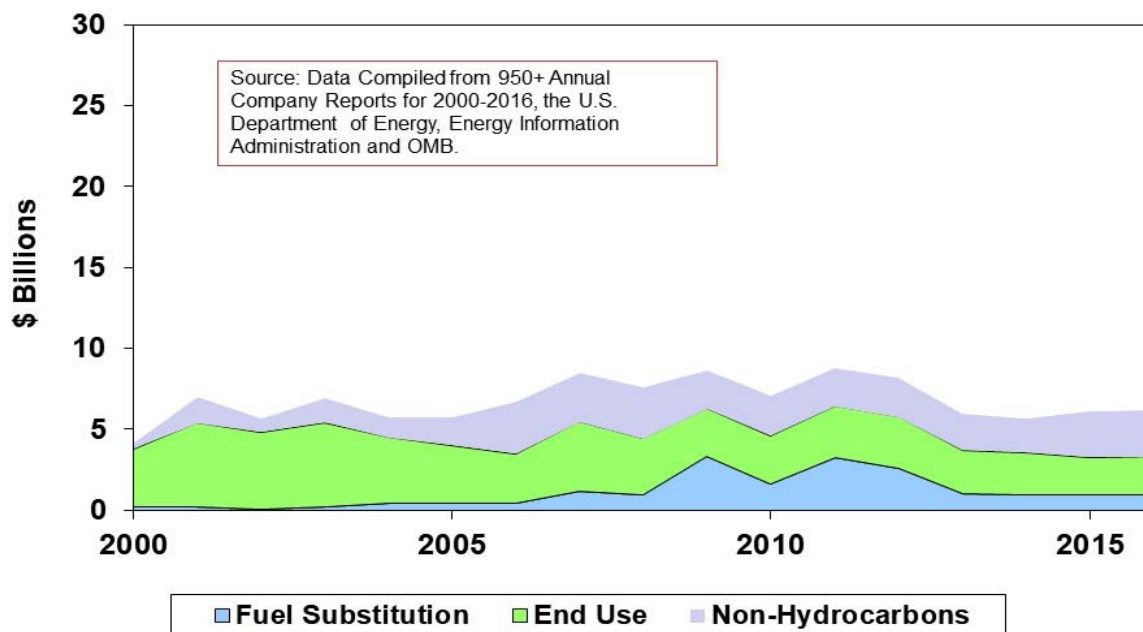
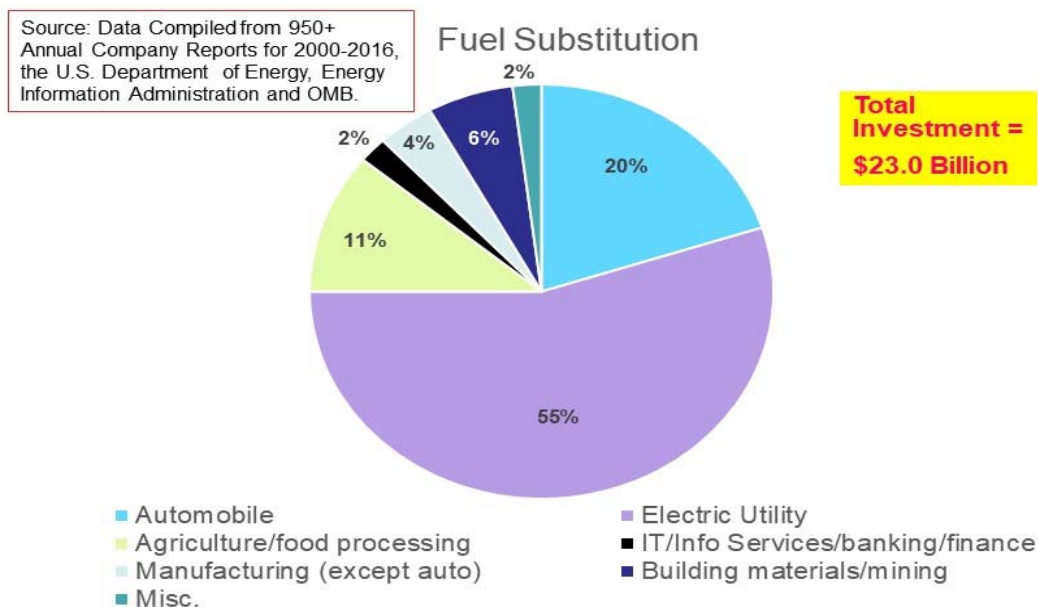


Figure 8

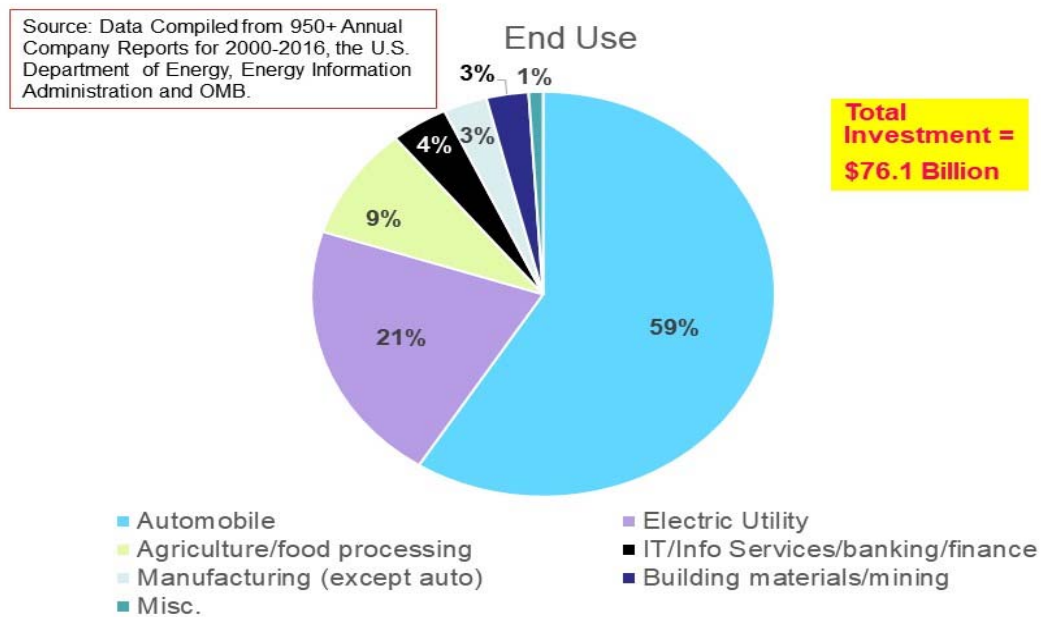
Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$



Automakers made up the bulk of investments, \$44.1 billion or 59%, in the end use category (**Figure 9**). Electric utilities and independent power producers made investments of \$15.7 billion (21%) of the end use category investments by other private firms, including carbon capture and sequestration, other efficiency improvements, and combined heat and power. Agricultural and food processors accounted for \$6.7 billion or 9 percent, mostly for combined heat and power and other efficiency improvements.

Figure 9

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$

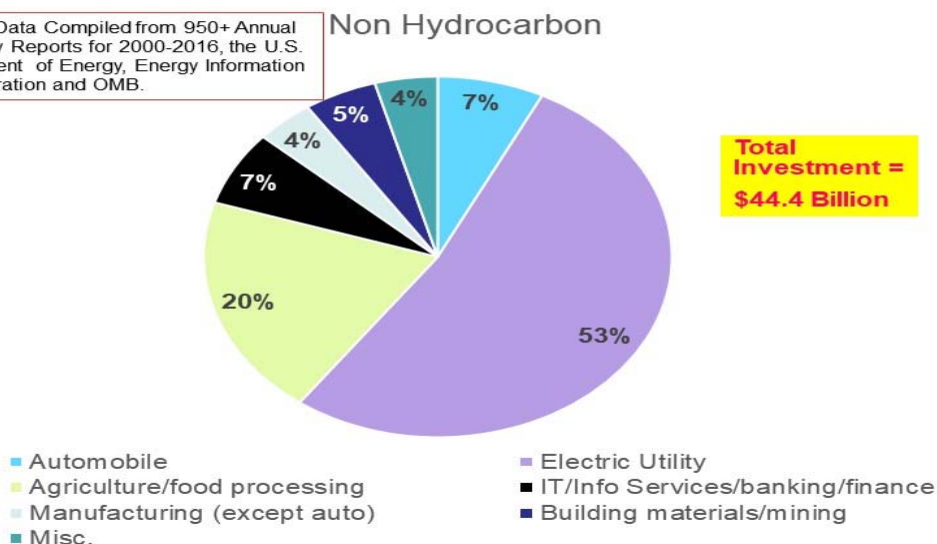


In the nonhydrocarbon category, electric utilities and independent power producers accounted for 53% or \$23.5 billion of the total sector investment of \$44.4 billion (**Figure 10**) in this technology category. This included various renewable energy like wind and solar, but also geothermal and biomass. Agricultural entities, including processors, accounted for 20% or \$8.9 billion, largely in corn-based ethanol.

Figure 10

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

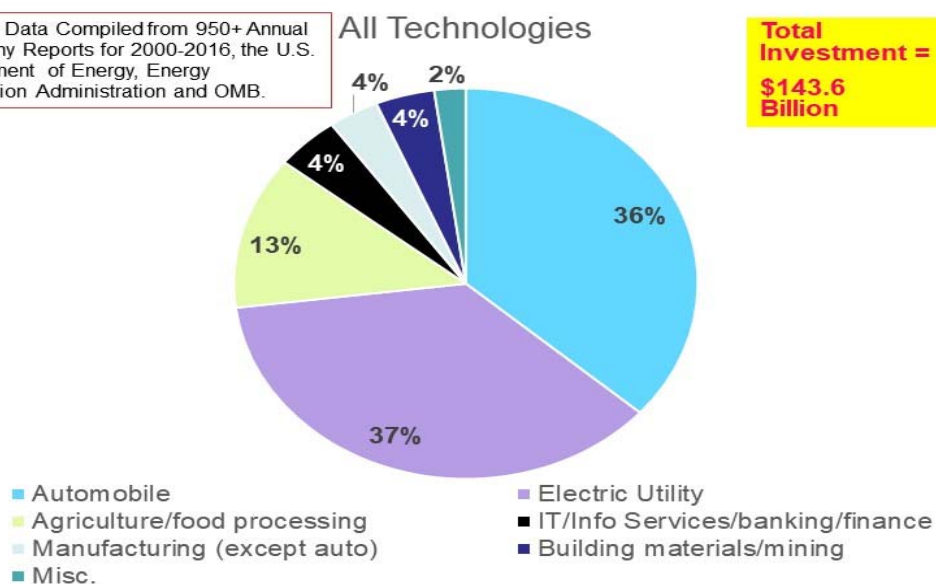


Of the total investments of \$143.6 billion made from 2000 through 2016 (**Figure 11**) by other private firms, the automotive sector accounted for 36% or \$51.7 billion, and the electric utilities and independent power producers for 37% or \$53.1 billion.

Figure 11

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.



Federal Government Investments from 2000 through 2016

The Federal government (**Figure 12**) has been the most diversified investor, supporting all sixteen technologies considered in this report. Total estimated expenditure in the years 2000-2016 of \$152.7 billion has been spread between fuel substitution, non-hydrocarbons (primarily ethanol, wind, and solar) and end-use (primarily advanced technology vehicles, cogeneration and lighting technologies).

Fifty-seven percent, or \$86.8 billion of the Federal government investment is estimated to be in end-use technology, including enhanced energy efficient lighting, combined heat and power and similar efficiency improvements as seen in **Figure 12**. Thirty-seven percent, or \$55.5 billion of the Federal government investment is in the nonhydrocarbon class (including wind, ethanol, solar, and biodiesel), 6 percent, or \$8.9 billion in the fuel substitution class (such as landfill gas and shale gas), and one percent, or \$1.3 billion fell into the enabling technology class.

Figure 12

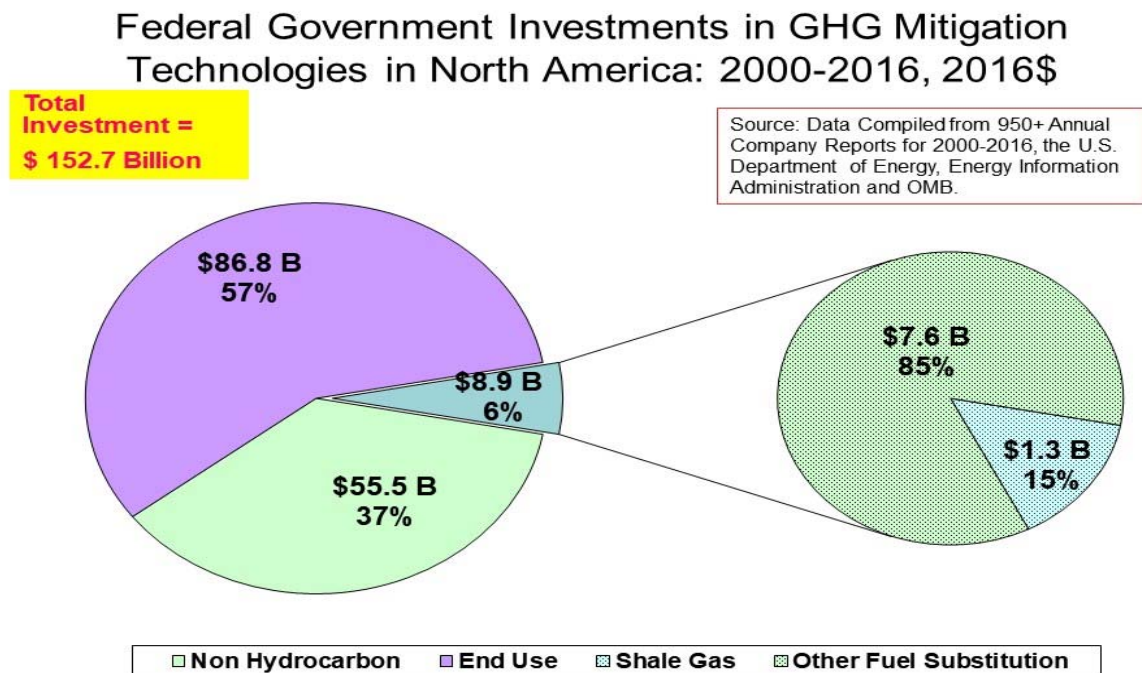


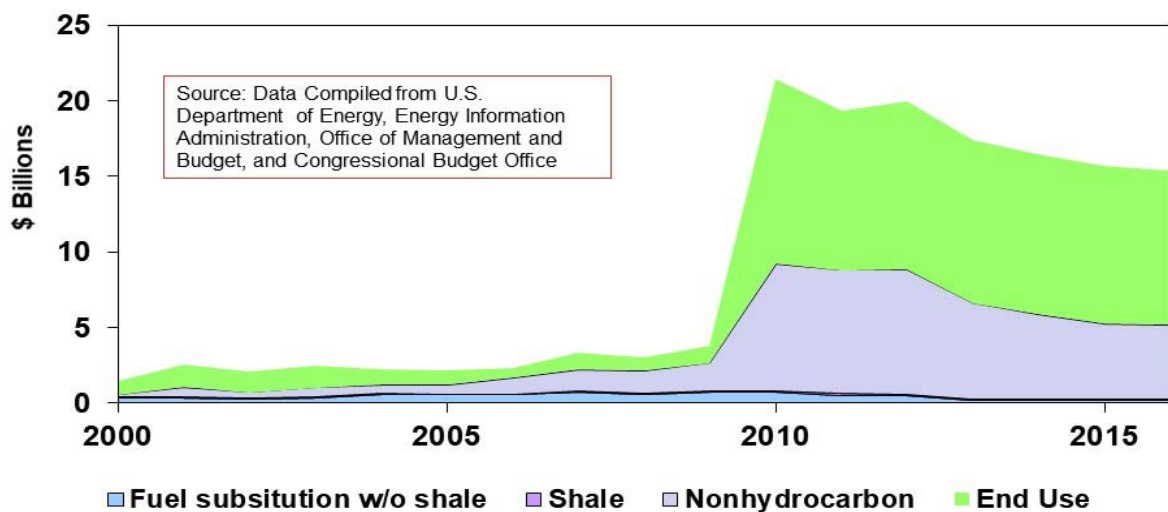
Figure 13 shows the investment pattern over the 2000-2016 period for the Federal Government. Significant new levels of investment occurred between 2009 and 2012, especially in non-hydrocarbon measures and efficiency, mostly as a result of Department of Energy spending of ARRA appropriations. According to the Government Accountability Office, the

Federal investments under ARRA were concentrated in energy efficiency and renewable technologies.²⁰

Another feature of the change in the amount of Federal Government investments after 2009 in addition to the significant increase in federal spending, was the nature of federal spending. In earlier periods, federal spending was more heavily focused on early-stage development investments, particularly at the basic research stage. Now it includes later stage and commercial plants investments, such as using Section 1603 direct grants to wind energy facilities in lieu of tax credits.

Figure 13

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$



Finally, it is important to recognize that aggregate investment levels for each technology are, and should be, consistent with the development status and market potential of that technology. This holds for all investor types. More mature technologies are likely to see higher levels of

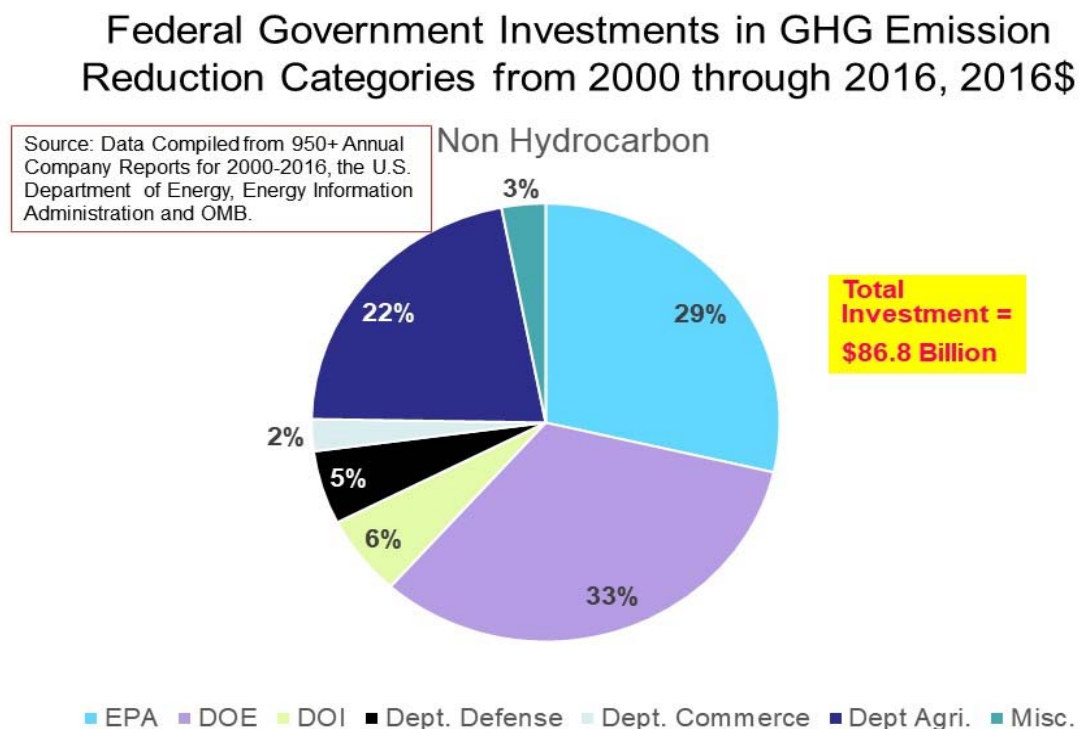
²⁰ Frank Rusco, Director Natural Resources and Environment, United States Government Accountability Office, Testimony Before the Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives, RECOVERY ACT Status of Department of Energy's Obligations and Spending, March 17, 2011

investment than technologies earlier in the development cycle. The technologies included here are at different stages in their development cycle and exhibit varying levels of market potential as indicated in part by relative expenditures. The distribution of investments can be expected to shift as different technologies mature or market conditions change.

Figures 14-17 show the investment by various agencies of the Federal Government for nonhydrocarbon technologies (**Figure 14**), end use technologies (**Figure 15**), fuel substitution technologies (**Figure 16**), and for all technologies (**Figure 17**).

The Department of Energy (DOE) and the Environmental Protection Agency (EPA) made up the bulk of investments, \$53.9 billion or 62%, in the non-hydrocarbon category (**Figure 14**) spread fairly broadly across the various technologies. The Department of Interior (DOI) and Department of Defense accounted for another \$9.5 billion or 11 percent, mostly for alternative fuels largely in corn-based ethanol and biodiesel.

Figure 14



In the end use category, DOE and EPA combined for 54% or \$30 billion of the total sector investment of \$55.5 billion (**Figure 15**) in this technology category. In the fuel substitution category (**Figure 16**) they represented 60% or \$5.3 billion.

Figure 15

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

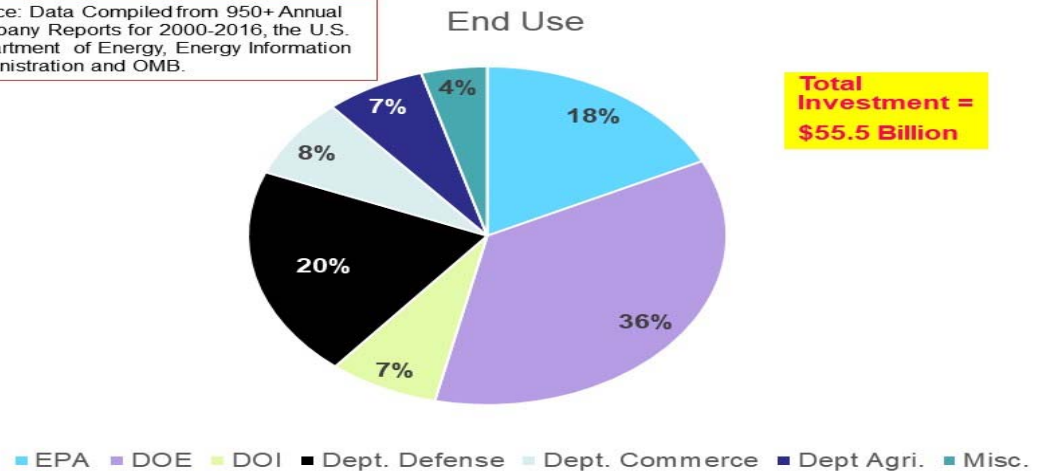
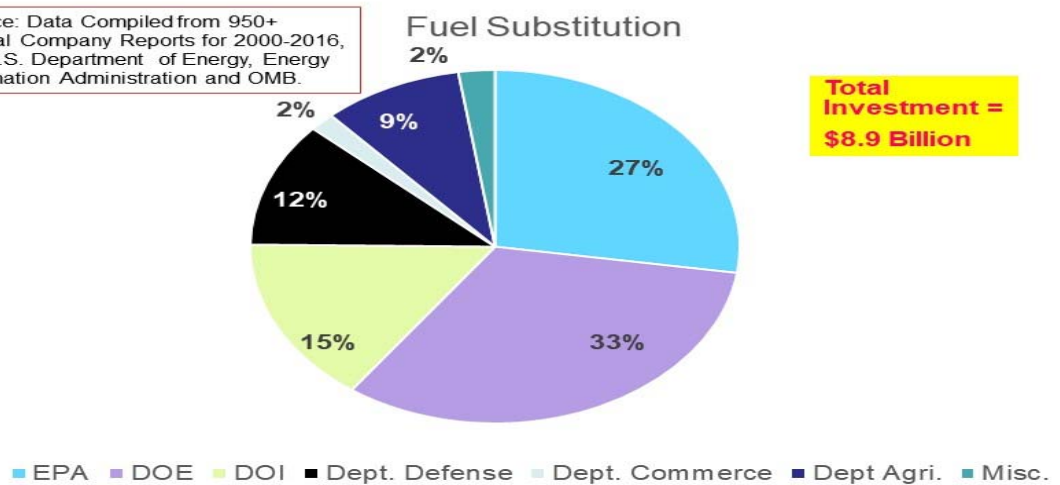


Figure 16

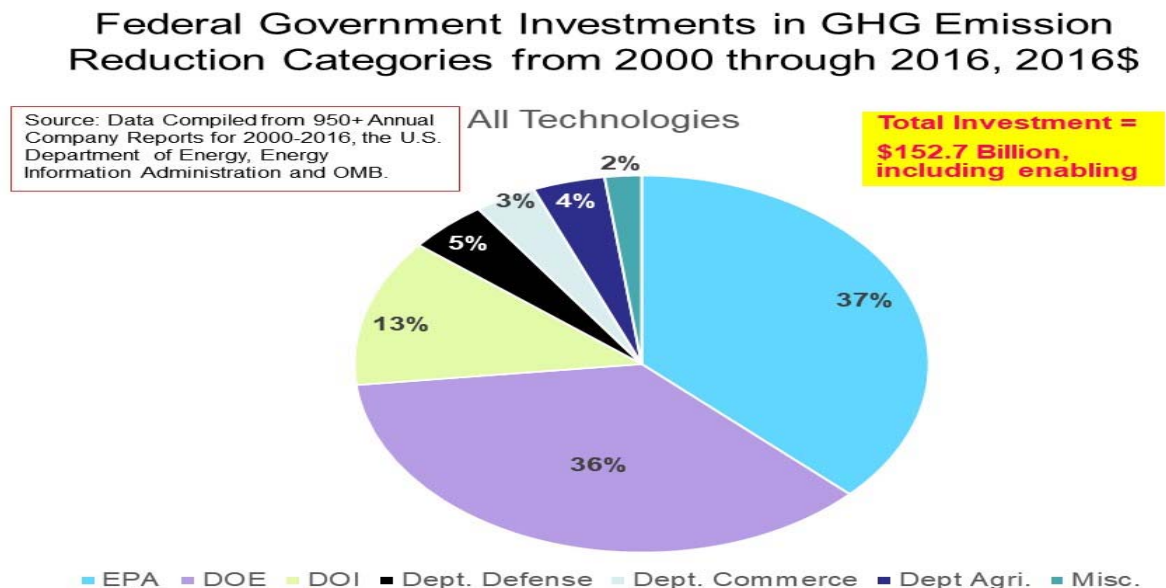
Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, 2016\$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.



Of the total investments of \$152.7 billion made from 2000 through 2016 (**Figure 17**) by the Federal government, EPA accounted for 37% or \$56.5 billion, and the Department of Energy for 36% or \$55.0 billion.

Figure 17



Technology Investments by Investor Types

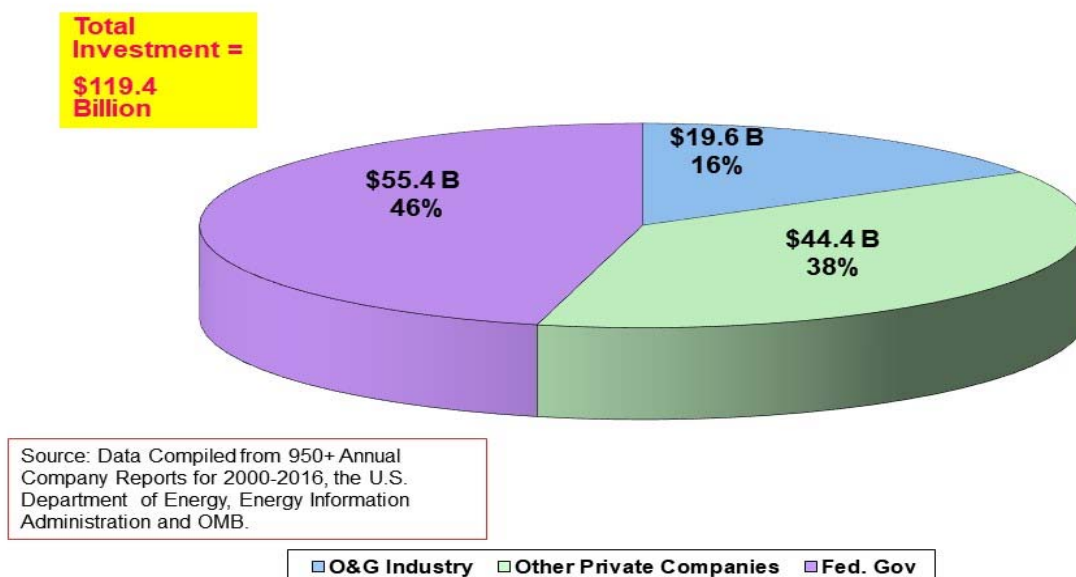
Figures 18-20 show, for each technology category, the investment shares by investor type.

Non-Hydrocarbon (18)

Other U.S.-based private companies invested roughly 38 percent of the \$119.4 billion non-hydrocarbon category total from 2000 to 2016. This includes independent power producers investing in renewables like wind and solar, and agricultural and renewable fuel interests investing in ethanol production. The U.S. based oil and gas industry invested approximately 16 percent of the category total, including investments in renewables like wind and solar, as well as ethanol. The Federal government invested approximately 46 percent, spread among the renewables, ethanol and other technologies, much of it in the second half of the 2000-2016 period.

Figure 18

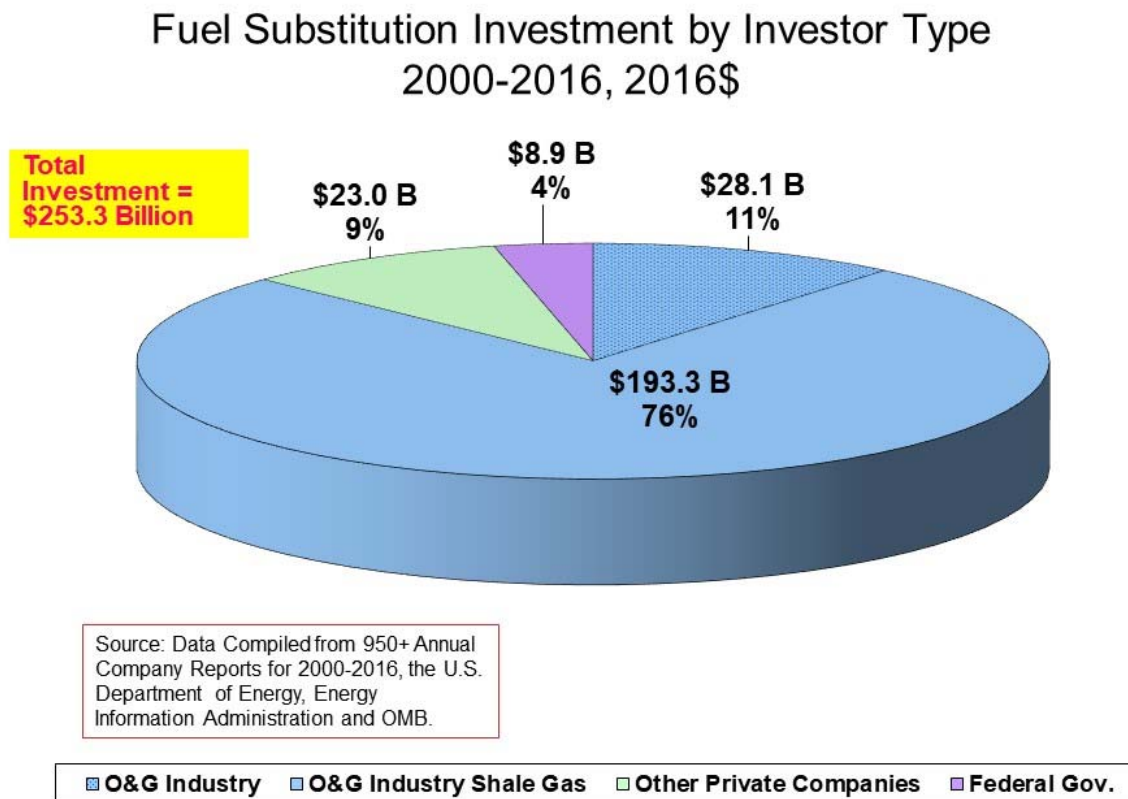
**Non-Hydrocarbon Investments by Investor Type
2000-2016, 2016\$**



Fuel Substitution (19)

The U.S.-based oil and gas industry invested approximately 87 percent of the fuel substitution category (46% of the category total without shale gas), with significant investments in liquefied natural gas (LNG) in early years and shifting to and increasing, dramatically, investments in shale gas in the later years. Other private companies accounted for roughly 9 percent in fuel substitution, with a significant proportion in landfill gas recovery and nuclear. The Federal government accounted for just under 4 percent of this category, including investments in nuclear and landfill gas recovery as well as shale gas.

Figure 19



End Use (20)

Within the end-use category, other U.S. based industries invested an estimated 34 percent or \$76.1 billion. This includes significant investments by automotive companies investing in advanced-technology vehicles, and coal companies' investments, along with electric utilities, in carbon capture and storage (CCS). U.S. based oil and gas industry invested approximately 27 percent, or \$60.4 billion of the \$223.3 billion total investment in this technology category, principally in cogeneration, carbon capture and storage and advanced technology vehicles, including advanced batteries. The Federal government invested approximately 39 percent, or \$86.8 billion in the end-use category, including investments in lighting technologies and advanced technology vehicles. In the case of advanced technology vehicles, Federal Government investments are typically used to match investments from both oil and gas companies and, more typically, from other private sector companies like automobile and battery makers.

Figure 20

**End Use Investments by Investor Type
2000-2016, 2016\$**

**Total
Investment =
\$223.3 Billion**



Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

■ O&G Industry ■ Other Private Companies ■ Fed. Gov.

Chapter II: Emission Reductions Reported

This chapter provides a compilation of greenhouse gas (GHG) emission reduction estimates reported by the U.S. based oil and natural gas industry. The emission reduction estimates for 2008-2016 presented herein were compiled strictly from company reports including annual shareholder reports and corporate responsibility reports. The authors did not solicit, receive, or utilize any nonpublic information to develop these estimates. As discussed in the Methodology section below, there are indications that this summary of reported reductions is an underestimate of actual reductions.

Reported reductions fall into three major categories:

- *Fuel substitution*, such as increasing natural gas supply through capturing fugitive emissions, and replacing more carbon intensive fuels,
- *Non-hydrocarbon*, such as biofuels produced at biorefineries, and,
- *End-use*, including combined heat and power.

The \$301.5 billion in GHG mitigation technologies made by the U.S. based oil and natural gas industry over 2000 to 2016 clearly resulted in emission reductions, both directly by the oil and gas companies and indirectly as other private companies like electric utilities have switched from coal to natural gas. However, it needs to be recognized that other factors make it difficult to specifically link aggregate emission reductions and individual past investments. For example, while this report documents reported emission reductions between 2008 and 2016, investments made can often take time to complete with actual emission reductions occurring with a lag of five years or more. Some of the reductions in 2014-2016 are likely due to investments made in the middle years of the 2000-2016 period.

U.S. based oil and gas industry sources have reported direct emission reductions totaling 57.1 million metric tons CO₂ equivalent for 2016 compared to 2015. The reduction of 57.1 million metric tons is equivalent to taking 12.1 million cars and light trucks off the road,²¹ or retiring nine 1000MW coal fired power plants and putting one more on part-time duty.²² For comparison,

²¹ Passenger vehicles estimate derived from <http://www.epa.gov/otaq/climate/420f05004.htm>, by dividing total reductions by average passenger vehicle emissions

²² Average coal plant estimate derived from <http://www.epa.gov/cpd/pdf/brochure.pdf> and http://www.eia.gov/coal/production/quarterly/co2_article/co2.html by calculating total MWh/year, mmBTU/MWh and MMT CO₂/mmBTU.

there are over 260 million cars, buses, motorcycles and trucks in the US, according to the U.S. Department of Transportation.²³

- An average of forty-one percent of the emission reductions occur in the fuel substitution category, over the period 2011-2016. This includes projects such as the installation of improved plunger lift seals and lower emission well completion technology, during such activities as hydraulic fracturing.
- An average forty percent of the reductions are in the end use category, largely from investments in combined heat and power (also known as cogeneration) at refineries and other facilities, especially investments begun in the years prior to 2008.
- The remainder of the reductions, an average of 19 percent, occur in the non-hydrocarbon category.

Table 2
Reported Emission Reductions 2008 -2016 relative to Prior Year
Oil and Gas Industry in North America
Million Metric Tons CO₂e

	Fuel Substitution	End Use	Nonhydrocarbon	Total
2011	19.8	24.3	9.0	53.1
2012	19.9	24.5	9.2	53.6
2013	20.4	24.8	9.2	54.4
2014	20.9	25.2	9.4	55.5
2015	21.1	24.7	9.1	54.9
2016	22.7	25.5	8.9	57.1
Average	20.8	24.8	9.1	54.7

These figures are generally supported by a report published by Bloomberg New Energy Finance (BNEF).²⁴ The five largest oil companies — Exxon Mobil Corp., Royal Dutch Shell PLC, Chevron Corp., BP PLC and Total SA — collectively cut their greenhouse gas emissions by an average of 13 percent from 2010 to 2015, according to BNEF. BP reported the largest percentage cut, at 25.5 percent, according to the report. Exxon, the largest emitter among the listed companies, achieved a 14 percent reduction.

²³<https://www.fhwa.dot.gov/policyinformation/statistics/2014/mv1.cfm>

²⁴ <https://www.bloomberg.com/news/articles/2017-09-18/big-oil-becomes-greener-with-cuts-to-greenhouse-gas-pollution>

Emissions Reduction Methodology

This analysis reflects a compilation of reported emission reductions from company reports, including annual shareholder reports and “Corporate Responsibility Reports.”²⁵

While this methodology is straightforward, there are indications that it could result in an underestimation of emission reductions.

- First, not all companies reported emission reductions, so the reductions compiled here are likely conservative.
- Second, methane emission reductions reported in EPA’s Natural Gas STAR program for the last reported year, 2013, are substantially greater than the total reported here. More specifically, the average 20.8 million metric tons of CO₂e reductions reported for the Fuel Substitution category includes but is not limited to methane emission reductions from improved exploration and production equipment and practices. However, EPA’s Natural Gas STAR program²⁶ reports 2013 methane reductions from producing entities, of 50.7 billion cubic feet or roughly 24 million metric tons of CO₂e. This exceeds the total average reductions reported here for the entire Fuel Substitution category each year.

For example, according to EPA data, methane emissions from natural gas development have fallen steadily since 2005, while natural gas production is rising steadily – even as less and less methane is being emitted from that production. Net methane emissions from natural gas production fell 38 percent from 2005 to 2015 – even as natural gas production increased dramatically. According to the most recent Environmental Protection Agency (EPA) Inventory of U.S. Greenhouse Gas Emissions and Sinks²⁷, U.S. natural gas systems had a methane leakage rate of 1.2 percent in 2015 – which is 30 percent lower than global average. Additionally, U.S. oil and gas system methane emissions represent just 10.5 percent of the world’s total oil and gas methane emissions.

²⁵ Corporate responsibility reports go by a variety of names including “sustainability reports,” “citizenship” and other similar names. We use “Corporate Responsibility” here in the generic sense to include all such reports.

²⁶ See <http://www.epa.gov/gasstar/accomplishments/index.html#three>

²⁷ <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

- Emissions reductions from substituting natural gas for coal are not included in reported emission reductions by oil and gas companies but are significant in reducing overall emissions (see following section.)

Emission reductions reported were then categorized based on company descriptions of how the reductions were achieved, where such descriptions were provided. For example, reductions achieved through efficiency improvements were assigned to the end use category. Emission reductions that were reported by some companies on a global basis were prorated to the North American market using secondary sources. This was done only in the fuel substitution category, associated with emission reductions due to methane capture from fugitive emissions. In this case we used reported emission reductions from EPA's Natural Gas Star Program for 2013, the last reported year, to prorate global emission reduction estimates to the North American market.

Some companies reported reductions (or intensity improvements) based upon their equity involvement in shared facilities (such as refinery complexes) while some reported the reductions for the entire facility, especially if they were or are the primary operator of that facility. We include reductions based on equity positions to avoid double counting. No specific link is suggested between a specific investment and emission reduction.

Investment Estimates Methodology

This analysis was carried out in several steps. The first was an identification of major categories of emerging energy sources, and the associated emissions control/reduction technologies. Second, a database of investments was constructed by GHG mitigation technology category and by investor type, including subcategories²⁸ within the category of "other private industries." The database was compiled from a review of over 950 publicly available company annual reports, federal budget documents, and other public sources, beginning with the database constructed for the 2015 report, *Key Investments in Greenhouse Gas Mitigation Technologies by Energy Firms, Other Industry and the Federal Government*: October 2015. This analysis examined capital expenditures as listed in the company reports and other documents. No confidential or non-public company investment information was sought, received, or utilized. If an investment amount for a relevant technology was specified in a source document, it was

²⁸ Subcategories were chosen based simply upon popular terminology. Subcategories were treated the same as other aggregate categories with respect to data sources. Any particular firm was assumed to be entirely within its primary subcategory. For example, a parent company whose primary endeavor is electric utility, was 'assigned' to electric utility even if it has business(es) in information technology. No effort was made to prorate investments into different business lines within a firm.

included in the database. All investments were initially tabulated in nominal dollars. Because the investments covered in this report have occurred over a fifteen-year period, it is appropriate to adjust the annual data for the inflation that has occurred over the study period. Given that most investments in greenhouse gas mitigation technology covered in this report are spread across many sectors of the economy, the deflator chosen to convert the annual data to 2016 dollars was the U.S. Department of Commerce, Bureau of Economic Analysis chain-type deflator for “Gross Private Domestic Investment.”²⁹

Third, each investment was reviewed to determine if it should remain in the database, be prorated, or otherwise adjusted from a global level to the North American market. For example, we identified three major types of investments for LNG: liquefaction, regasification facilities, and ships. We have only included investments in North American LNG regasification facilities. The global LNG market also includes investments in ships, and liquefaction facilities in foreign and domestic locations. Investments in ships and liquefaction facilities were not included in the data base as they, to a large extent, fall outside the area of the North American market.

²⁹ Available at <http://research.stlouisfed.org/fred2/series/GPDICTPI?cid=21>

Appendix A

Figures Presented in Nominal Dollars

Figure A-1

GHG Mitigation Investments in North America 2000-2016
(Total Investment=\$534.2 billion, Nominal \$)

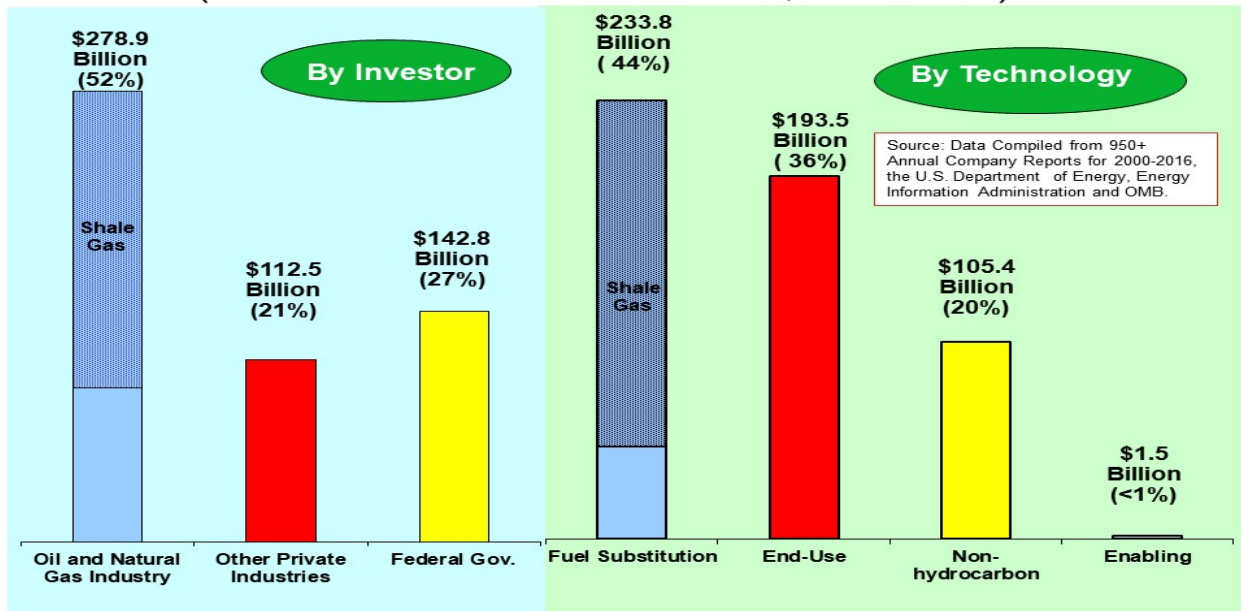


Figure A-2

Leading GHG Mitigation Investments In North America
2000-2016, Nominal \$

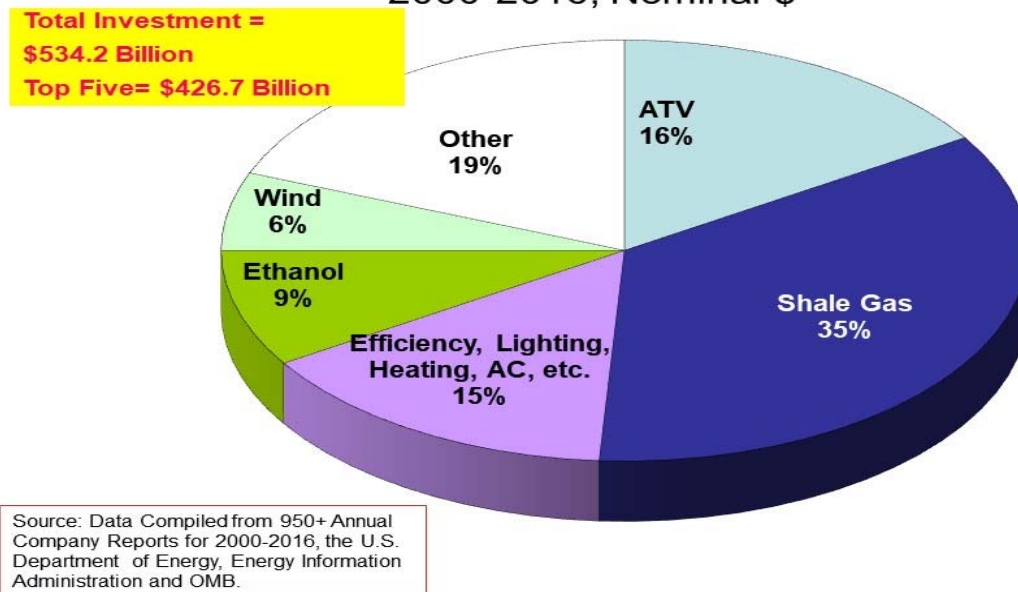
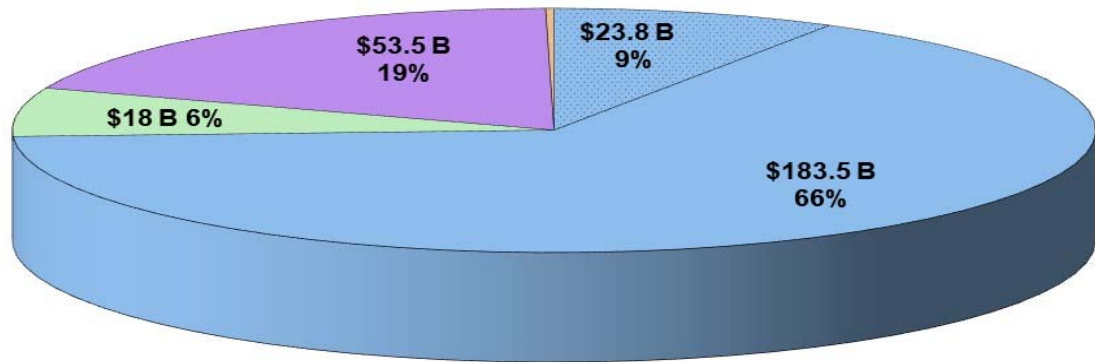


Figure A-3

Oil and Natural Gas Industry Investments in GHG Mitigation Technologies in North America: 2000-2016, Nominal \$

Total Investment = \$278.9 Billion



Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

Fuel Substitution w/o Shale Gas Shale Non Hydrocarbon End Use Enabling

Figure A-4

Oil and Natural Gas Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

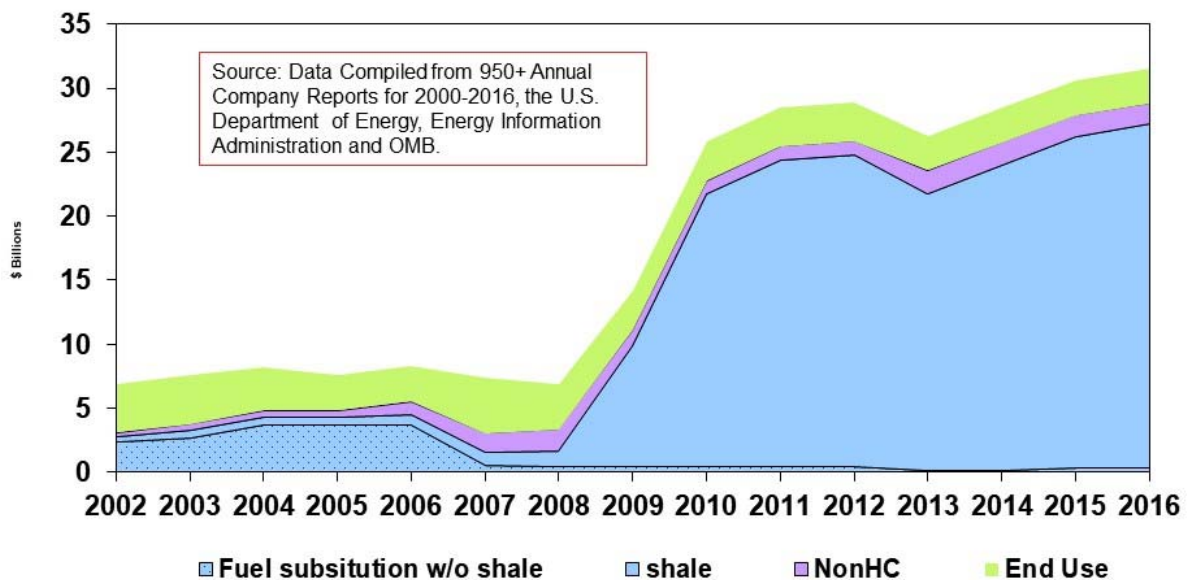


Figure A-5

Other Private Industry Investments in GHG Mitigation Technologies in North America: 2000-2016, Nominal \$

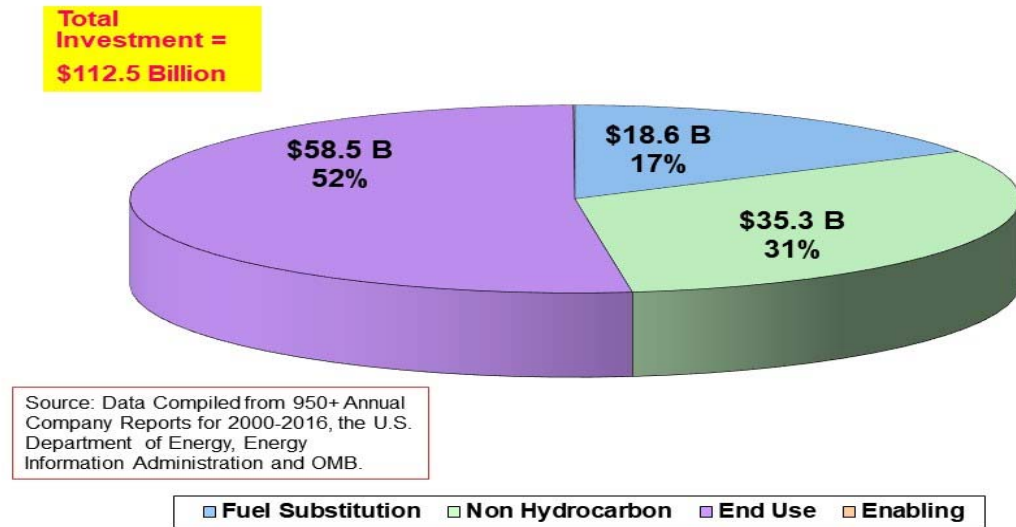


Figure A-6

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

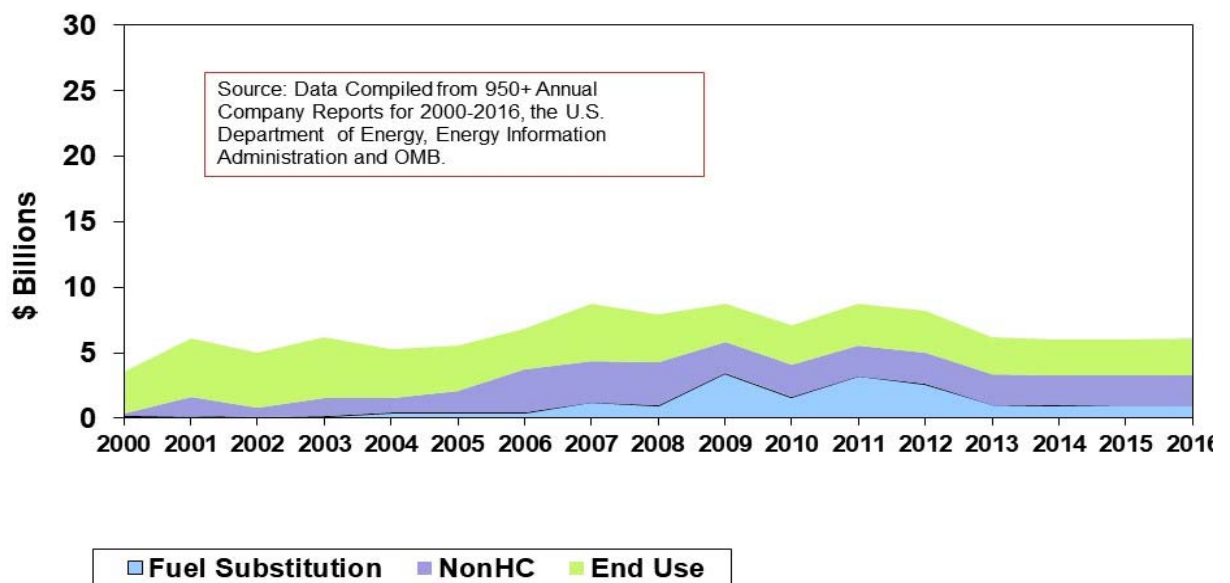
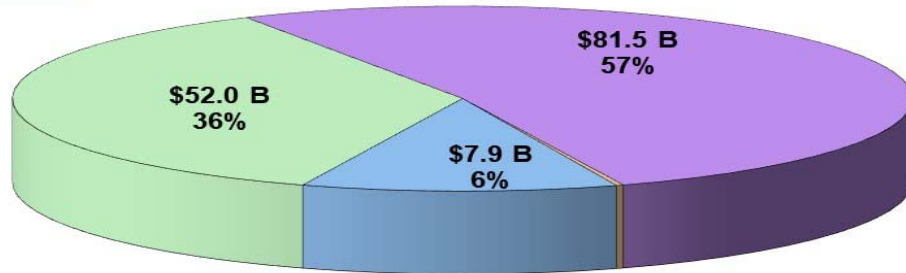


Figure A-7

Federal Government Investments in GHG Mitigation Technologies in North America: 2000-2016, Nominal \$

**Total
Investment =
\$142.7 Billion**



Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

Fuel Substitution Non-Hydrocarbon End Use Enabling

Figure A-8

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

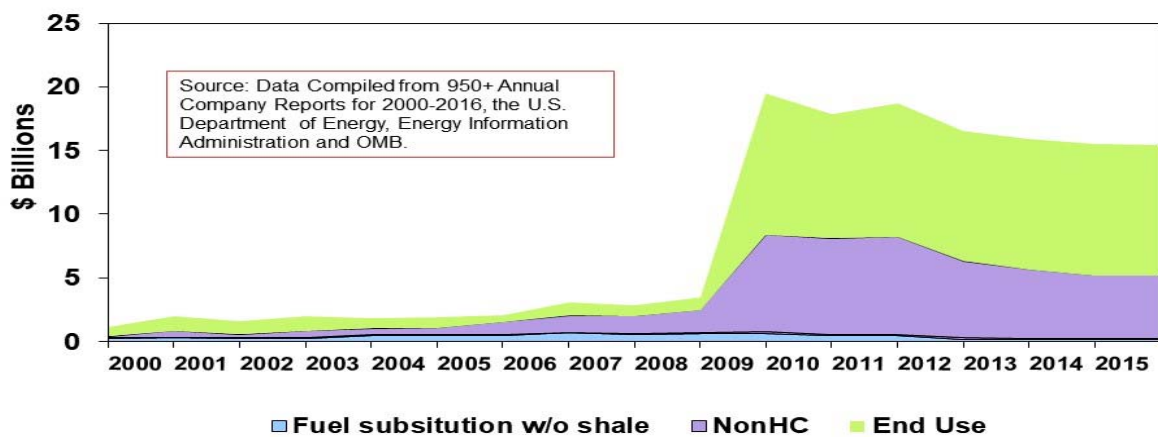


Figure A-9

Fuel Substitution Investment by Investor Type
2000-2016, Nominal \$

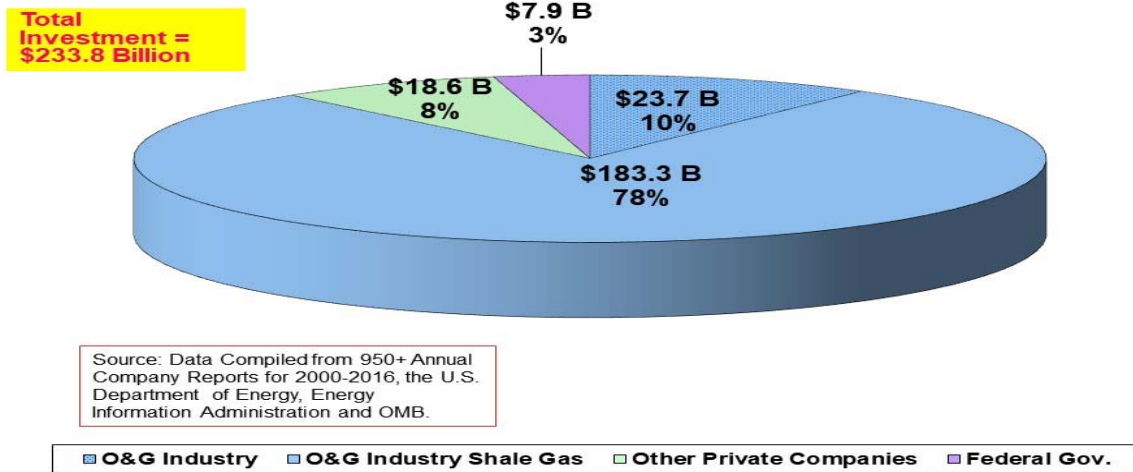


Figure A-10

Non-Hydrocarbon Investments by Investor Type
2000-2016, Nominal \$

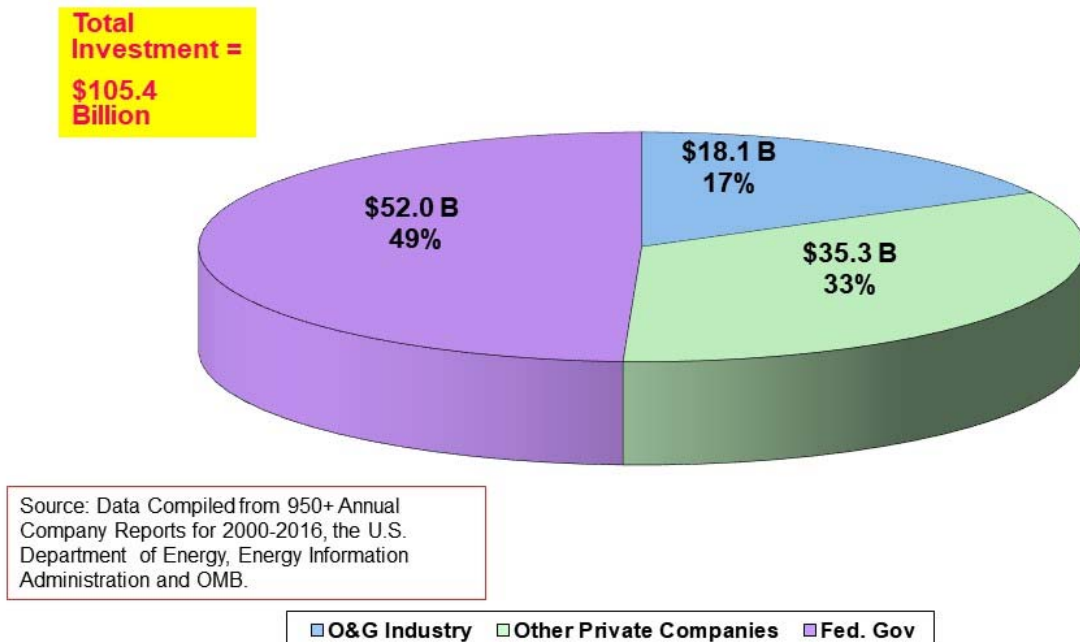


Figure A-11

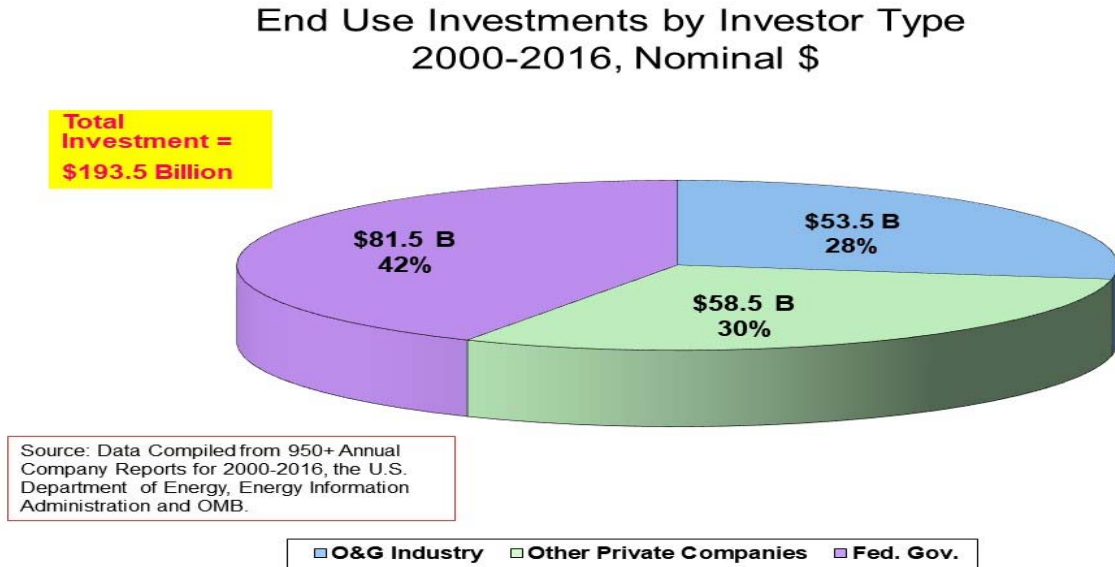


Figure A-12

**Other Private Industry Investments in GHG Emission
Reduction Categories from 2000 through 2016, Nominal \$**

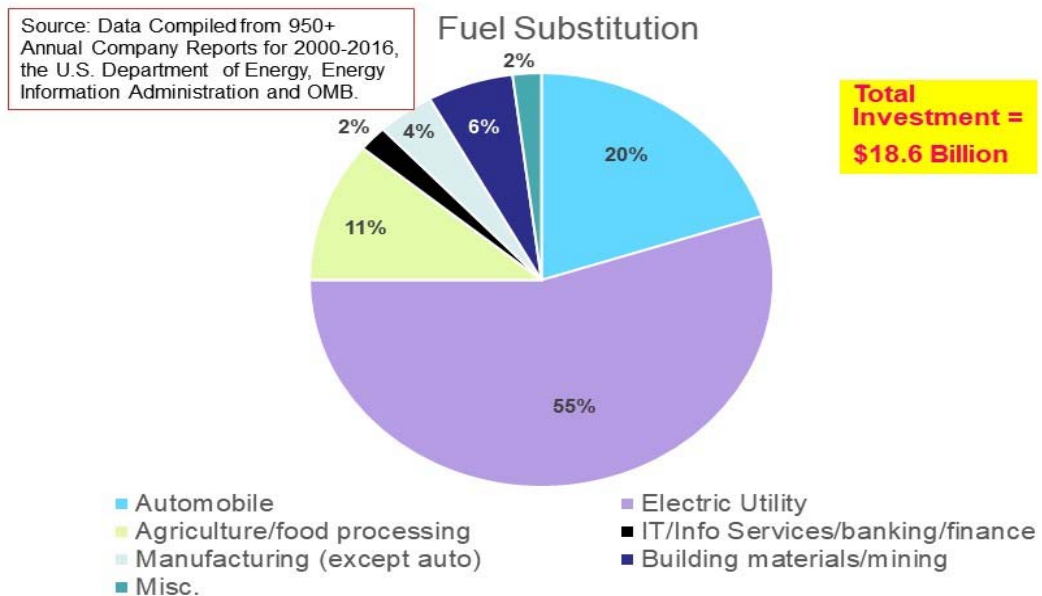


Figure A-13

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

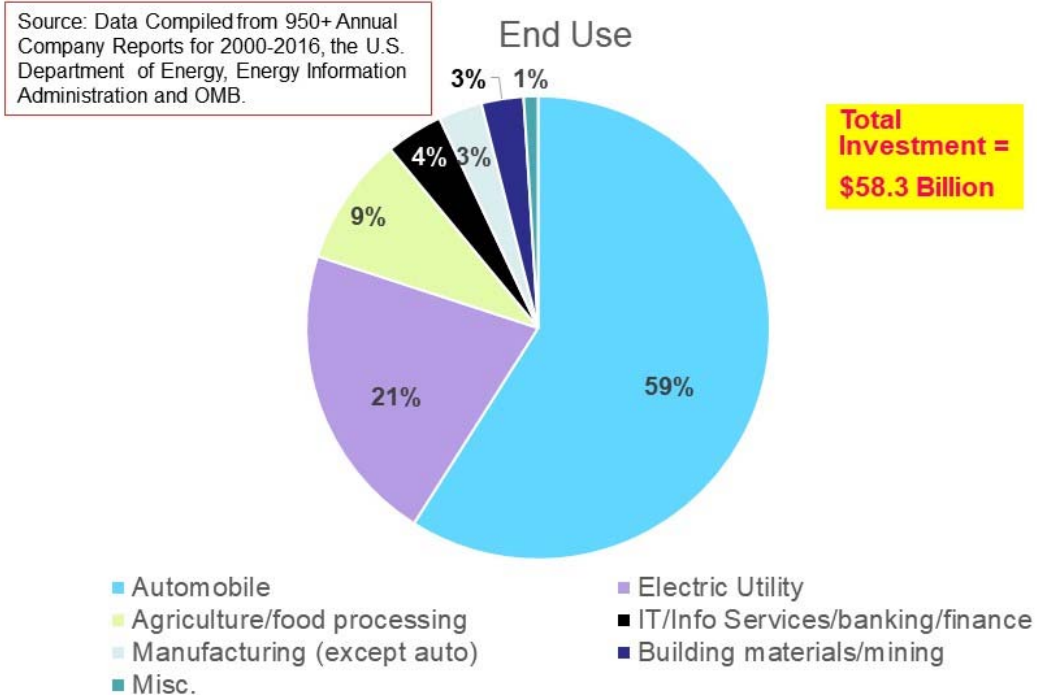


Figure A-14

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

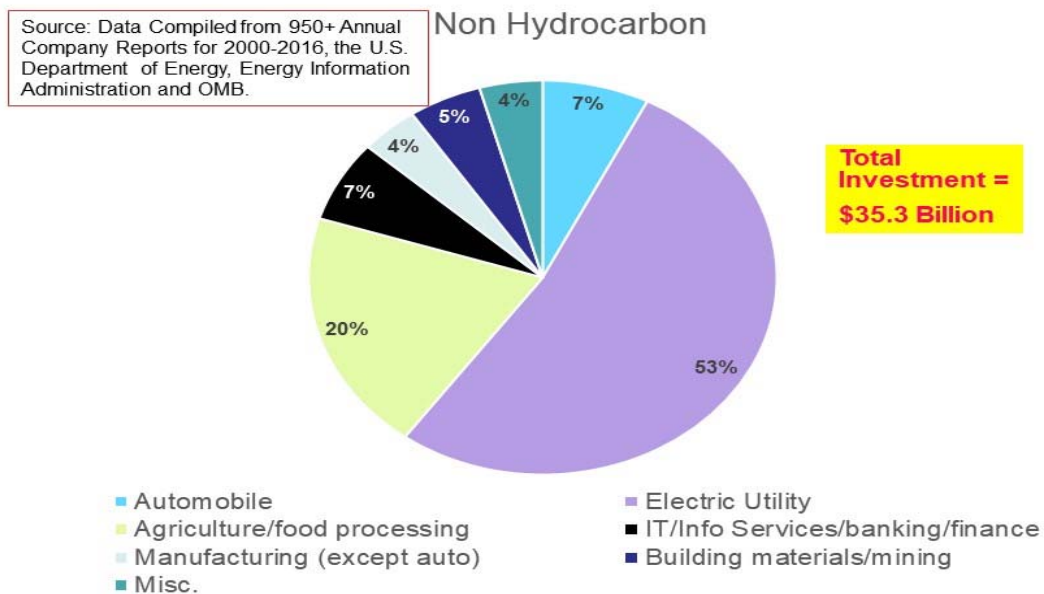


Figure A-15

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

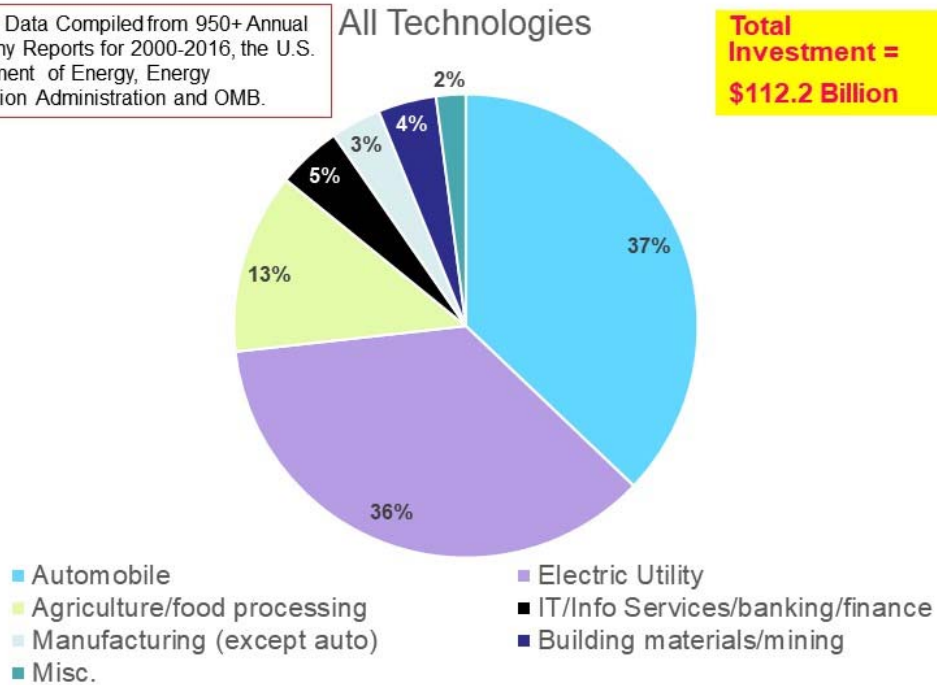


Figure A-16

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

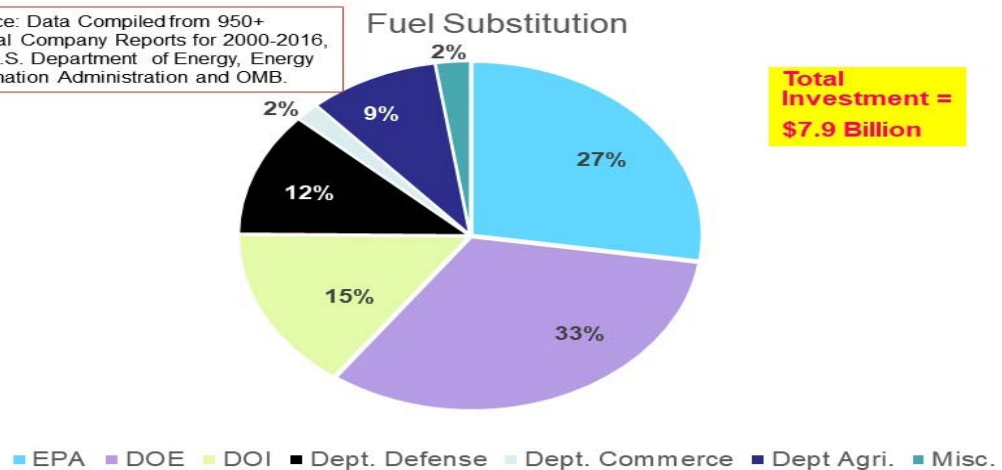


Figure A-17

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

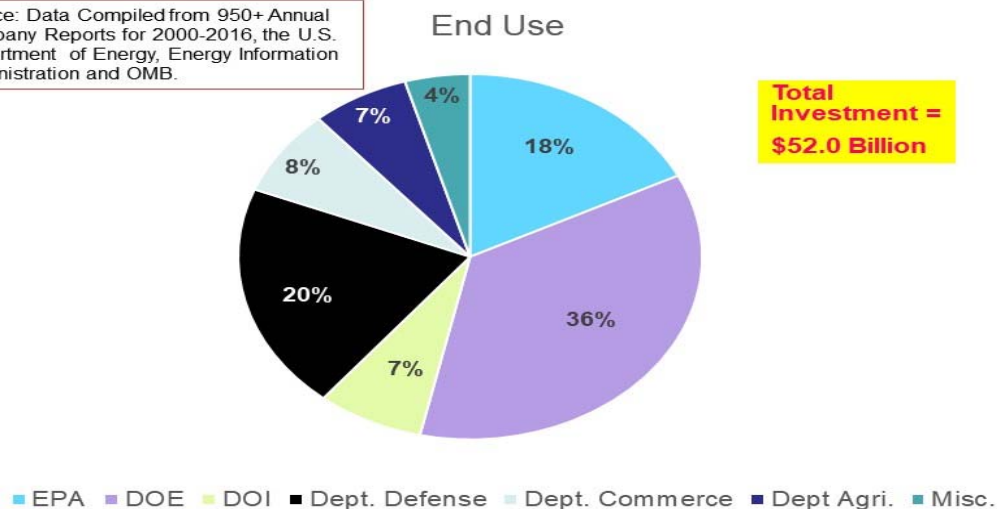


Figure A-18

Federal Government Investments in GHG Emission Reduction Categories from 2000 through 2016, Nominal \$

Source: Data Compiled from 950+ Annual Company Reports for 2000-2016, the U.S. Department of Energy, Energy Information Administration and OMB.

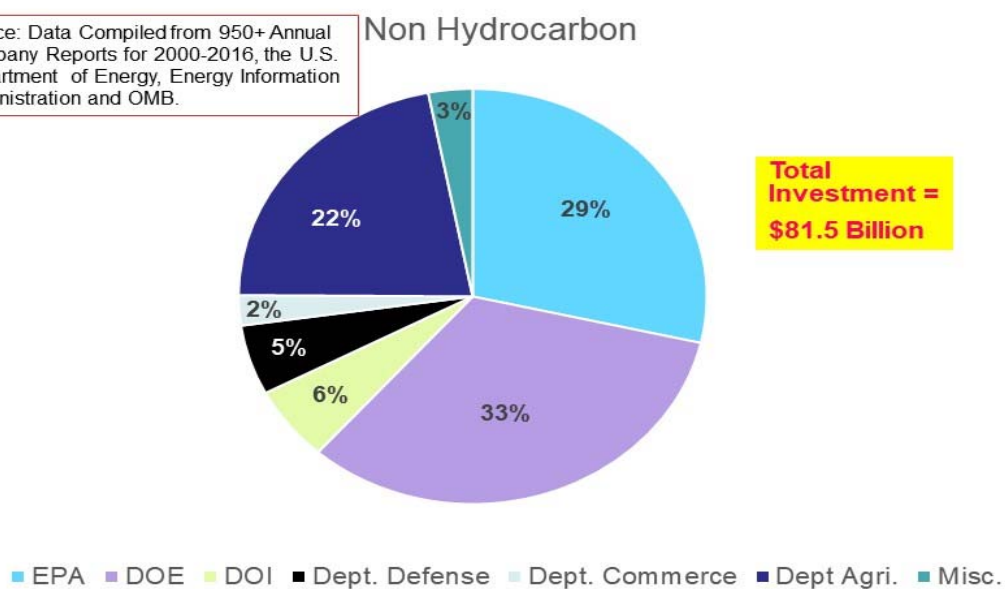


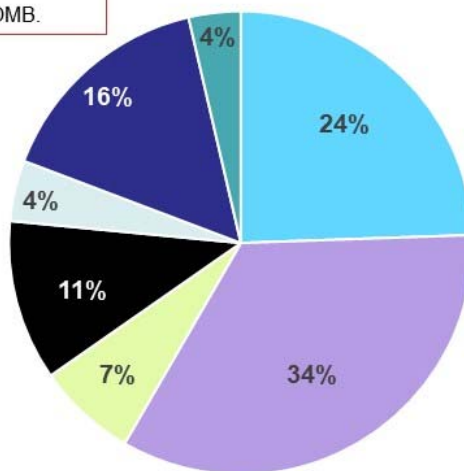
Figure A-19

**Federal Government Investments in GHG Emission
Reduction Categories from 2000 through 2016, Nominal \$**

Source: Data Compiled from 950+ Annual
Company Reports for 2000-2016, the U.S.
Department of Energy, Energy
Information Administration and OMB.

All Technologies

**Total
Investment =
\$142.7 Billion**



■ EPA ■ DOE ■ DOI ■ Dept. Defense ■ Dept. Commerce ■ Dept Agri. ■ Misc.

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