

**Key Investments in Greenhouse Gas
Mitigation Technologies
from 2000 Through 2014
by Oil and Gas Firms, Other Industry and
the Federal Government**

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Undertaken for API

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 is an increasingly important sub-group of this technology. Biodiesel is produced by chemically altering plant oils (e.g., soybean oil) and/or animal fats into diesel fuel substitutes. The term 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. Technologies to produce ethanol from cellulose have just begun commercial application.

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 from the earth and natural gas associated with the oil is produced to the surface as well. In areas of the world lacking natural gas infrastructure and markets, this associated gas is usually flared (burned) or sometimes vented (emitted as unburnt 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 is sulfur hexafluoride. It 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. Industry continues to develop substitutes for those fluorocarbons.

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. The potential for greenhouse gas mitigation is determined, however, by the amount of gas-on-gas substitution versus gas-on-coal.

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.

“Global Warming Potential” of Greenhouse Gases

Each greenhouse gas has been defined by the U.S. Environmental Protection Agency as having a different “global warming potential” that is measured relative to carbon dioxide (CO₂). The gases that are included within this analysis have been reported to have the following global warming potentials¹:

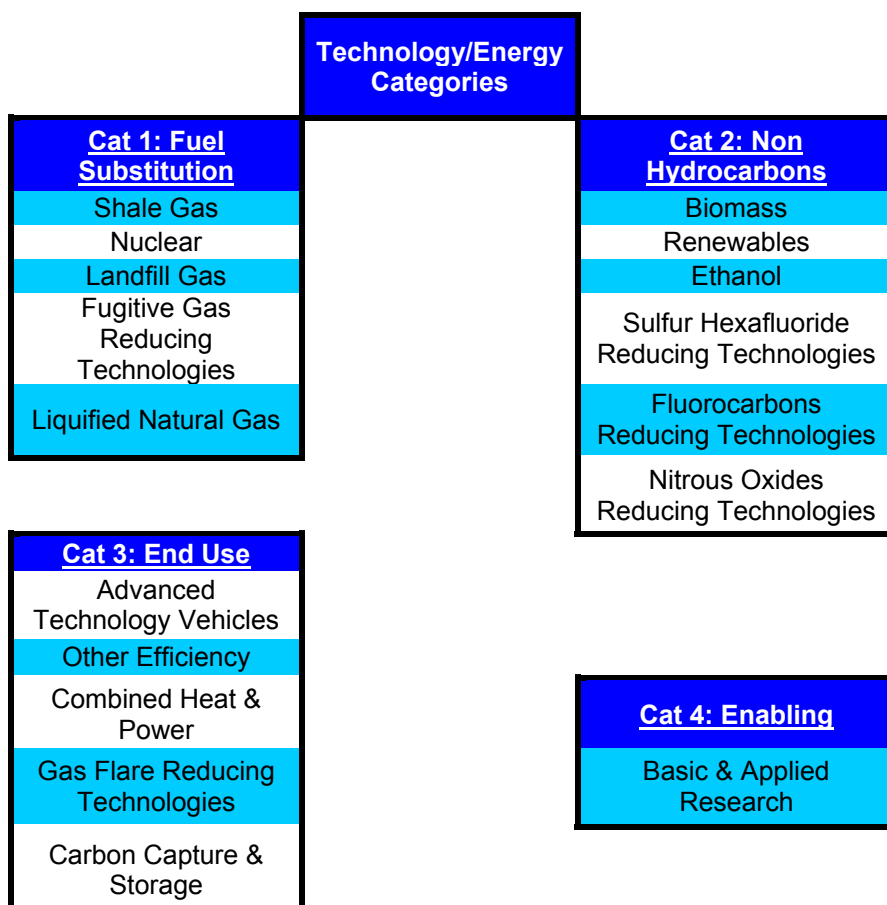
• Carbon Dioxide (CO ₂)	1
• Methane (CH ₄)	25
• Nitrous Oxide (N ₂ O)	298
• Halogenated Fluorocarbons	1030-14,800*
• Fluorocarbons	7,400-10,300*
• Sulfur Hexafluoride (SF ₆)	22,800

*Actual value depends on specific chemical within a class

¹ U.S. Environmental Protection Agency, Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2011 (April 2013); <http://www.epa.gov/climatechange/emissions/usinventoryreport.html> GWP numbers from IPCC’s Fourth Scientific Assessment Report.

Figure P-1

Categorization of GHG Mitigating Technologies



Executive Summary

This report provides estimates of the investments made from 2000 through 2014 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 \$431.6 billion (2010 dollars) between 2000 and 2014.² Figure ES-1 summarizes these greenhouse gas mitigation investments by investor type and by technology category. Over the 2000 – 2014 period, the U.S. based oil and natural gas industry invested an estimated \$217.5 billion in GHG mitigating technologies including shale gas, or \$90.0 billion without shale gas investments, other U.S. based private industries invested an estimated \$102.8 billion, and the Federal Government invested an estimated \$111.3 billion, or \$110.3 billion without shale gas investments.

Major investments by the oil and natural gas industry included shale gas (especially over the 2009-14 period), efficiency improvements including combined heat and power, and 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 somewhat more modestly. In 2011 and 12, investments had increased by about \$108 billion, or about \$65 billion not including shale gas, while in 2013 and 14 the increase was about \$95 billion, or about \$52 billion not including shale gas.

Emission Reductions

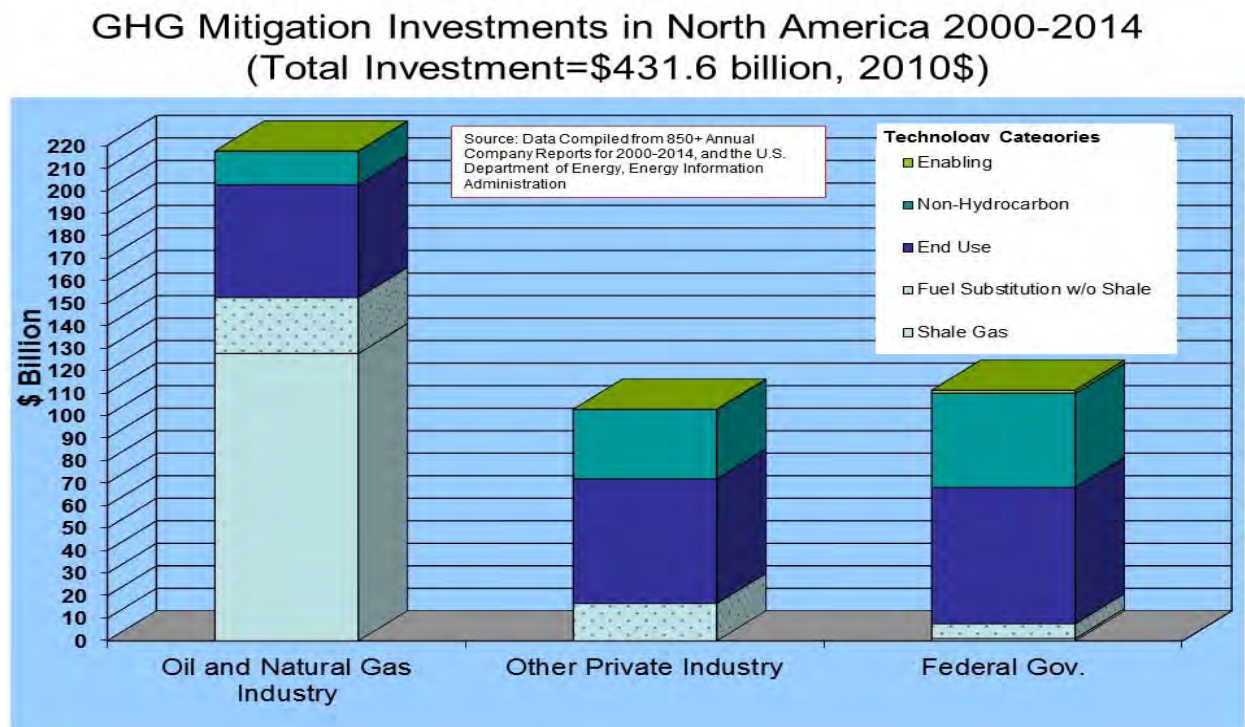
The EIA³ has reported that energy-related CO₂ emissions in the United States increased in each of the last four years. The total CO₂ emissions in 2014 remained 10%, or 580 million

² “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 2010 dollars.

³ <http://www.eia.gov/totalenergy/data/monthly/#environment>

metric tons, below the peak of 2007. Energy-related carbon dioxide emissions have declined in six of the past fourteen years.

Figure ES-1



In 2014 GDP grew by 4.1 percent (current dollars)⁴ while emissions increased just under 1 percent⁵, 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 2014 GHG emissions are only about 7.5 percent more than 1990 levels. GDP has increased by 78 percent over that same time period, as measured in constant chained dollars⁶. At the same time the U.S. population has increased by about 69 million people or a little over 20 percent⁷.

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

⁴ <http://bea.gov/national/index.htm#gdp> Table "gdplev" Current-Dollar and "Real" Gross Domestic Product release date 8/27/2015

⁵ <http://www.eia.gov/totalenergy/data/monthly/#environment>

⁶ <http://bea.gov/national/index.htm#gdp>

⁷ <http://www.multpl.com/united-states-population/table>

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, 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 and 2012 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

*Emissions reductions associated with fuel substitution do not include reductions by 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 55.5 million metric tons CO₂ equivalent for 2014 compared to 2013. The reduction of 55.5 million metric tons is equivalent to taking 11.8 million cars and light trucks off the road,⁸ or retiring nine 1000MW coal fired power plants and putting one more on half time work⁹. For comparison, there were 256 million cars and trucks in the US in 2013, according to the U.S. Department of Transportation.¹⁰

Major Changes Since Last Report

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

⁸ Passenger vehicles estimate derived from <http://www3.epa.gov/otaq/climate/documents/420f14040a.pdf>, by dividing total reductions by average passenger vehicle emissions

⁹ 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.

¹⁰<http://www.fhwa.dot.gov/policyinformation/statistics/2013/mv1.cfm>

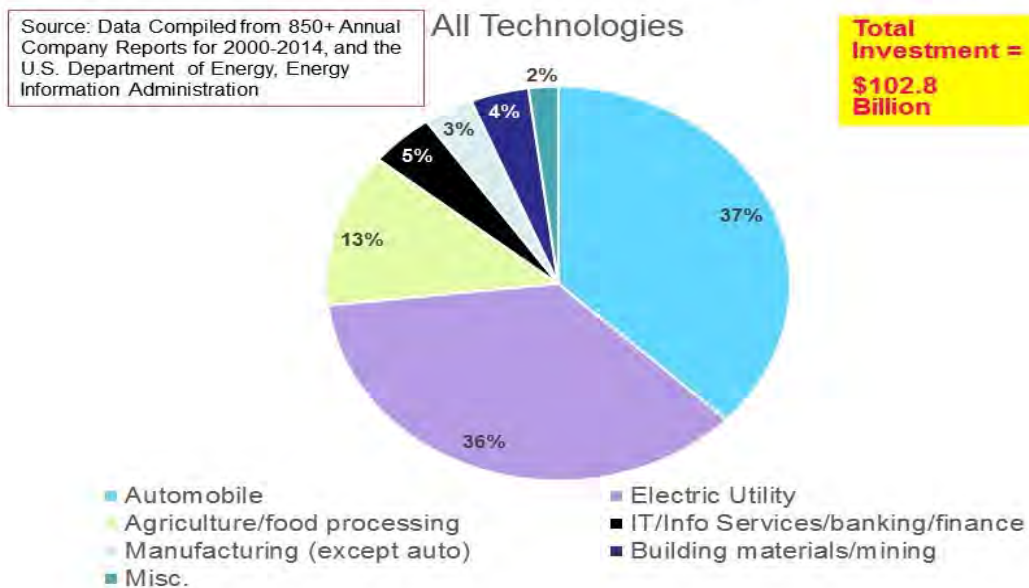
market. Since the last report that covered investment from 2000-12¹¹, total investment in these technologies has increased by approximately \$95.3 billion in the 2013-14 period, or approximately 28 percent, from \$336 billion to \$432 billion¹².

In addition, the investments made by other private industries have been disaggregated into specific industry groups. Figure ES-2 shows the investments by private sector firms in different industries, including:

- Automotive
- Electric utilities, including independent power Producers
- Agriculture/food processing
- Information Technology/Info Services/banking/finance
- Manufacturing (except auto)
- Building materials/mining
- Misc. including online retail

Figure ES-2

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, 2010\$



¹¹ Thomas Tanton, *Key Investments in Greenhouse Gas Mitigation Technologies from 2000 Through 2012 by Energy Firms, Other Industry and the Federal Government*, October 2013

¹² Note that early reports in this series provided estimated investments in nominal dollars; these have been adjusted to constant 2010 dollars throughout here and in the last two reports. Figures showing nominal dollars are provided in Appendix A.

Chapter I: Investments From 2000-2014

Introduction

This report summarizes identified investment in GHG mitigation technologies in North America during the period 2000 through 2014.¹³ Investments are reported for the private sector and the Federal government by technology or energy category. The data were compiled from a review of over 850 company annual reports, federal budget documents, and other public sources.¹⁴ 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 multiple reasons such as to increase or diversify energy supplies, or to improve efficiency.

The issue of climate change continues to draw the attention of scientists, government officials, the media and public. As climate policy in the U.S. continues to evolve, it is important to understand how current and emerging technologies including those that mitigate greenhouse gas (GHG) emissions are being invested in today and by which major stakeholders.

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 are reducing releases 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

¹³ 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.

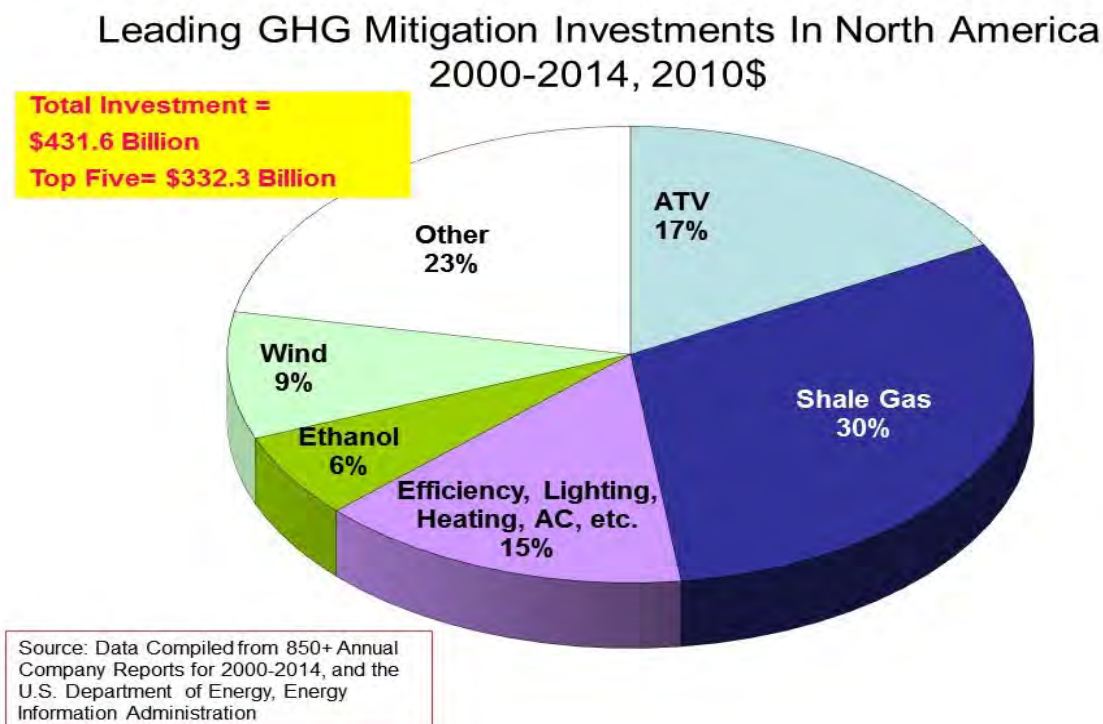
¹⁴ See bibliography for a list of data sources used in this study. Not all company reports reviewed provided data for the analysis undertaken in this report.

grants, such as the Federal Section 1603 grants 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.

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, 30 percent (\$128.6 billion); advanced technology vehicles (ATV), 17 percent (\$74.3 billion); efficiency, 15 percent (\$63.2 billion)¹⁵; wind, 9 percent (\$39.4 billion); and ethanol, 6 percent (\$26.8 billion). These top five technologies commanded 77 percent of the estimated total investments, or \$332 billion over the 2000 – 2014 period in the North American market. All other technologies combined comprised 23 percent of the estimated total investments.¹⁶

Figure 1



¹⁵ “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.*

¹⁶ Percentages may not add to 100% due to rounding.

Major Movers

During the 2000 to 2014 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. According to the EIA, a sharp increase in proved natural gas reserves in 2013 more than offset the significant decline experienced in 2012, and set a new record (354 trillion cubic feet) for U.S. natural gas proved reserves¹⁷. In addition, according to EIA, exploration and production companies operating in the U.S. raised their oil reserves by over nine percent or three billion barrels in 2013. The EIA now estimates that the U.S. has about 36.5 billion barrels of oil that are economically producible, the most volume since 1985¹⁸.

During 2013 and 2014 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 \$111.3 billion. Direct expenditures by the Federal Government helped drive a 2013 through 2014 investment surge in solar (\$5 billion) and efficiency improvements (\$14.2 billion). 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.

With respect to biofuels, overall investments in cellulosic ethanol for all investor types declined over the 2011-12 period as some development efforts stumbled.¹⁹ They have not yet recovered.

Figure 2 summarizes the major changes in technology focus, showing the percent of total investments in the 2000 to 2012 and 2013 to 2014 periods.

¹⁷ <http://www.eia.gov/naturalgas/crudeoilreserves/?src=home-bl>

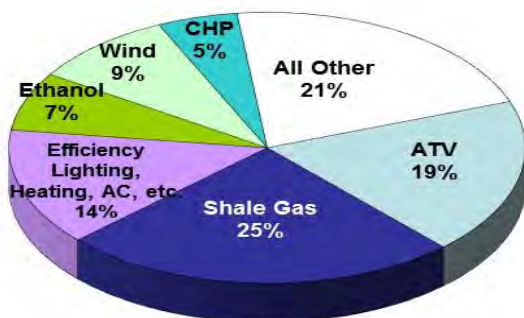
¹⁸ <http://www.eia.gov/naturalgas/crudeoilreserves/?src=home-bl>

¹⁹ <http://www.financialsense.com/contributors/robert-rapier/first-commercial-cellulosic-ethanol-plant-goes-bankrupt>

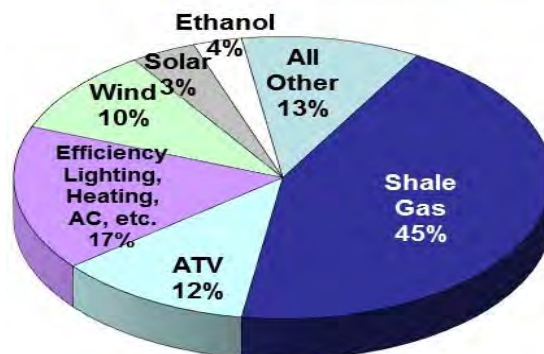
Figure 2

Comparison of 2000-2012 and 2013-2014 Technology Emphasis

Total 2000-2012 Investment = \$336.3 Billion
Top Six = \$264.7 Billion



Total 2013-2014 Investment = \$95.3 Billion
Top Six = \$87.9 Billion



Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

Greenhouse Gas Mitigation Technology Investments

U.S. based companies²⁰ and the Federal government invested approximately \$431.6 billion (2010 dollars) from 2000 to 2014 on greenhouse gas mitigating technologies in the North American market. The U.S. based oil and gas industry invested \$217.5 billion (\$90 billion without shale gas), 50 percent of the \$431.6 billion total, in end-use, fuel substitution, non-hydrocarbon, and enabling technologies. Other private companies invested an estimated \$102.8 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 \$111.3 billion (\$110.3 without shale gas), or 26 percent of the total North American investment (**Figure 3**). This does not include state and local expenditures nor investments.

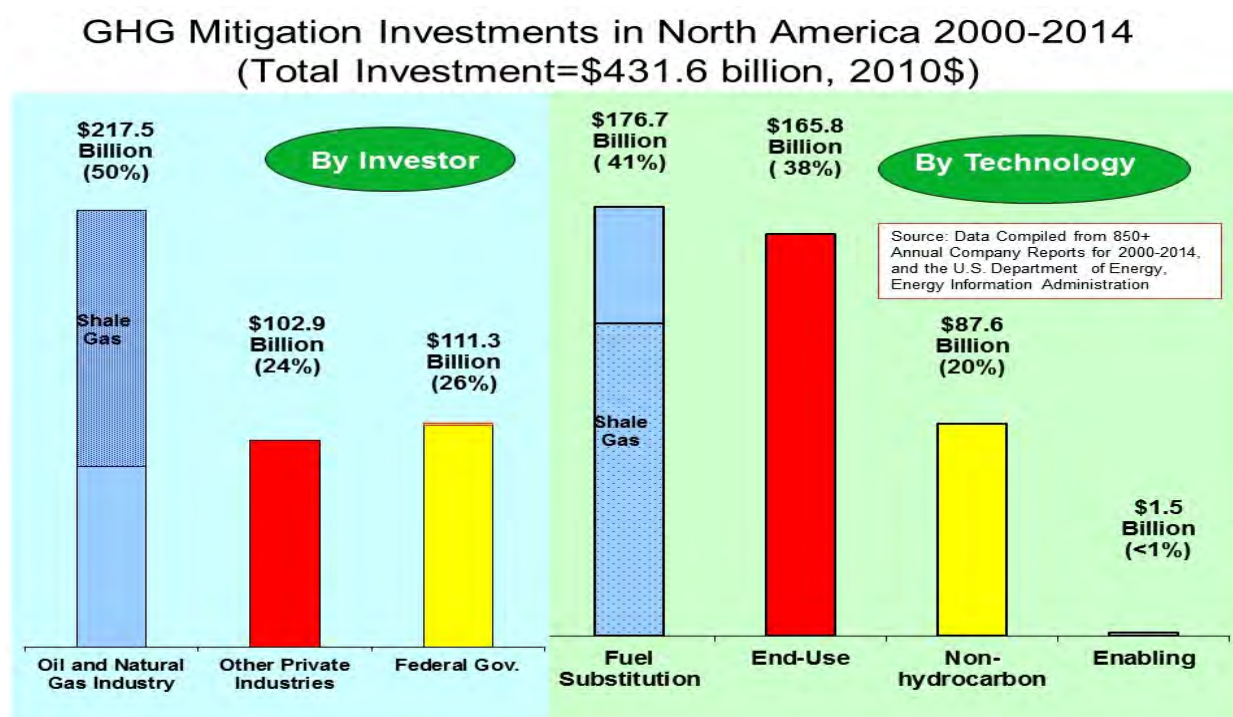
Oil and Gas Industry Investments from 2000 through 2014

It is estimated that U.S. based oil and natural gas companies invested \$217.5 billion (\$90 billion without shale gas) from 2000 through 2014 in GHG mitigating technologies in the North

²⁰ U.S. based companies include both U.S. companies and foreign-owned companies operating in the U.S.

American market.²¹ (**Figure 4**) This expenditure represents 50 percent of the estimated total of \$431.6 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 \$14.9 billion over the 2000 – 2014 period, or about 7 percent of the oil and natural gas industry’s investments. This represents 17 percent of the total industry and Federal government investments of approximately \$87.6 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.

Figure 3



The largest share of investments made by the oil and gas industry, roughly 70 percent or \$152 billion, was in the fuel substitution category (Figure 4). This \$152 billion investment in fuel substitution technologies represents 83 percent of the estimated \$180.9 billion invested in total in this technology class (**Figure 11**). Of this \$152 billion, \$127.6 billion, (84 percent of the oil and natural gas industry fuel substitution investment), was invested to expand shale gas development. The remaining fuel substitution technologies received \$24.9 billion from the oil

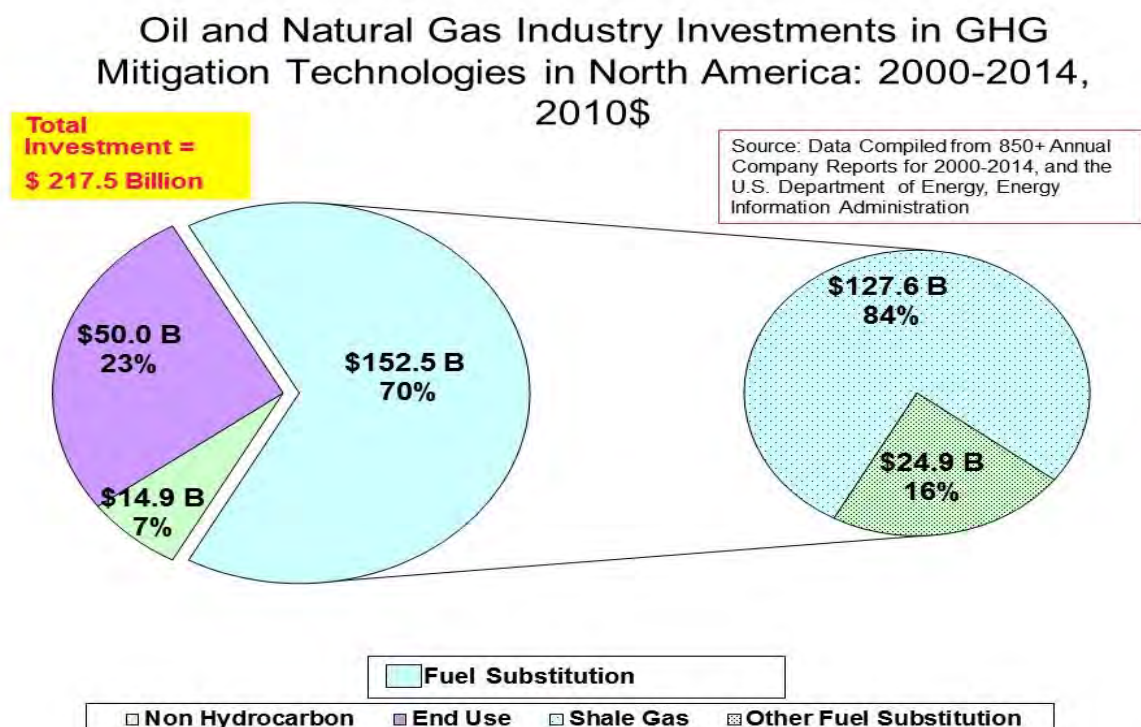
²¹ “North American market” is used herein to include Canada and the U.S.

and natural gas industry, or 11 percent of the \$152 billion oil and natural gas industry fuel substitution investment.

The oil and gas industry invested \$50 billion (or 23 percent of its \$217.5 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 storage²² and for advanced technology vehicles. Significantly, this \$50 billion investment in end-use technologies represents 30 percent of the estimated total amount (\$162.2 billion) spent by all U.S. companies and the Federal government in this technology category (**Figure 12**).

Figure 5 shows the investment pattern over the 2000-2012 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.

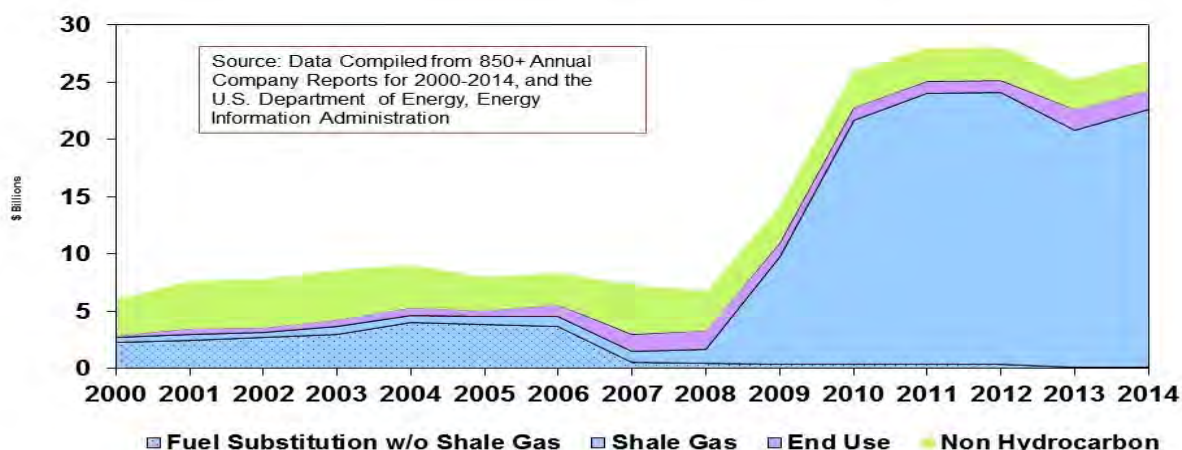
Figure 4



²² 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.

Figure 5

Oil and Natural Gas Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, 2010\$



Other Private Industries' and Federal Government Investments from 2000 to 2014

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 \$102.8 billion (or 24 percent of the \$431.6 billion total) from 2000 to 2014 (**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 \$102.8 billion sector total, \$55.2 billion (54 percent) is associated with end-use technologies, \$30.6 billion (30 percent) with non-hydrocarbons and \$16.8 billion (16 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 35 percent of the non-hydrocarbon investment, 9 percent of the fuel substitution category and 33 percent of the end-use category. (**Figures 10-12**).

Figure 6

Other Private Industry Investments in GHG Mitigation Technologies in North America: 2000-2014, 2010\$

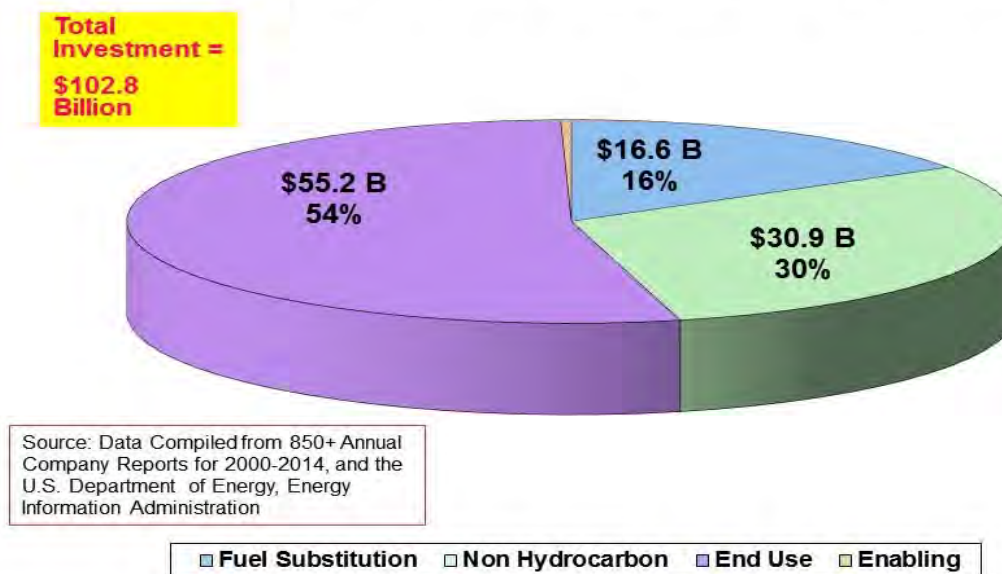


Figure 7 shows the investment pattern over the 2000-2014 period for other private companies. Significant new levels of investment occurred starting in 2009 in non-hydrocarbon technologies such as wind energy, largely driven by various states Renewable Portfolio Standards, favorable tax credits and the 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 2013 and 2014, the amount of investment by other private industry declined compared to 2012.

Figures 8 through 12 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 all technologies (figure 11.)

Electric utilities and independent power producers invested approximately \$9.1 billion or 55% of the fuel substitution investments by other private industries, primarily in renewables and nuclear. Approximately 20% or \$3.3 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 2014, 2010\$

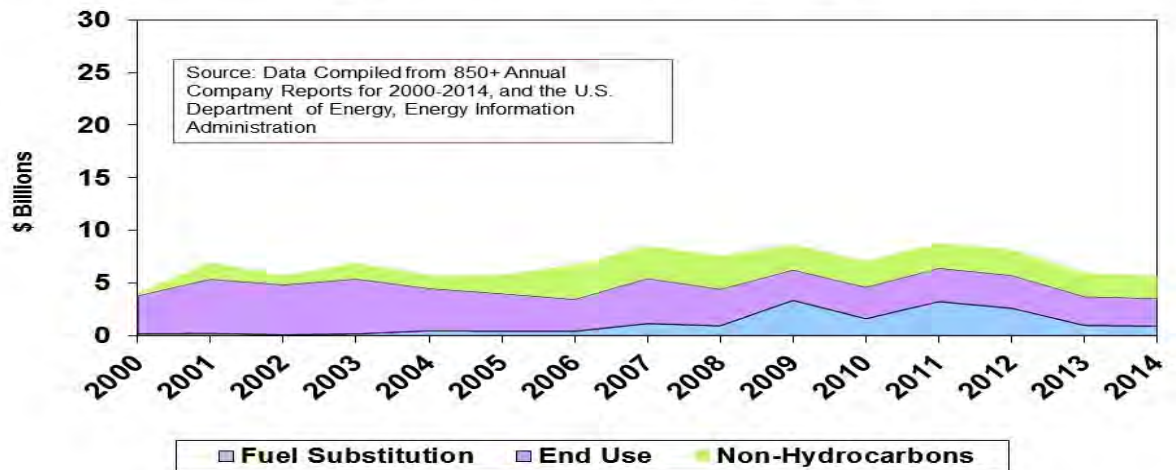
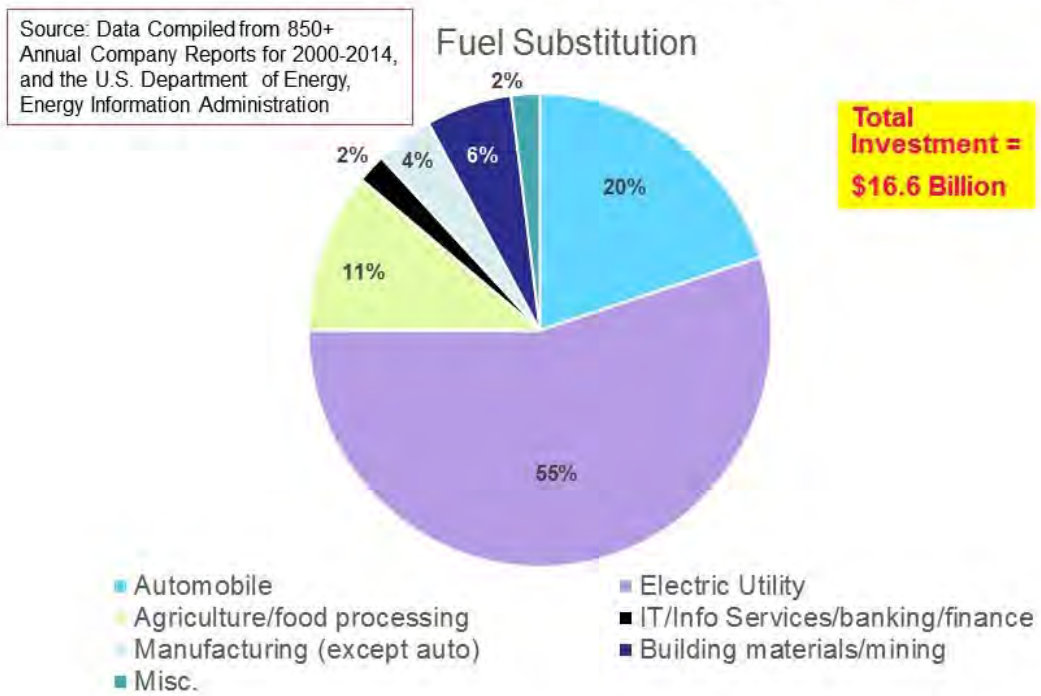


Figure 8

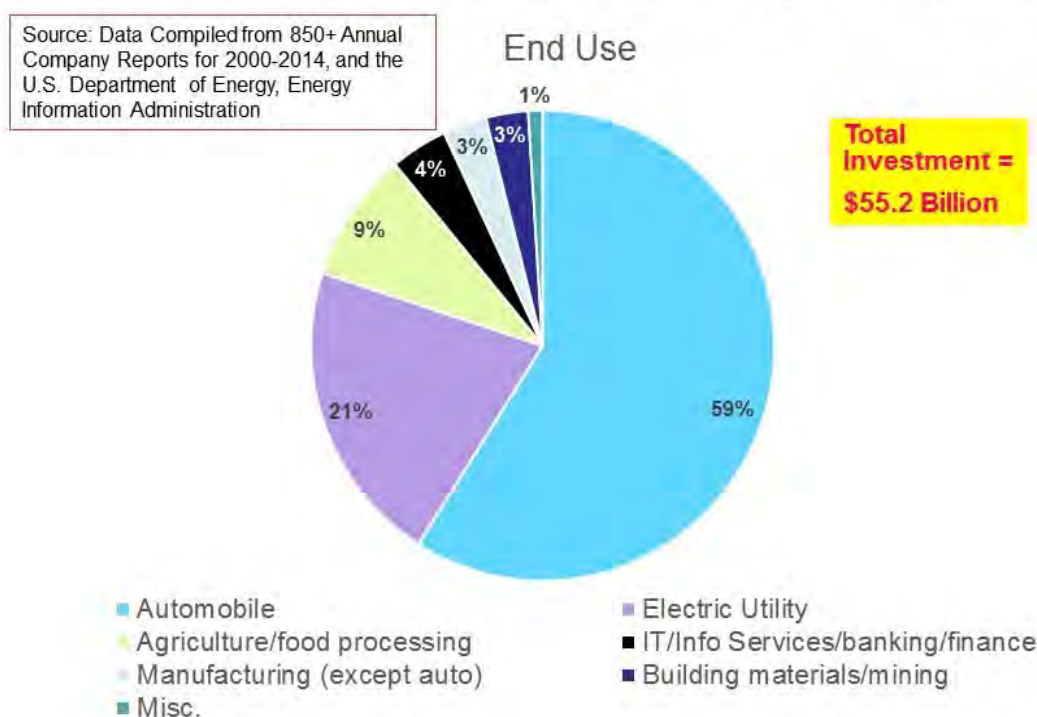
Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, 2010\$



Automakers made up the bulk of investments, \$32.6 billion or 59%, in the end use category (Figure 9.) Electric utilities and independent power producers made investments of \$11.6 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 \$5.0 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 2014, 2010\$

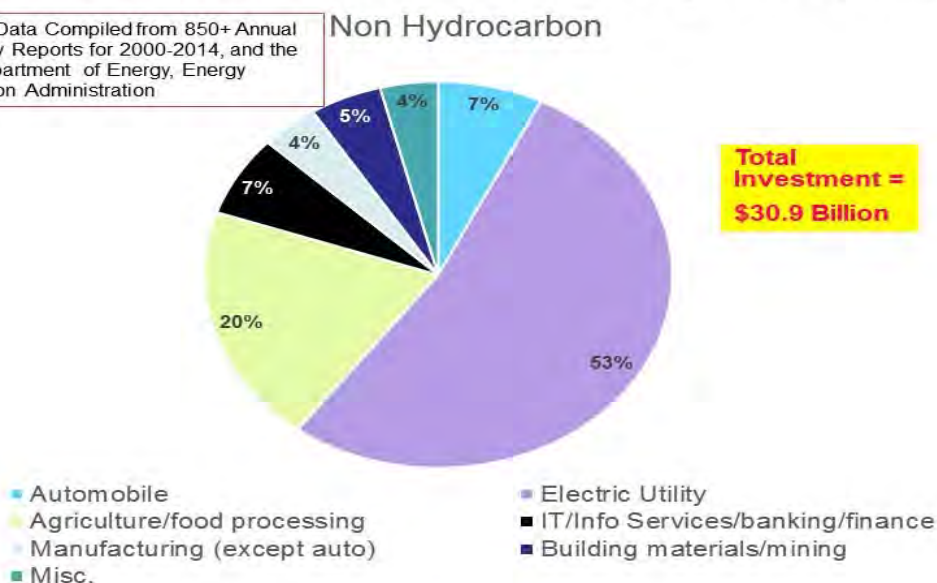


In the nonhydrocarbon category, electric utilities and independent power producers accounted for 53% or \$16.4 billion of the total sector investment of \$30.9 billion (figure 10) in this technology category. This included various renewable energy like wind and solar, but also geothermal and biomass. Agricultural entities, including processors, accounted for 20% or \$6.2 billion, largely in corn based ethanol.

Figure 10

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, 2010\$

Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

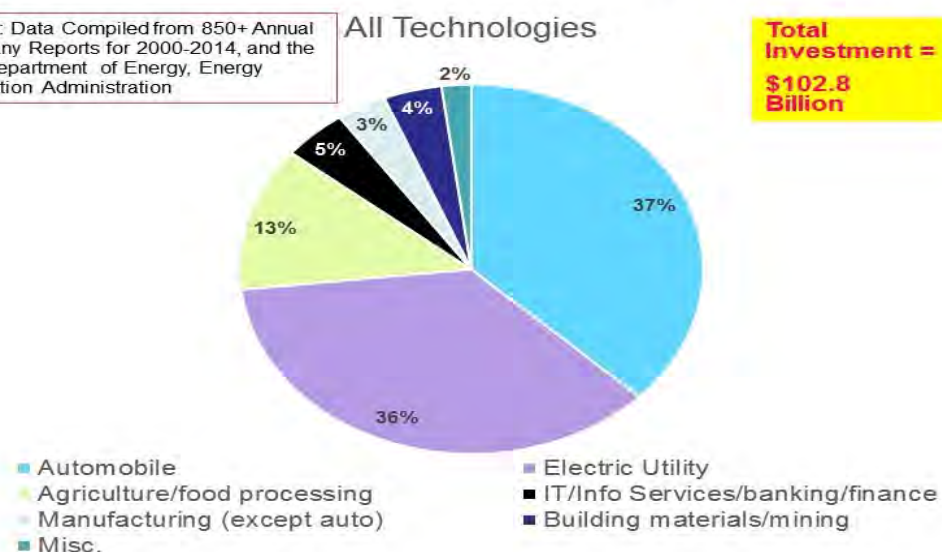


Of the total investment of \$102.8 billion investments made from 2000 through 2014 (figure 11) by other private firms, the automotive sector accounted for 37% or \$38.2 billion, and the electric utilities and independent power producers for 36% or \$37.1 billion.

Figure 11

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, 2010\$

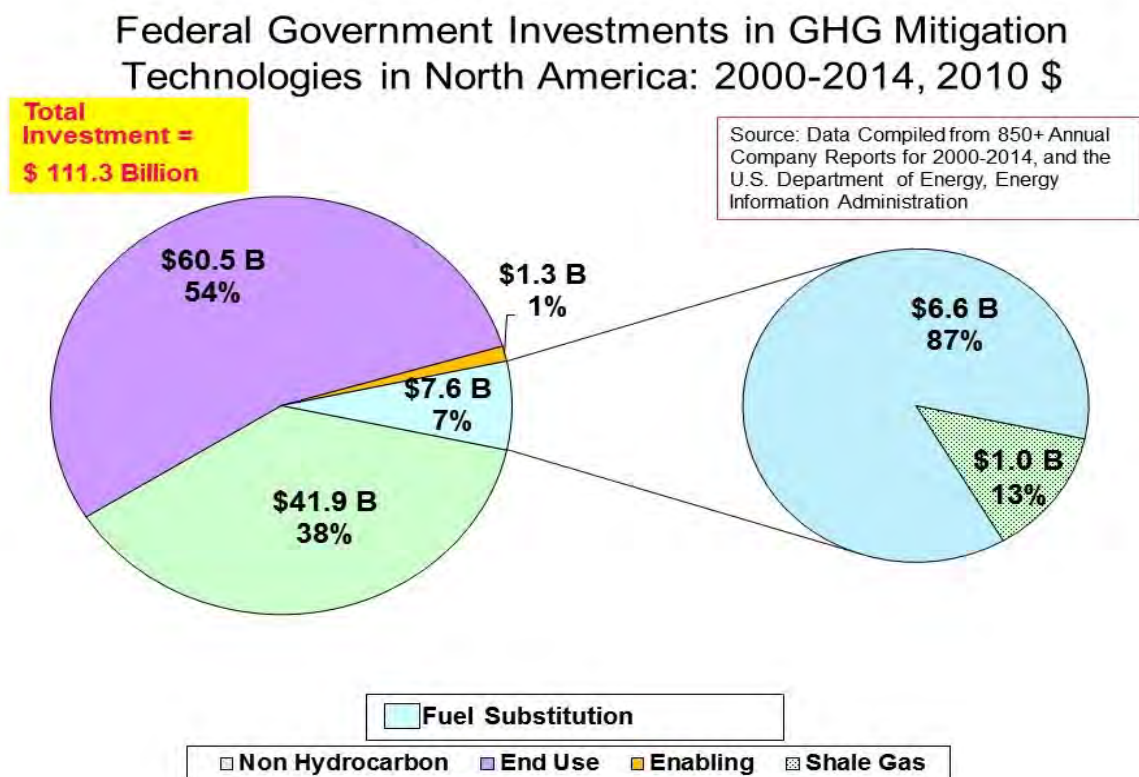
Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration



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 2000-2014 of \$111.3 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-four percent, or \$60.5 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-eight percent, or \$41.9 billion of the Federal government investment is in the nonhydrocarbon class (including wind, ethanol, solar, and biodiesel), 7 percent, or \$7.6 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



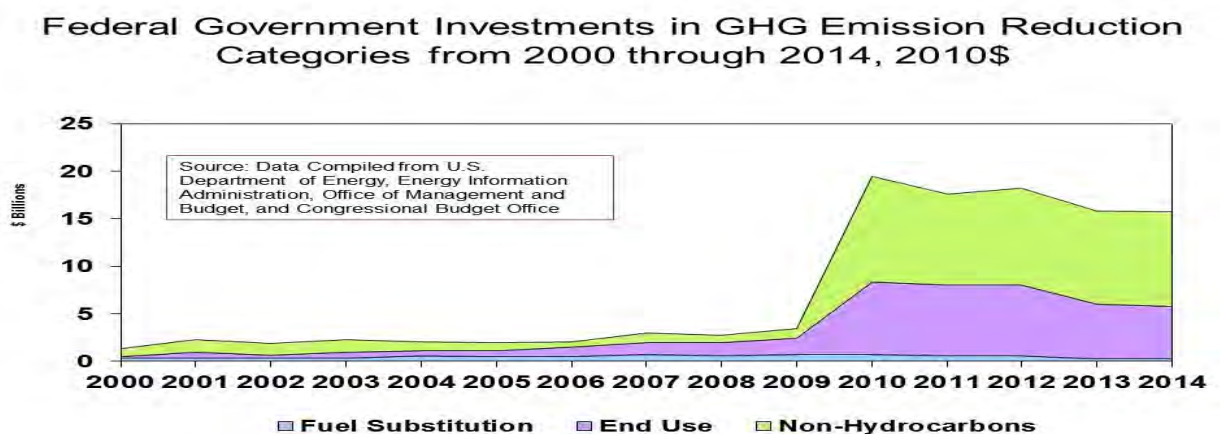
Between 2009 and 2012 major investments were made by the Federal government in end use and non-hydrocarbons as part of ARRA expenditures, often paired with investments by private sector entities. These investments have continued but at a reduced pace during 2013 and 2014.

Figure 13 shows the investment pattern over the 2000-2014 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.²³

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, using Section 1603 direct grants to wind energy facilities in lieu of tax credits.

Figure 13



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 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.

²³ 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

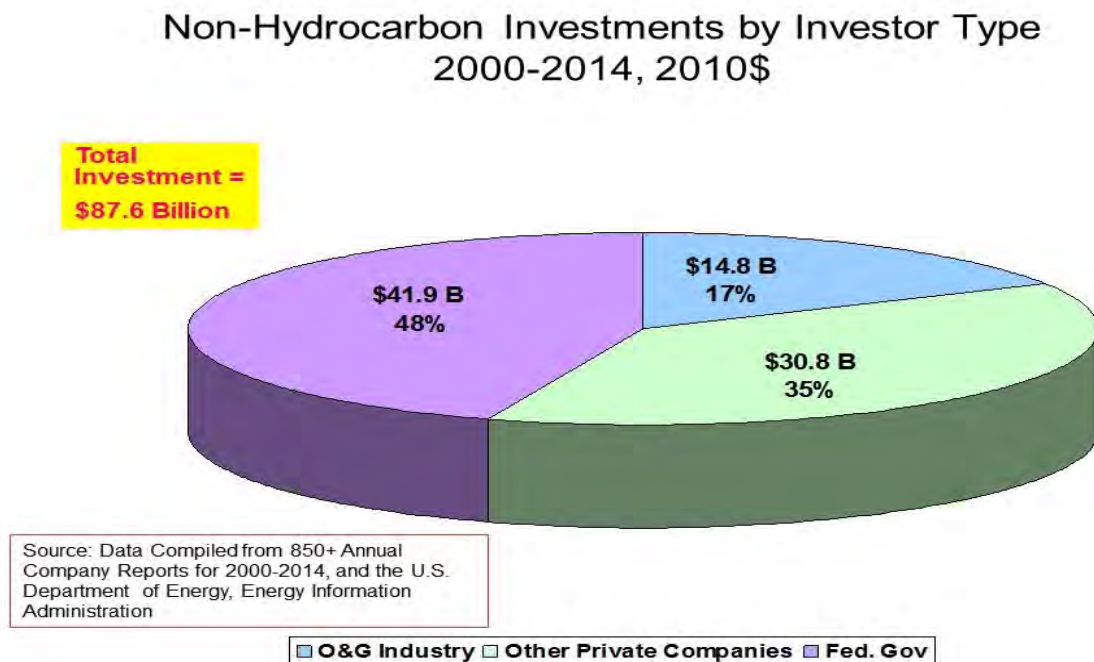
Technology Investments by Investor Types

Figures 14-16 show, for each technology category, the investment shares by investor type.

Non-Hydrocarbon (14)

Other U.S.-based private companies invested roughly 35 percent of the \$87.6 billion non-hydrocarbon category total from 2000 to 2014. 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 17 percent of the category total, including investments in renewables like wind and solar, as well as ethanol. The Federal government invested approximately 48 percent, spread among the renewables, ethanol and other technologies, much of it in the last six years of the 2000-2014 period.

Figure 14



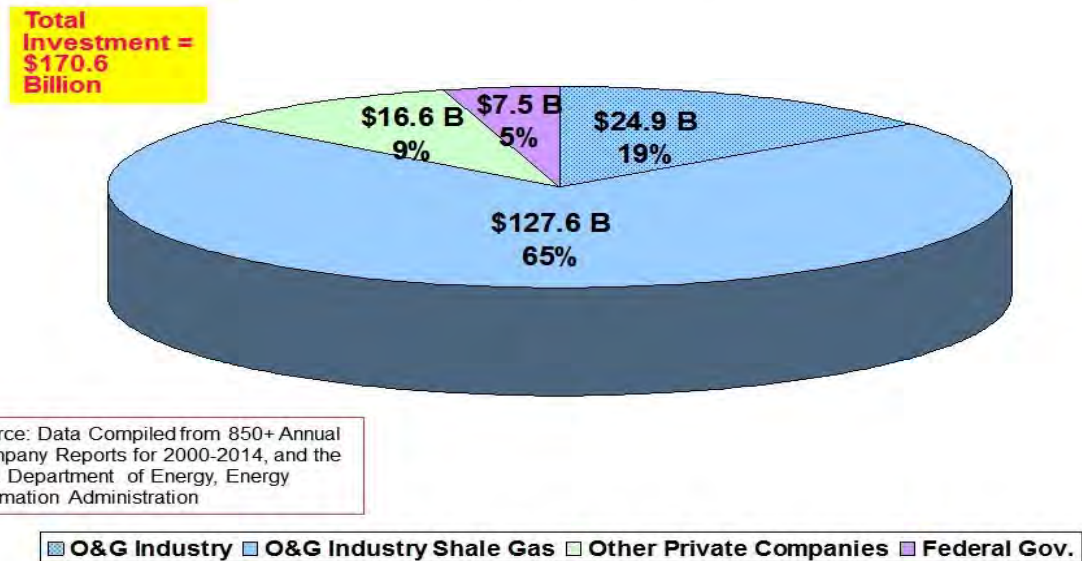
Fuel Substitution (15)

The U.S.-based oil and gas industry invested approximately 86 percent of the fuel substitution category (50.8% 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 about 5 percent of this category, including investments in nuclear and landfill gas recovery as well as shale gas.

Figure 15

Fuel Substitution Investment by Investor Type 2000-2014, 2010\$



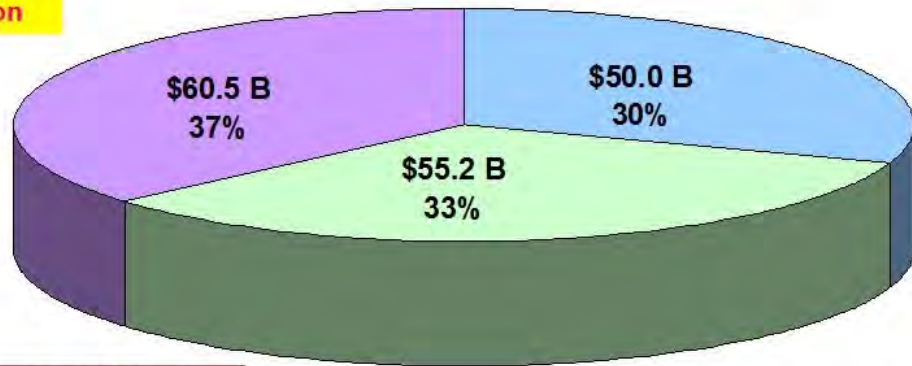
End Use (16)

Within the end-use category, other U.S. based industries invested an estimated 33 percent or \$55.2 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 30 percent, or \$50 billion of the \$165.8 billion total investment in this technology category, principally in cogeneration, carbon capture and storage and advanced technology vehicles. Advanced batteries are an example of the advanced technology vehicle investments made by the U.S. based oil and gas industry. The Federal government invested approximately 37 percent, or \$60.5 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 16

**End Use Investments by Investor Type
2000-2012, 2010\$**

**Total
Investment =
\$165.8 Billion**



Source: Data Compiled from 650+ Annual Company Reports for 2000-2012, and the U.S. Department of Energy, Energy Information Administration

■ 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 2008-2014 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 \$217.5 billion in GHG mitigation technologies made by the U.S. based oil and natural gas industry over 2000 to 2014 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 2014, investments made can often take time to complete with actual emission reductions occurring with a lag of up to five years. Some of the reductions in 2008-2014 are likely due to investments made in the middle years of the 2000-2014 period.

U.S. based oil and gas industry sources have reported direct emission reductions totaling 55.5 million metric tons CO₂ equivalent for 2014 compared to 2013. The reduction of 55.1 million metric tons is equivalent to taking 11.2 million cars and light trucks off the road,²⁴ or retiring nine 1000MW coal fired power plants and putting one more on half time duty²⁵. For comparison,

²⁴ Passenger vehicles estimate derived from <http://www.epa.gov/otaq/climate/420f05004.htm>, by dividing total reductions by average passenger vehicle emissions

²⁵ 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 256 million cars and trucks in the US, according to the U.S. Department of Transportation.²⁶

- An average of forty-one percent of the emission reductions occur in the fuel substitution category, over the period 2008-2014. 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 -2014 relative to Prior Year
Oil and Gas Industry in North America
Million Metric Tons CO₂e

	Fuel Substitution	End Use	Nonhydrocarbon	Total
2008 Reductions (MMT)	22.2	16.9	9.2	48.3
2009 Reductions (MMT)	22.2	21.6	9.0	52.8
2010 Reductions (MMT)	21.2	25.2	9.5	55.9
2011 Reductions (MMT)	19.8	24.3	9.0	53.1
2012 Reductions (MMT)	19.9	24.5	9.2	53.6
2013 Reductions (MMT)	20.4	24.8	9.2	54.4
2014 Reductions (MMT)	20.9	25.2	9.4	55.5

Emissions Reduction Methodology

This analysis reflects a compilation of reported emission reductions from company reports, including annual shareholder reports and “Corporate Responsibility Reports.”²⁷

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 are substantially greater than the total reported here. More specifically, the 19.8 million

²⁶<http://www.fhwa.dot.gov/policyinformation/statistics/2013/mv1.cfm>

²⁷ 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.

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 program²⁸ 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 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 2013 – even as natural gas production increased dramatically. Further, methane from hydraulically fractured natural gas wells fell 79 percent from 2005 to 2013²⁹.

- 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 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.

²⁸ See <http://www.epa.gov/gasstar/accomplishments/index.html#three>

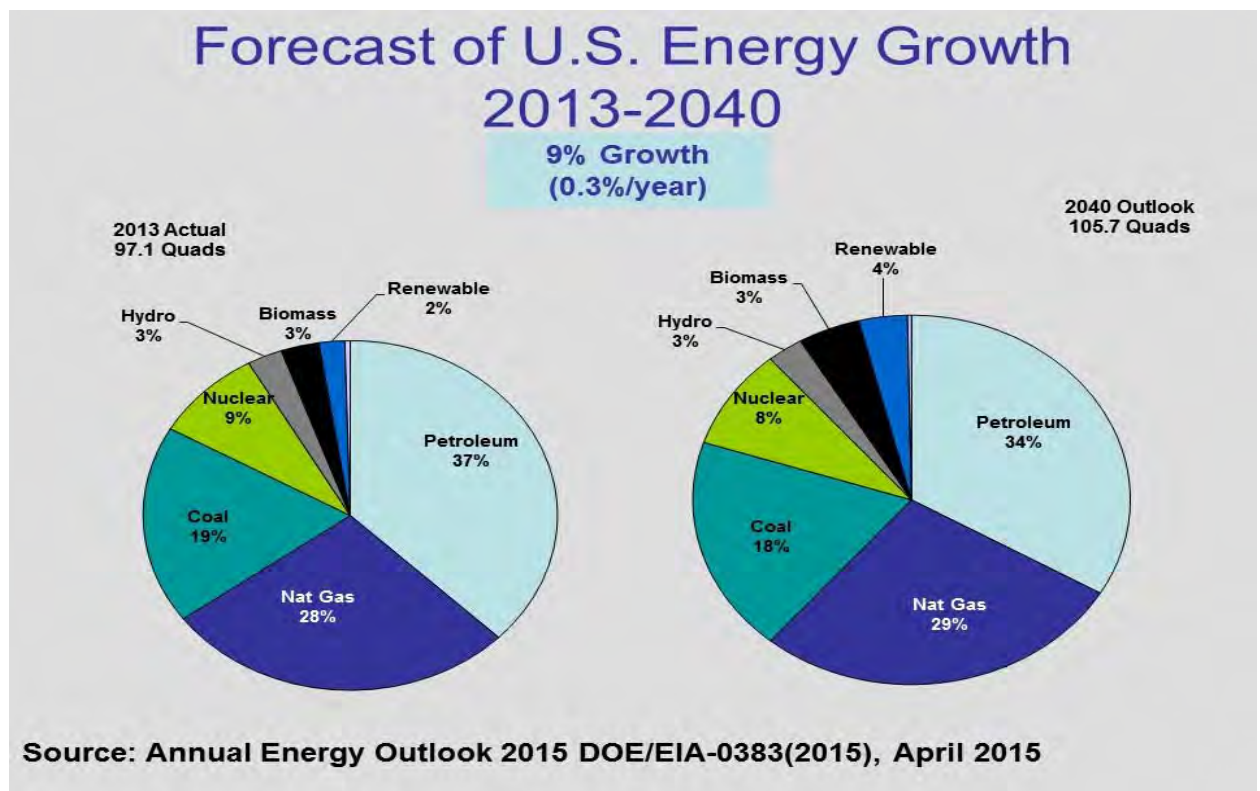
²⁹ <http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf>

Chapter III: The Challenge of Emission Reductions

Energy consumption in the United States is forecast by the Energy Information Administration (EIA), an agency of the U.S. Department of Energy, to increase approximately 9 percent over the 2013 to 2040 period, or about 0.3 percent annually. (**Figure 17**) This projected increase is tempered by a predicted improvement in energy intensity (energy usage per real dollar of GDP).³⁰ The DOE reference case forecast results in an average annual reduction in energy use per capita of 0.4%/year from 2013 through 2040 and an average annual decline in energy use per 2009 dollar of GDP of 2.0%/year. As renewable fuels and natural gas account for larger shares of total energy consumption, carbon intensity (CO₂ emissions per unit of GDP) continues to decline by an average 2.3%/year from 2013 to 2040.

To meet increased demand for energy, the EIA projects that hydrocarbons (crude oil and natural gas and their derivatives) will remain the mainstay of the U.S. energy sector at least over the next several decades. The market share of oil, natural gas, and coal is projected to be approximately 81 percent in 2040, little changed from 83 percent in 2013.

Figure 17



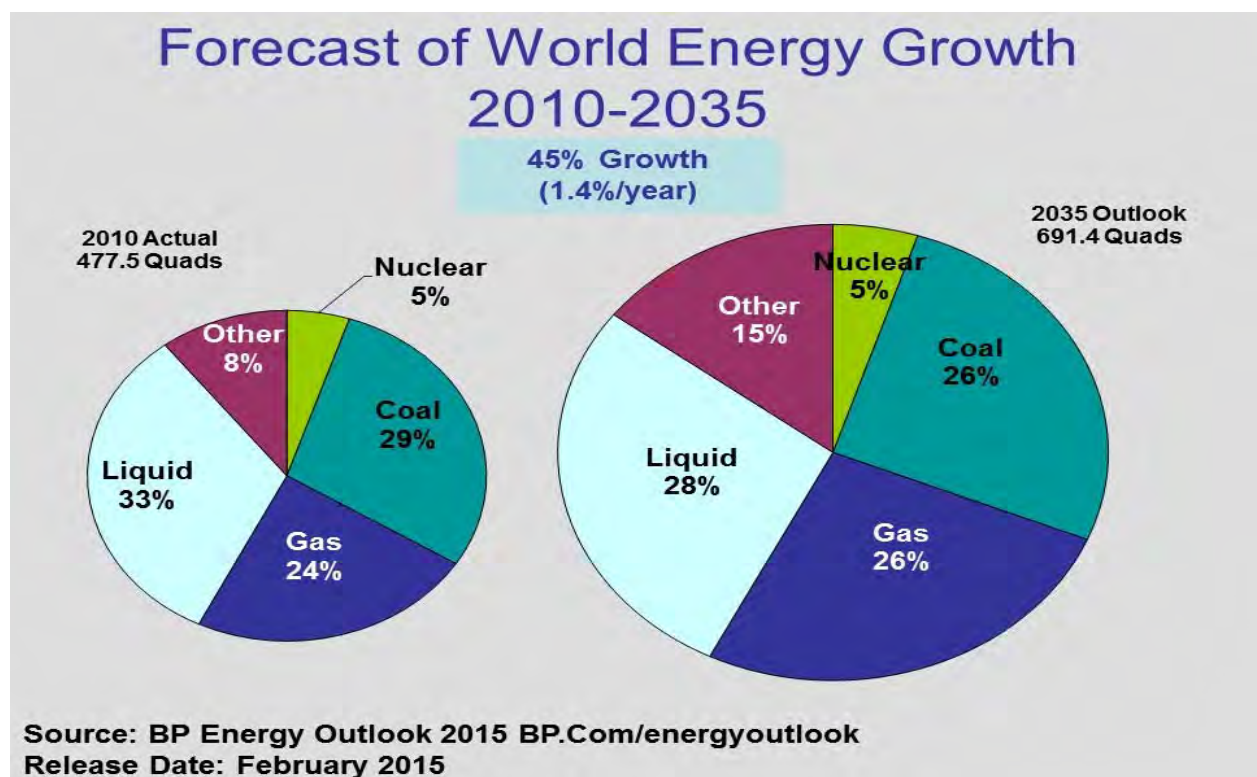
³⁰ Noted trends and statistics in this section are from Energy Information Administration, *Annual Energy Outlook 2015*, April 2015.

According to BP's "Energy Outlook 2035", by 2035, the world's population is projected to reach 8.7 billion, up 1.6 billion people from today. Global gross domestic product is expected to more than double, with much of the growth in Asia. China and India will become the world's largest and 3rd largest economies respectively, jointly accounting for about one-third of global population and GDP³¹.

The global outlook for energy consumption is for an increase of 45% between 2010 and 2035, with growth averaging 1.4% per year. Virtually all (96%) of the projected growth is in non-OECD countries, with energy consumption growing at 2.2% per year. OECD energy consumption, by contrast, grows at just 0.1% per year over the period. The projected growth rate of global energy consumption is slower than the trend of 2.5% per year for 2000-10.

Natural gas is the fastest growing fossil fuel (1.9% per year), with oil (0.8% per year) marginally ahead of coal. The fastest fuel growth is seen in renewables (6.3% per year). The combined share for fossil fuels (coal, liquids and gas) drops from 86% of the total in 2010 to 80% in 2035. (Figure 18)

Figure 18



³¹ Noted trends and statistics regarding global energy are from BP's "Energy Outlook 2035" bp.com/energyoutlook, Feb. 2015.

These projections of energy demand highlight the importance of continued economically viable investments leading to more efficient, and lower-GHG emitting technologies, as well as the development of efficient technology transfer programs to developing countries.

National Trends

There has been significant progress in mitigation of U.S. GHG emissions although significant challenges remain going forward.³²

In 2013 and 2014, energy-related carbon dioxide (CO₂) emissions in the United States increased compared to 2012. However, unlike 2013, when emissions and gross domestic product (GDP) grew at similar rates (2.5% and 2.2%, respectively), 2014's CO₂ emissions growth rate of 0.7% was much smaller than the 2014 GDP growth rate of 2.4%.

Energy-related CO₂ emissions are the largest component of overall U.S. greenhouse gas emissions. Changes in CO₂ emissions reflect changes in economic and energy-related indicators. The previous two years have largely followed the economic trends in terms of increasing population and per capita GDP, but have slowed the trends of declining energy and carbon intensities.

Population grew at an average annual rate of 0.7% during 2005-14, and the U.S. economy, as measured by GDP, grew by 1.4% per year.

The amount of energy consumption per unit of GDP, or the energy intensity of the U.S. economy, has generally improved in the past decade, as less energy was needed to produce economic growth. In 2014, the United States required 13% less energy than in 2005 per unit of GDP. In 2013 there was a slight increase in energy intensity of 0.7%, largely because of weather-related energy consumption, but energy intensity improved in 2014 by 1.2%.

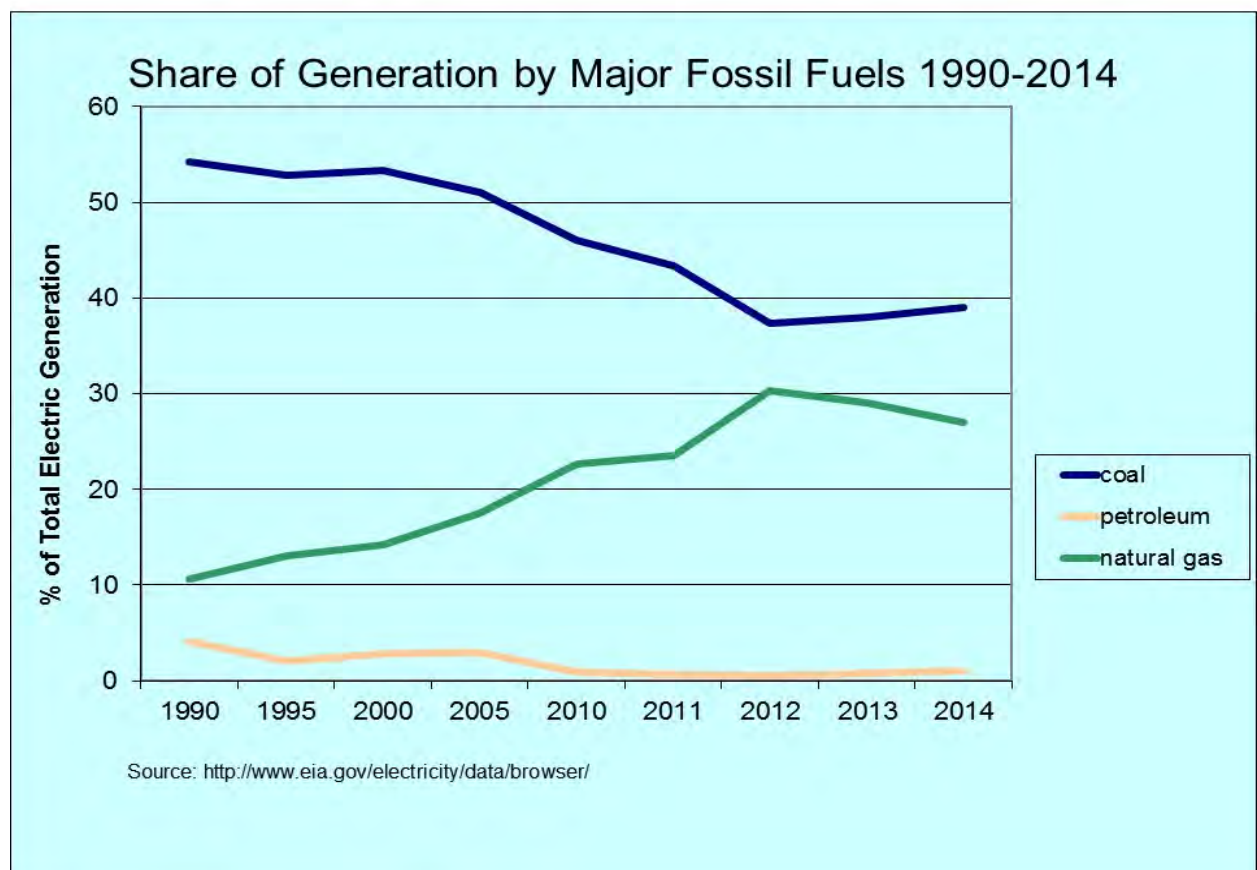
Carbon intensity, or the amount of CO₂ emissions per unit of energy consumption, declined in total by 8% during 2005-14, with an average annual decline of 0.9%. In 2013 and 2014, however, carbon intensity declined by only 0.4%.

³² Noted trends and statistics in this section are from Energy Information Administration, U.S. ENERGY-RELATED CARBON DIOXIDE EMISSIONS INCREASE IN PAST TWO YEARS, April 20, 2015 <http://www.eia.gov/todayinenergy/detail.cfm?id=20872>

Estimated emissions of 5,404 million metric tons of CO₂ from energy-related sources occurred in 2014, and energy-related CO₂ emissions are projected to increase slightly in both 2015 and 2016. In the Reference case in EIA's recently released *Annual Energy Outlook 2015*, emissions are expected to increase only slightly, at a rate of 0.1% annually, and to remain below 2005 levels by more than 400 million metric tons in 2040, and below 1996's³³ level of 5509 million metric tons. Future energy consumption and related emission levels will depend largely on a mix of weather, energy sources, and economic factors—as well as potential changes in national and state policies.

According to EIA, since May 2012, a combination of an up-tick in prices for natural gas and increased demand for electricity during the summer months led electric systems across much of the country to increase their use of coal-fired units. In March 2013, coal-fired units generated a little over 130,000 MWh of electricity, while natural gas units produced nearly 85,000 MWh³⁴.

Figure 19



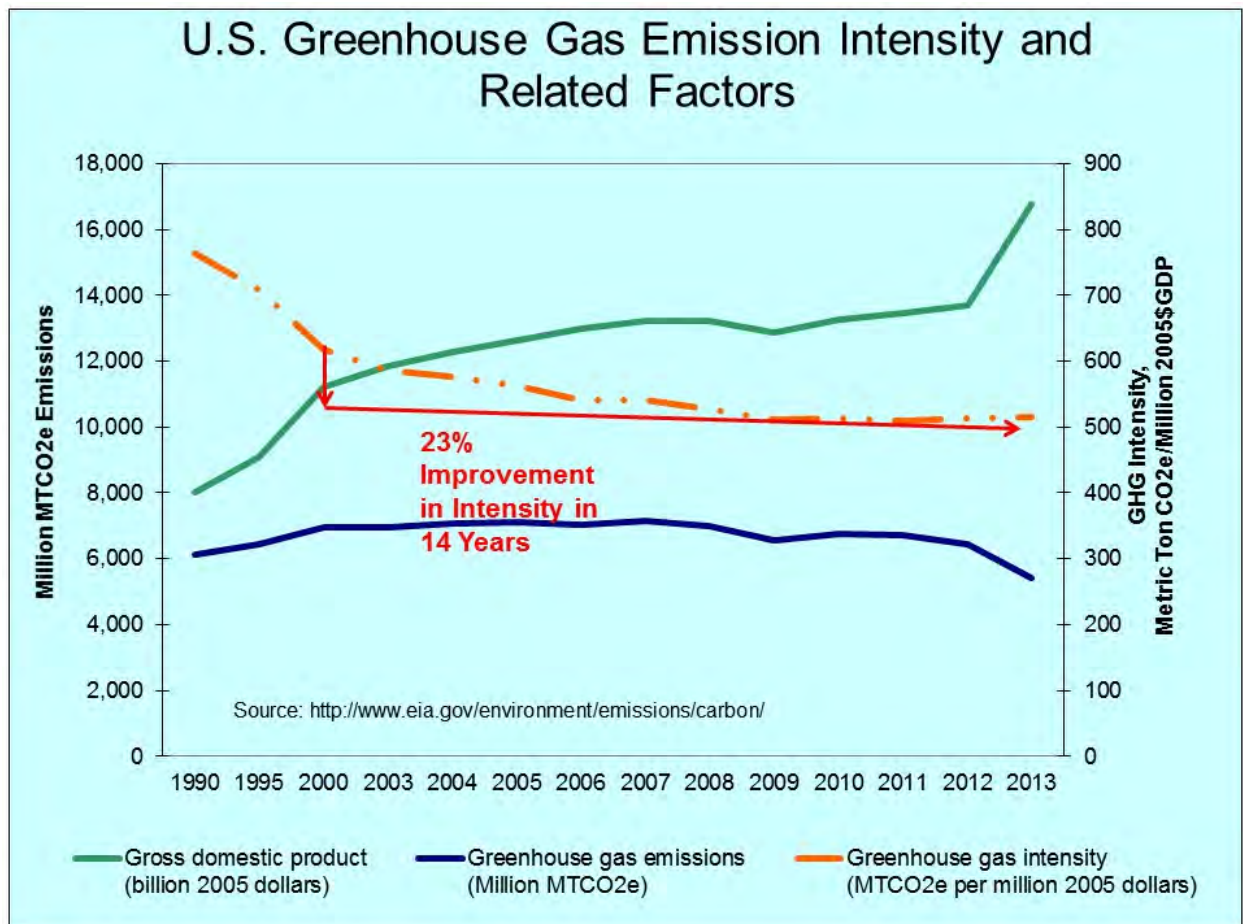
³³ 1996 is shown here as it is the first year OECD published International Development Goals including greenhouse gas emissions levels. OECD, *Shaping the 21st Century: The Contribution of Development Co-operation*, May 1996

³⁴ <http://www.eia.gov/todayinenergy/detail.cfm?id=11391>

Source: <http://www.eia.gov/environment/emissions/carbon/> and <http://www.eia.gov/todayinenergy/detail.cfm?id=11391#>

From 2000 through 2014, the overall carbon dioxide intensity of the U.S. economy—measured as metric tons carbon dioxide equivalent (MTCO₂e) emitted per million dollars of gross domestic product (GDP) — improved by more than 18 percent or 1.4 percent per year overall, with notable year-to-year differences, as shown in **Figure 20**. Oil and gas industry investments over the last decade in GHG mitigating technologies have contributed to this improving trend.

Figure 20



Source: Energy Information Administration, *U.S. Energy-Related Carbon Dioxide Emissions, 2011*, Release Date: August, 2012 and <http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2013&subject=0-AEO2013&table=17-AEO2013®ion=1-0&cases=ref2013-d102312a>

The U.S. Energy Information Administration³⁵ estimates that, with improved efficiency of energy use and a shift away from the most carbon-intensive fuels (including natural gas for coal), U.S. energy-related carbon dioxide (CO₂) emissions will remain below the 2005 level, even through 2040. CO₂ emissions from the transportation sector decline by an average of 0.2%/year, with

³⁵ U.S. EIA, *Annual Energy Outlook, 2015*, April 2015

overall improvements in vehicle energy efficiency offsetting increased travel demand, growth in diesel consumption in freight trucks, and consumer's preference for larger, less-efficient vehicles as a result of the lower fuel prices that historically accompany strong growth of domestic oil and dry natural gas production. EIA attributes the lower emissions to be the result of the adoption of more efficient automotive technology, and shifts in consumer behavior. Emissions from coal use in the generation of electricity are expected to continue downward as power generation shifts away from coal to lower-carbon fuels.

CO₂ emissions per 2005 dollar of GDP (carbon intensity) have historically tracked closely with energy use per dollar of GDP. The U.S. EIA estimates, however, that as lower-carbon fuels account for a larger share of total energy use, CO₂ emissions per 2005 dollar of GDP will decline more rapidly than energy use per 2005 dollar of GDP, falling by 56 percent from 2005 to 2040, at an annual rate of 2.3 percent per year further improving our carbon intensity.

The most recent analysis, last completed in 2013, by EIA of global emissions³⁶ has non-OECD Asia accounting for 70 percent of the world's increased CO₂ emissions through 2040. China's share of global energy-related CO₂ emissions is projected to grow from 21 percent in 2007 to 32 percent in 2040. India accounts for the second-largest share of the projected increase, 7 percent. The U.S. share of world CO₂ emissions is projected to fall to 12.5 percent (5691 MMT out of a global total of 45,455 MMT) in 2040, from about 19.5% today, although the improvement is likely to be even more pronounced with the larger improvements in carbon intensity, as described above, through 2040.

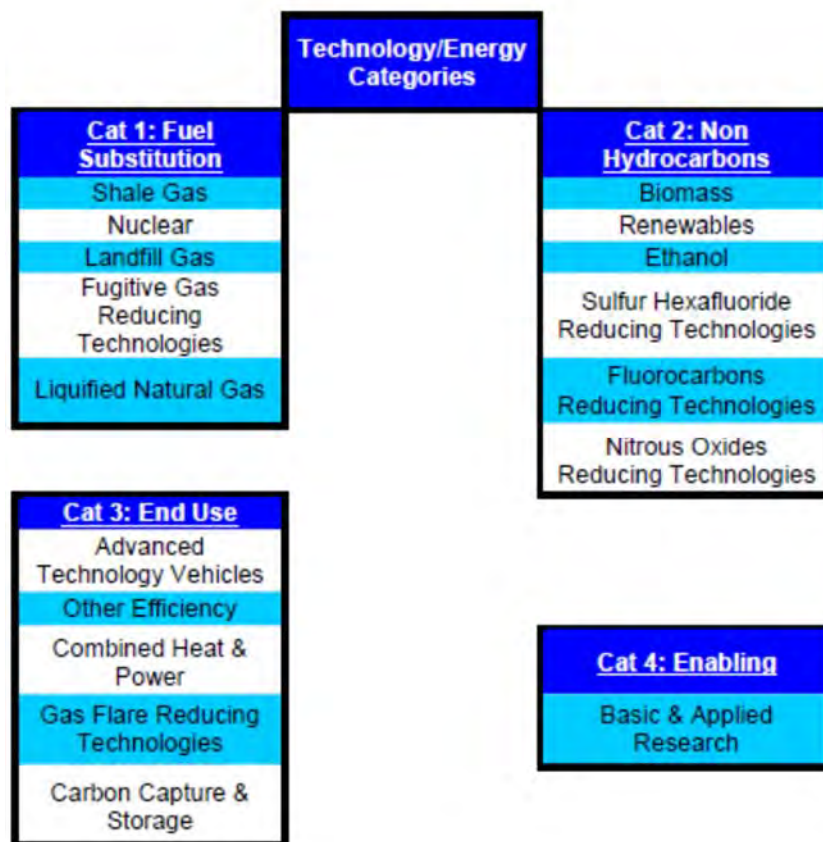
Greenhouse Gas Emission Mitigation Technologies

A principal objective of this report is to identify key technologies and their associated investments that mitigate GHG emissions, or that have the potential to do so in the future. Sixteen major energy technologies have been identified in this study as actual or potential mitigation technologies. These technologies have been grouped into four categories (**Figure 21**): *fuel substitution*, (five technologies), *nonhydrocarbon* (six technologies), *end-use*³⁷ (five technologies), and *enabling*. Biomass, within the non-hydrocarbon category, is further delineated into electricity and transportation applications, and ethanol is separated into corn and cellulosic ethanol. Sugar cane is not included here as it is not a major source in the North American market.

³⁶ U.S. EIA *International Energy Outlook 2013*, July 25, 2013

³⁷ Carbon Capture and Storage has been moved from "enabling" in the May 2008 Report to "end-use" in the 2011 and later reports.

Figure 21
Categorization of GHG Mitigating Technologies³⁸



Category 1. “Fuel substitution” technologies include shale gas, liquefied natural gas (LNG), nuclear, landfill gas, and methane captured by fugitive gas reducing technologies.

- *Shale Gas* is an important source of expanded supply of natural gas in the U.S. 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-based liquid fuels. The potential for greenhouse gas mitigation is determined, however, by the amount of gas-on-gas substitution versus gas-on-coal. Several recent studies demonstrate the greenhouse gas emission reductions are associated with substituting shale gas for coal and other higher GHG intensity fuels. The Massachusetts Institute of Technology (MIT) Energy Initiative found:
 - “the role of natural gas is likely to continue to expand, and its relative importance is likely to increase even further when greenhouse gas emissions are constrained.”³⁹

³⁸ In previous editions of this Report, “Fugitive Gas Reducing Technologies” was placed in the End Use Category in this chart.

³⁹ MIT Energy Initiative – Future of Natural Gas, Abstract, p. ix, June 2011

MIT further found that replacement of coal by natural gas in U.S. electric generation would involve the “substitution of coal units with an average efficiency of 30% to 35% with gas combined cycle plants with efficiencies in the range of 45% to 55%.”⁴⁰

Similarly the International Energy Agency in their World Energy Outlook 2011 – Special Report – “Are We Entering a Golden Age of Gas?” concluded that “shale gas produced to proper standards of environmental responsibility has slightly higher ‘well-to-burner’ emissions than conventional gas, with the combustion of gas being the dominant source of emissions.”⁴¹ (emphasis added) The National Energy Technology Laboratory (NETL) provided relative lifecycle GHG emission factors⁴²:

- Average Coal: 2,453 lbs CO₂e per MWh;
 - Average Conventional [natural] Gas: 1,041 CO₂e per MWh;
 - Average Unconventional [natural] Gas: 1,139 CO₂e per MWh.
- *Liquefied natural gas* (LNG) is natural gas that has been super-cooled to a liquid. This dramatically reduces the volume for cost-effective transport in ships (where transport via conventional natural gas pipelines is cost prohibitive or not feasible). LNG as a transport mode opens up natural gas to become a much more broadly traded international commodity.
 - *Nuclear* is limited to the production of electricity and reduces the amount of coal or natural gas consumption for that purpose, and consequently the associated greenhouse gas emissions.
 - *LFG* is landfill gas (methane) produced by the anaerobic digestion of waste material. Historically, that methane was emitted into the atmosphere, but more recently has been collected and used to produce electricity or in transportation applications. According to the Environmental Protection Agency, of the 2,300 or so currently operating or recently closed municipal solid waste landfills in the United States, more than 510 have LFG utilization projects.⁴³ The generation of electricity from LFG makes up about two-thirds of the currently operational projects in the United States, with the remainder in direct use (heat) and transportation application. LFG acts to reduce greenhouse gas emissions first by reducing the amount of methane released to the atmosphere, and secondarily by substituting for higher-carbon content fossil fuels such as coal and petroleum.
 - *Fugitive Gas Emissions* can occur when methane, a potent greenhouse gas, is collected and transported, and certain amounts leak out to the atmosphere. Investments made to reduce fugitive emissions directly and indirectly reduce greenhouse gas emissions. Emissions may indirectly be reduced as lower carbon natural gas is added to the fuel supply.

Category 2. “Non-hydrocarbon” technologies include any energy form that is not a hydrocarbon energy source. This category includes: wind energy conversion, solar to electric, geothermal

⁴⁰ MIT Energy Initiative – Future of Natural Gas, Appendix 1A; Life-Cycle Climate Impacts from Fossil Fuel Use, p. 2, June 2011

⁴¹ International Energy Agency – World Energy Outlook 2011 – Special Report – “Are We Entering a Golden Age of Gas?” p.7, 2011

⁴² National Energy Technology Laboratory – *Life Cycle Greenhouse Gas Analysis of Natural Gas Extraction & Delivery in the United States*, Timothy J. Skone, May 12, 2011

⁴³ <http://www.epa.gov/lmop/faq/lfg.html>

(electric and direct use for industrial application), biomass and biorefinery, biodiesel, and ethanol production. Ethanol and biodiesel production were included in this category rather than in the fuel substitution category where they could have also arguably been placed. This category also includes technologies that facilitate reductions in halogenated fluorocarbons (HFC), perfluorocarbons and sulfur hexafluoride (SF₆).

- *Ethanol* is currently produced by the fermentation of various sugars and starches, primarily from corn and sugar cane. Significant fossil fuel use is involved in corn-based ethanol production both for growing the corn and in producing the ethanol. Most ethanol for fuel is produced in Brazil or the United States. Technological advances may allow ethanol production from cellulosic materials in the longer term. Greenhouse gas emissions benefits associated with corn-based ethanol are likely to be marginal or zero⁴⁴, and there is significant uncertainty surrounding greenhouse gas emissions benefits associated with cellulosic ethanol, although they are expected to be better than corn based ethanol.

As part of revising the National Renewable Fuel Standard program (commonly known as the RFS program) as required by the Energy Independence and Security Act of 2007 (EISA), EPA has analyzed lifecycle greenhouse gas (GHG) emissions from increased renewable fuels use. In February 2010 EPA determined that ethanol produced from corn starch at a new natural gas, biomass, or biogas fired facility (or expanded capacity from such a facility) using advanced efficient technologies will achieve about 20% GHG emission reduction compared to the 2005 gasoline baseline.⁴⁵

- *Biomass* projects also use plant or animal waste materials to produce energy either from direct combustion, through thermal gasification, or biologic treatment. Biomass gasification is included in biomass/biorefining, as a precursor to ultimate use, within the nonhydrocarbon group.
- *Bio-refineries* produce a broad slate of products from plant materials, including energy and fuels, plastics, pharmaceuticals and animal feeds. Biodiesel is produced by chemically altering oils (e.g., soybean oil) into diesel fuel substitutes. Also included are other bio-derivatives including those produced as refinery products, such as certain alcohols and alkanes. Another sub-category of biologically derived petroleum substitutes are called biobased products (or bioproducts).
- *Solar, wind and geothermal* are electricity generation technologies that substitute for fossil-based generation technologies. Because, wind and solar can be intermittent in their output, they often require other power plants on a grid to operate in less efficient modes of operation—termed ramping—which can result in reduced or no reductions in fuel use and GHG emissions.
- *Sulfur hexafluoride (SF₆) and Halogenated Fluorocarbons/Perfluorocarbons* are gases used in industrial applications and refrigeration. Various substitute gases have recently been developed to reduce those applications' greenhouse gas emissions, or their global

⁴⁴ National Research Council. *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy*. Washington, DC: The National Academies Press, 2011.

⁴⁵ <http://www.epa.gov/otaq/renewablefuels/420f10006.htm>

warming potential. These gases substitute for other industrial and commercial gases, but are not “fuels” and not considered as fuel substitutes.

- *Nitrous Oxides* (N₂O) are produced by both natural and human sources. Primary human-related sources of N₂O are agricultural soil management, animal manure management, sewage treatment, adipic acid production, and nitric acid production. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests. Control mechanisms for human sources include improved tillage practices and fertilization techniques, and improved efficiency in manufacture of adipic acid and combustion.

Category 3. “End-use” technologies include stationary fuel-cell applications⁴⁶, transportation applications (fuel cell, electric hybrid, and flex-fuel vehicles, high efficiency gasoline and diesel engines), and cogeneration—regardless of fuel source. The extent of greenhouse gas mitigation from flexible fuel vehicles depends on the consumers’ actual use of different fuels, and may be negligible. This category also includes investments made to improve thermodynamic efficiency.

- *Advanced-Technology Vehicles* use both petroleum and non-petroleum based fuels (or mixtures), advanced batteries for hybrid vehicles or fuel-cell technologies. Automakers, engine manufacturers, and oil and gas companies are actively developing vehicle technologies and the advanced fuels of the future that will power them.
- *Cogeneration, or combined heat and power* (CHP) is the simultaneous production of both electricity and thermal energy (steam, hot water, hot air). CHP is an important efficiency improvement compared to separate production of electricity and heat. These facilities range from very small units in commercial buildings to large units at petroleum refineries, and are captured separately from other efficiency improvements.
- *Efficiency* measures include a whole range of technologies, from improved combustion burners, to advanced lighting, and improved process efficiencies, but does not include, for purposes of this report, combined heat and power.
- *Gas Flaring* can occur when methane associated with crude oil production is combusted. In areas of the world lacking infrastructure and markets, this associated gas is usually flared (burned) or sometimes vented (emitted as un-burnt gas). Reducing this flared gas reduces greenhouse gas emissions of either CO₂ if the gas is burned, or of methane if the gas is vented. Safety issues may impact the flaring or venting decision.
- *Carbon Capture and Storage* is the capture and long-term storage of carbon dioxide emissions from combustion processes. Over 200 CCS projects were active or planned worldwide at the end of 2010, a net rise of 26 from 2009⁴⁷. Of these, 77 are large-scale integrated projects at various stages of development. North America, Europe, and Australia are home to 87% of all projects. This technology has moved beyond the basic research stage.

Category 4. “Enabling Technologies” are necessary and often basic science and technology that allow other technologies’ use. They include various consortia that are researching and

⁴⁶ Note that fuel cells as a technology are not separately listed, as they depend on a variety of fuels and can be used in a variety of applications, including transportation and combined heat and power. They are subsumed in the various categories where applicable.

⁴⁷ *Carbon Capture and Storage: A Mixed Review*, Robin Beckwith, JPT/JPT Online, May 2011

developing a wide variety of technologies, and include several university programs. Their basic and cross cutting application does not allow categorization into one of the other categories.

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 subcategories⁴⁸ within the category of “other private industries.” The database was compiled from a review of over 850 publicly available company annual reports, federal budget documents, and other public sources, beginning with the database constructed for the 2013 report, *Key Investments in Greenhouse Gas Mitigation Technologies by Energy Firms, Other Industry and the Federal Government*: October 2013. 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 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 2010 dollars was the U.S. Department of Commerce, Bureau of Economic Analysis chain-type deflator for “Gross Private Domestic Investment.”⁴⁹

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.

⁴⁸ 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.

⁴⁹ Available at <http://research.stlouisfed.org/fred2/series/GPDICTPI?cid=21>

Appendix A

Figures Presented in Nominal Dollars

Figure A-1

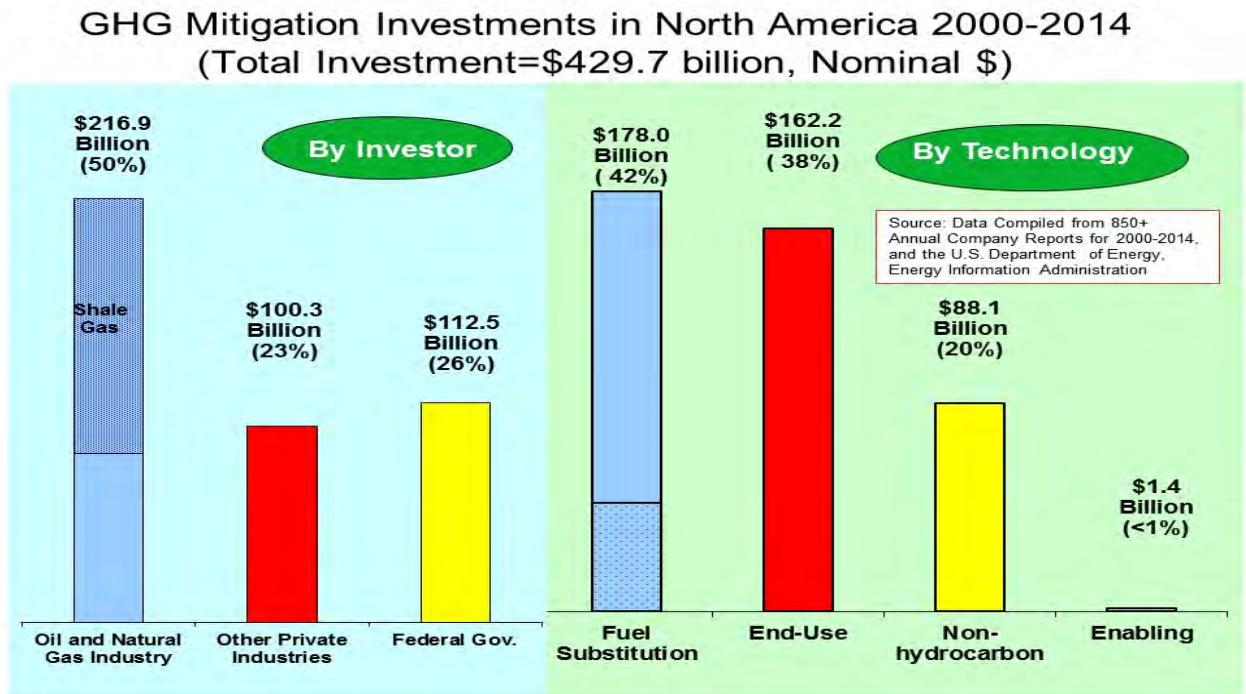


Figure A-2

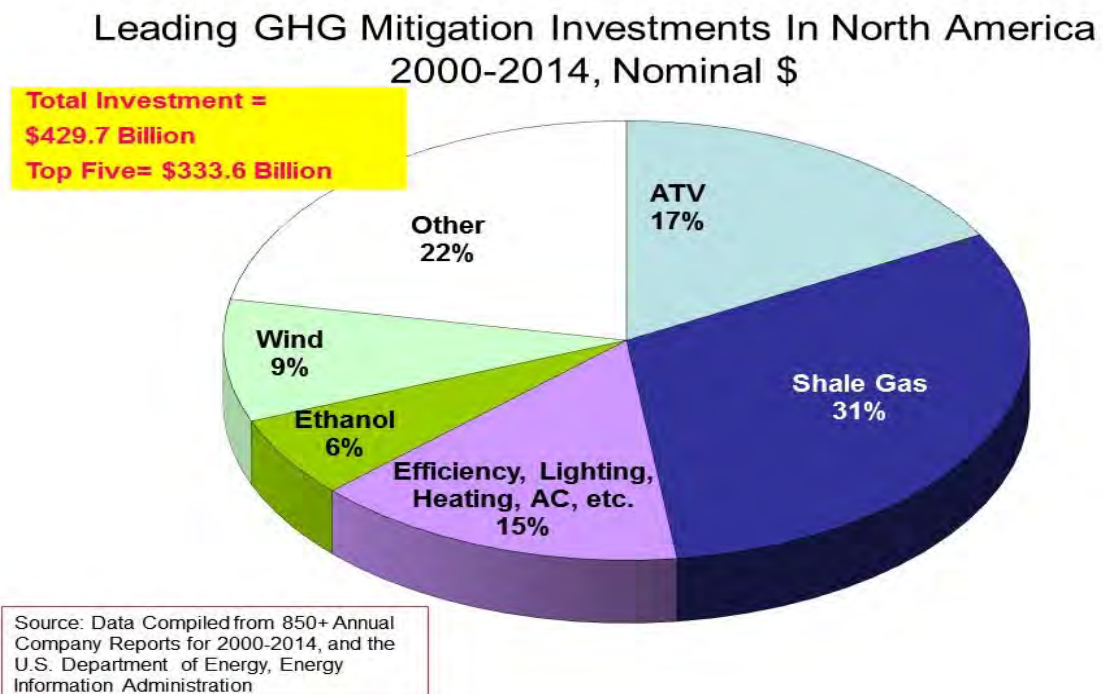


Figure A-3

Oil and Natural Gas Industry Investments in GHG Mitigation Technologies in North America: 2000-2014, Nominal \$

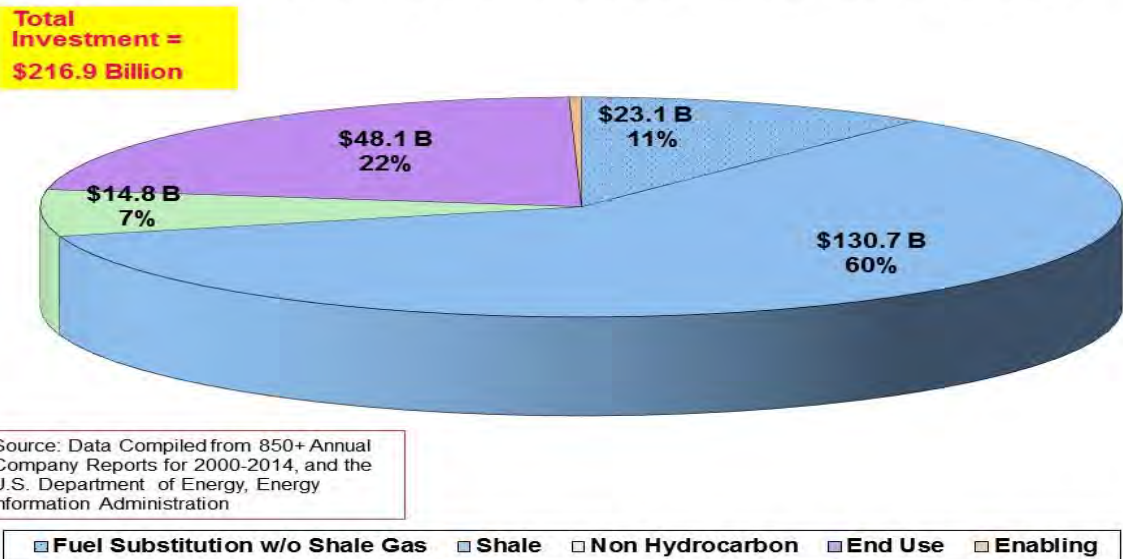


Figure A-4

Oil and Natural Gas Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, Nominal \$

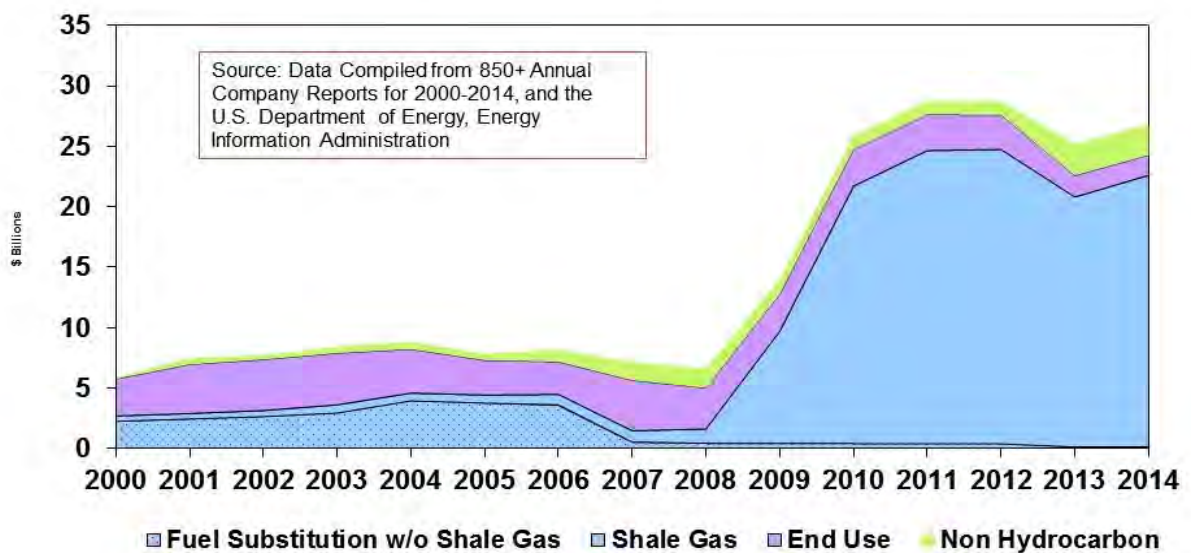


Figure A-5

Other Private Industry Investments in GHG Mitigation Technologies in North America: 2000-2014, Nominal \$

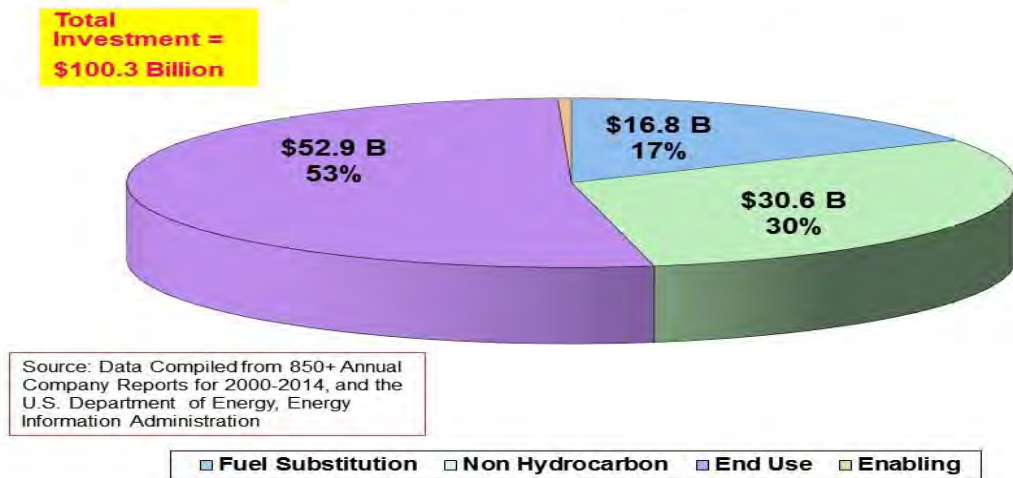


Figure A-6

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, Nominal \$

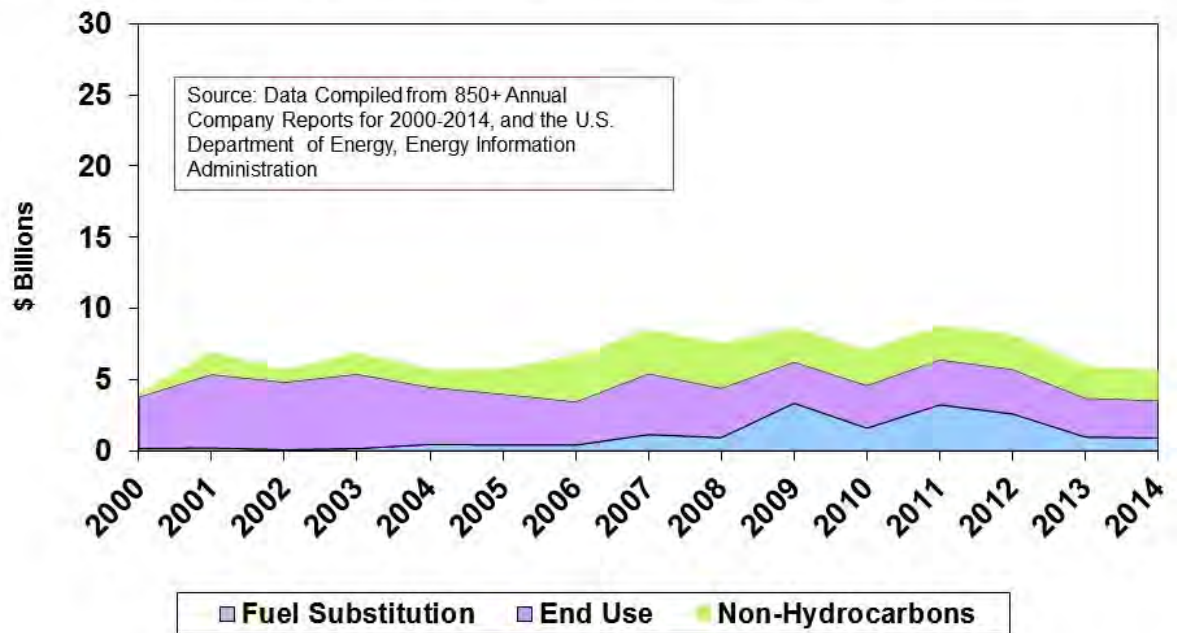


Figure A-7

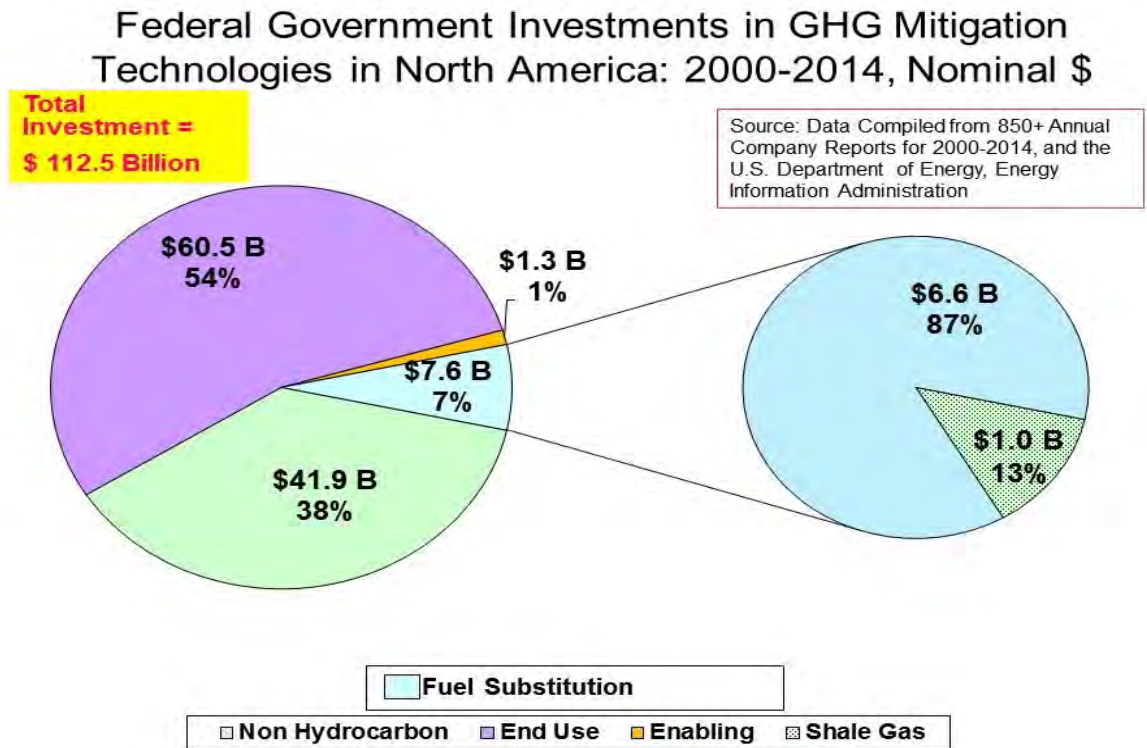


Figure A-8

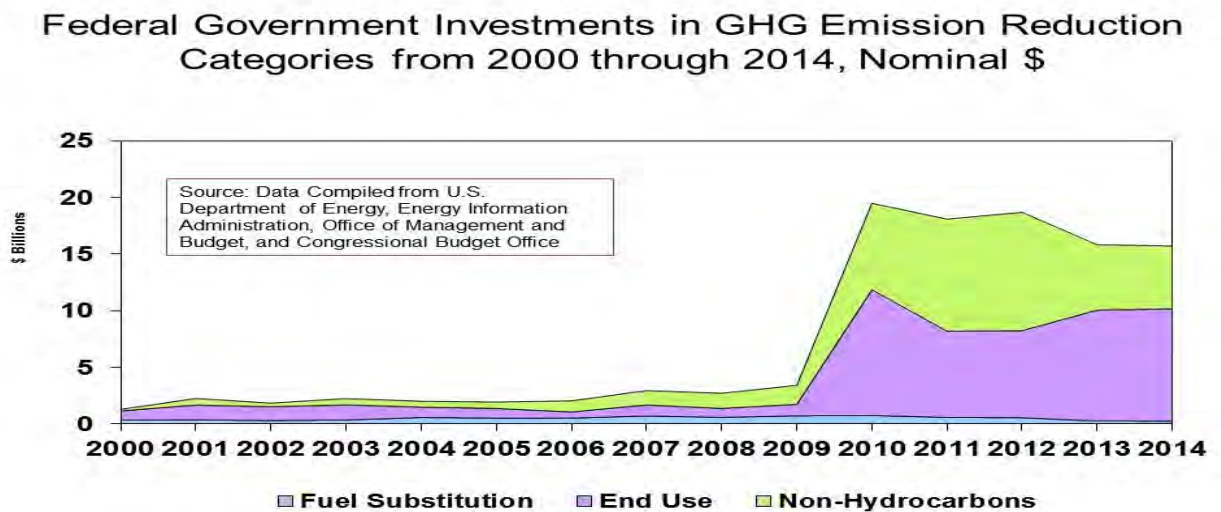
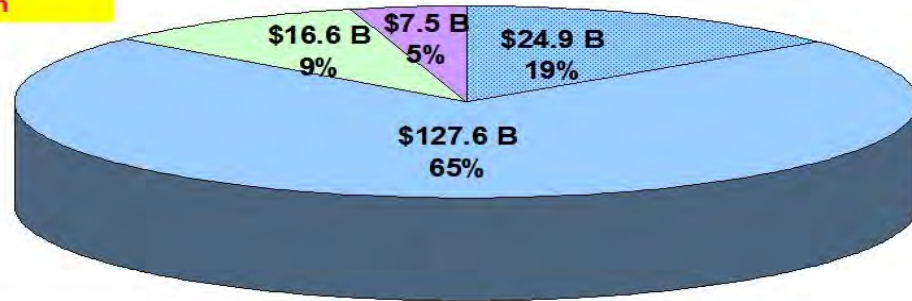


Figure A-9

Fuel Substitution Investment by Investor Type 2000-2014, Nominal \$

**Total
Investment =
\$170.6
Billion**



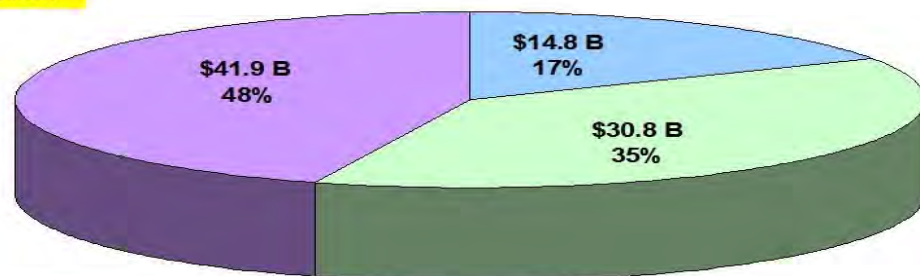
Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

■ O&G Industry ■ O&G Industry Shale Gas ■ Other Private Companies ■ Federal Gov.

Figure A-10

Non-Hydrocarbon Investments by Investor Type 2000-2014, Nominal \$

**Total
Investment =
\$87.6 Billion**



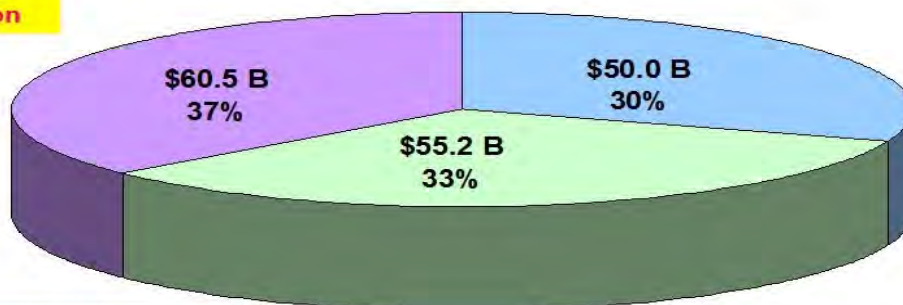
Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

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

Figure A-11

End Use Investments by Investor Type 2000-2012, Nominal \$

**Total
Investment =
\$165.8 Billion**



Source: Data Compiled from 650+ Annual Company Reports for 2000-2012, and the U.S. Department of Energy, Energy Information Administration

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

Figure A-12

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, Nominal \$

Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

Fuel Substitution

**Total
Investment =
\$16.8 Billion**

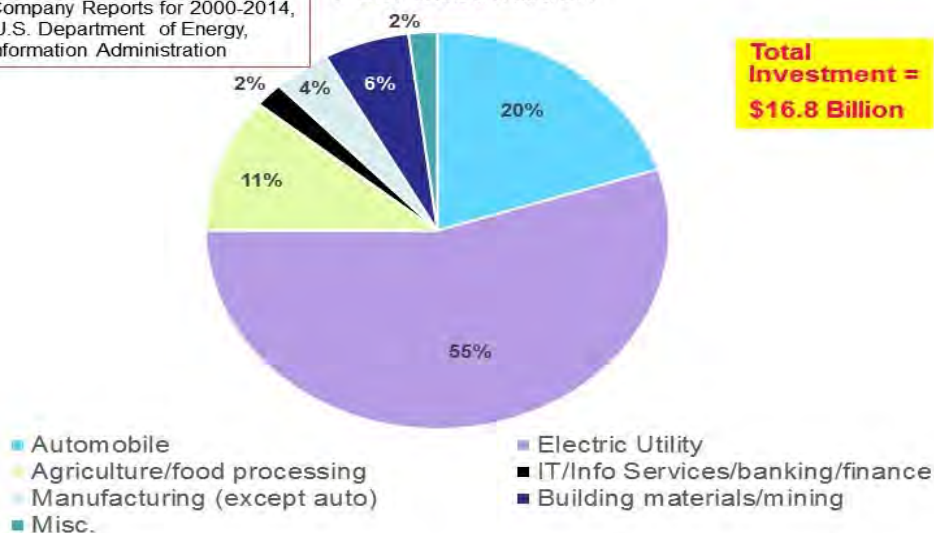


Figure A-13

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, Nominal \$

Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

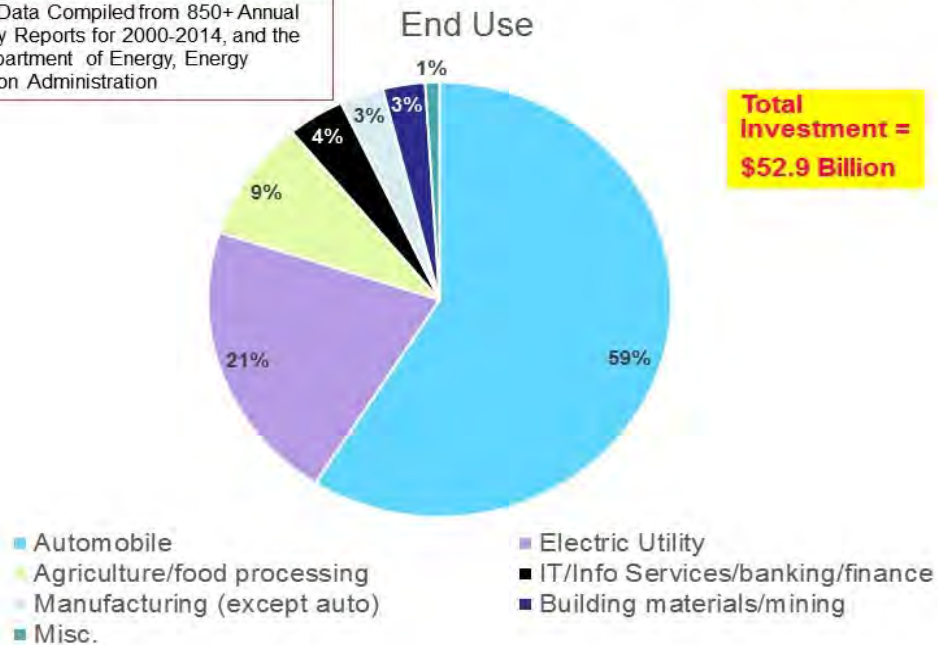


Figure A-14

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, Nominal \$

Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration

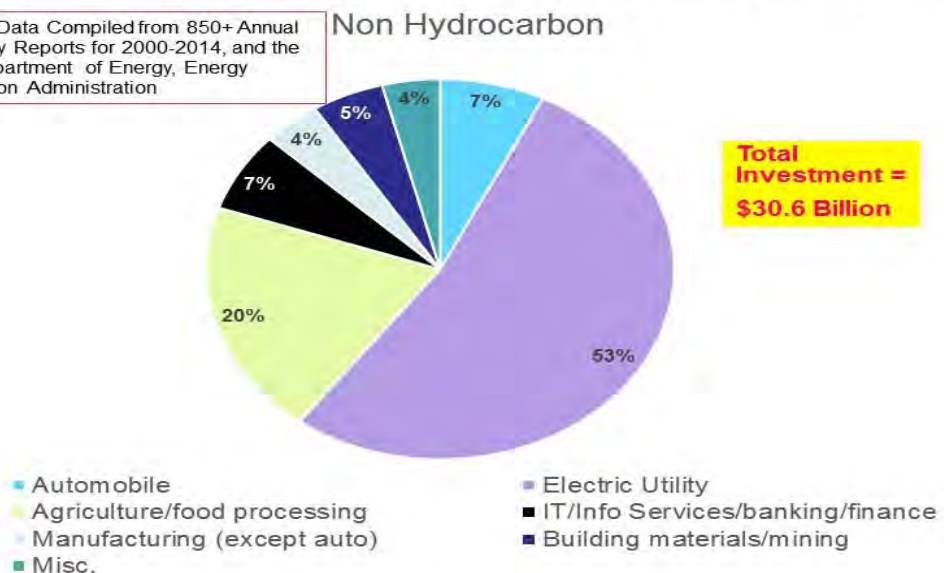
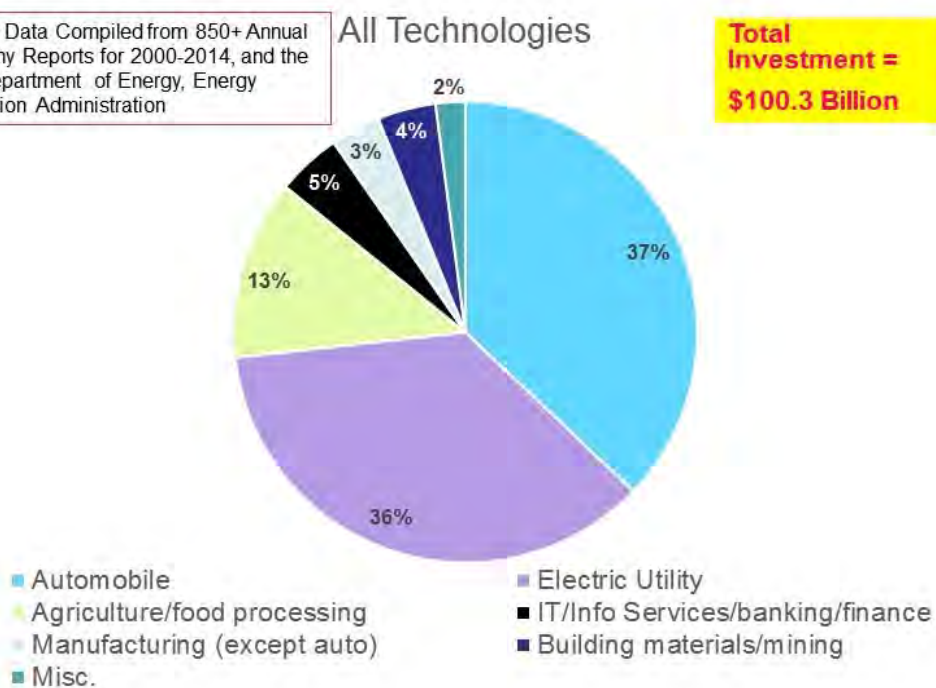


Figure A-15

Other Private Industry Investments in GHG Emission Reduction Categories from 2000 through 2014, Nominal \$

Source: Data Compiled from 850+ Annual Company Reports for 2000-2014, and the U.S. Department of Energy, Energy Information Administration



Appendix B

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