

Oil and Gas Industry Investments In Alternative Energy, Frontier Hydrocarbons and Advanced End-Use Technologies: An Update

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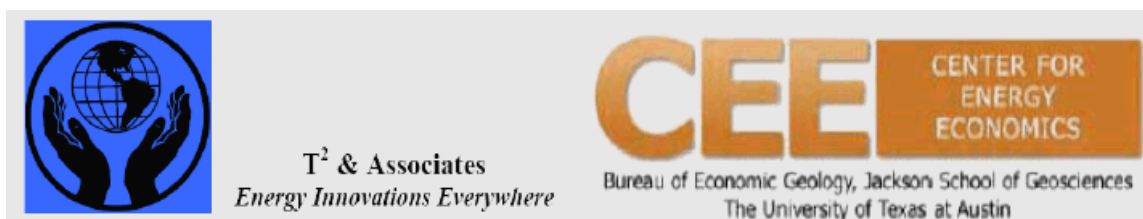
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Undertaken for API



Glossary of Terms

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

Biodiesel is produced by chemically altering oils (e.g., soybean oil) into diesel fuel substitutes.

Biomass projects use plant materials to produce energy, typically electricity.

Biorefineries produce a broad slate of products from plant materials. *Biodiesel* is an increasingly important sub-group of this technology.

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

Ethanol is produced by the fermentation of various sugars, primarily from corn and sugar cane.

Frontier Hydrocarbons encompass various hydrocarbon fuels and technologies that are emerging as supply options to substitute for or complement petroleum and natural gas use. They include: gasification of coal or petroleum coke (but not direct combustion), gas-to-liquids (GTL), heavy oil (both enhanced oil recovery and refining thereof), liquefied natural gas (LNG), oil sands, and shale oil.

Gasification is a thermal process for converting solid materials (e.g. coal or petroleum coke) into a synthetic gas. The gas may be used directly, or further transformed to serve hydrogen or liquid fuel requirements.

Gas-to-liquids (GTL) is a process that converts methane (natural gas) to higher molecular weight hydrocarbons ranging from light gases to waxes or diesel fuel.

Liquefied natural gas (LNG) is natural gas that has been super-cooled to a liquid for oceanic travel. The conversion from a gas to a liquid dramatically reduces the volume of gas for cost-effective transport by tanker.

Oil sands are a type of petroleum deposit. They are naturally occurring mixtures of sand or clay, water and an extremely dense and viscous form of petroleum called bitumen. They are also termed *tar sands*.

Oil shale is a fine-grained sedimentary rock containing significant amounts of kerogen, which can be mined and processed to provide a petroleum substitute.

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.

Emerging Energy Technologies

Frontier Hydrocarbon
Gasification (inc. hydrogen and coal to liquids)
Gas to Liquids
Heavy Oil Conversion
Liquefied Natural Gas (LNG)
Shale Oil Development
Oil Sands Production

Non-hydrocarbon
Biomass/Biorefineries
Ethanol and Biodiesel
Geothermal
Landfill Digester Gas
Nuclear Power
Solar electric
Wind Power

End Use
Advanced Technology Vehicles
Cogeneration (CHP)
Fuel Cells (inc. hydrogen usage)

Executive Summary

This report updates a 2006 report that documented investments in emerging energy technologies in North America over the 2000-2005 period.¹

The global energy challenge over the next several decades, and beyond, will be the task of meeting an ever-growing energy demand with an affordable and reliable supply, while ensuring environmental protection and quality improvements. Recent years have witnessed historically high energy prices, a consequence of which has been an expansion of investments in alternative energy, frontier hydrocarbons, and advanced end-use technologies that portend continuing growth in the diversity of energy supply. This report summarizes these emerging technology investments by the U.S. oil and gas industry, other private industries, and the Federal government in the North American market over the 2000-2007 period, adding the years 2006 and 2007 to the previous report².

The emerging technologies identified in this report serve a stated aim of U.S. energy policy by either:

- Prominently increasing North American energy supplies, thereby increasing energy security (technologies include frontier hydrocarbon technologies such as gasification, including hydrogen production; gas-to-liquids; oil shale, oil sands, and other heavy crude extractive and processing technologies);
- Providing additional non-hydrocarbon supply options (ethanol, biodiesel, wind and solar);
- Moving towards globalizing a regionally limited natural-gas market to reduce risks associated with supply and price (LNG); or
- Reducing emissions of greenhouse gases (new low emission supplies such as nuclear, wind, or solar; reduced emissions from hydrocarbon usage such as coal gasification, cogeneration and deployment of CO₂ capture and sequestration technologies; more efficient end-use technologies such as hydrogen fuel cells and advanced-technology vehicles).

This report documents the results of a database compilation of significant investments made in North America in the covered technologies during the period 2000-2007. The database was compiled from a review of over 350 company annual reports, federal budget documents, and other public sources.³ No claim is made to have captured 100 percent of investments in each technology, but the authors believe that further refinements to the database would change the relative distributions only at the margin.

In addition, this report does not attempt to document or assess so-called “disruptive” energy technologies that have the potential for significantly altering energy production, distribution and use in either the U.S.

¹ Bradley, Robert, Thomas Tanton, et al.: *Oil and Gas Industry Investments in Alternative Energy, Frontier Hydrocarbons and Advanced End-Use Technologies*; May 2006.

² “North American market” is used herein to include Canada and the U.S.

³ See bibliography in Appendix B for a list of sources used in this study.

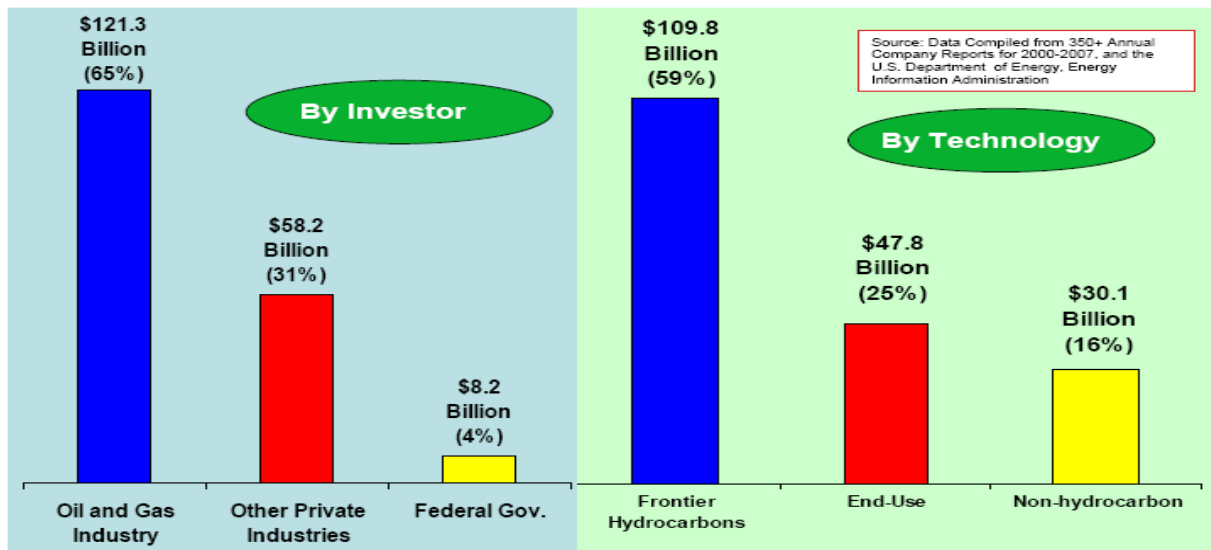
or the world. Disruptive technologies include nanotechnology and advanced materials that can be used for superconducting “smart grids” to vastly improve electricity transmission; for reducing weight while maintaining or increasing vehicle safety; or for reducing friction and improving energy efficiency for both air and ground modes of transportation.

Oil and Gas Industry Investment in Emerging Energy Technologies from 2000 to 2007

To help meet a projected U.S. energy demand growth of 19 percent over the next two decades⁴, U.S. based oil and gas companies invested an estimated \$121.3 billion from 2000 through 2007 on emerging energy technologies in the North American market⁵ (**Figure ES-1**). This expenditure represents 65 percent of the estimated total of \$188 billion spent by U.S. based companies and the Federal government. Of the oil and gas industry investments, \$103.9 billion (or 86 percent of the \$121.3 billion total) was directed toward frontier hydrocarbons. The ability of major oil companies to upgrade oil sands and heavy oil into refinery feedstock, and to turn waste and residue hydrocarbons (gasification including hydrogen production) into high-value products, is a natural extension of the industry’s expertise.

Figure ES-1

Emerging Energy Investments in North America 2000-2007
(Total Investment=\$188 billion)



U.S. oil and gas industry investments go beyond frontier hydrocarbons. The industry invested an estimated \$15.9 billion (or 13 percent of the \$121.3 billion total) for advanced end-use technologies from 2000 through 2007. Most of this investment went to (1) efficiency improvements through combined heat

⁴ Energy Information Administration, *Annual Energy Outlook 2008*, June 2008.

⁵ U.S. based companies include both U.S. companies and foreign-owned companies operating in the U.S.

and power (cogeneration) and (2) advanced-technology vehicles including fuel-cell and advanced battery technologies. Significantly, this \$15.9 billion investment in end-use technologies represents 33 percent of the estimated total amount (\$47.8 billion) spent by U.S. based companies and the Federal government in this area.

Publicly announced non-hydrocarbon investment by the U.S. oil and gas industry is estimated at \$1.5 billion, representing roughly 5 percent of the total industry and Federal investment of approximately \$30.1 billion in this area. While the oil and gas industry's top investment in non-hydrocarbons was in wind, expenditures were also made in the solar, geothermal, and landfill digester gas sectors.

Other Private Industry and Federal Government Investments from 2000 to 2007

In addition to the U.S. oil and gas industry, the motor-vehicle industry, agricultural industry, electric utilities, the renewable-fuel industry, and the Federal government made significant emerging technology investments. Investments from these other private industries are estimated at \$58.2 billion (or 31 percent of the \$188 billion total) from 2000 to 2007. Of the \$58.2 billion, \$28.9 billion (50 percent) is associated with end-use technologies, \$27.1 billion (47 percent) with non-hydrocarbons, and \$2.2 billion (3 percent) with frontier hydrocarbons.

Likewise, the Federal government is estimated to have invested \$8.2 billion in emerging technologies (approximately 4 percent of the \$188 billion total) from 2000 to 2007. Of the \$8.2 billion, \$3.6 billion (44 percent) is associated with investments in frontier hydrocarbons, \$1.6 billion (20 percent) with non-hydrocarbons, and \$3.0 billion (37 percent) with end-use technologies. While the level of investment is low relative to the private sector, seed-money investments, particularly at the basic research stage, can leverage billions of dollars of later private investment.

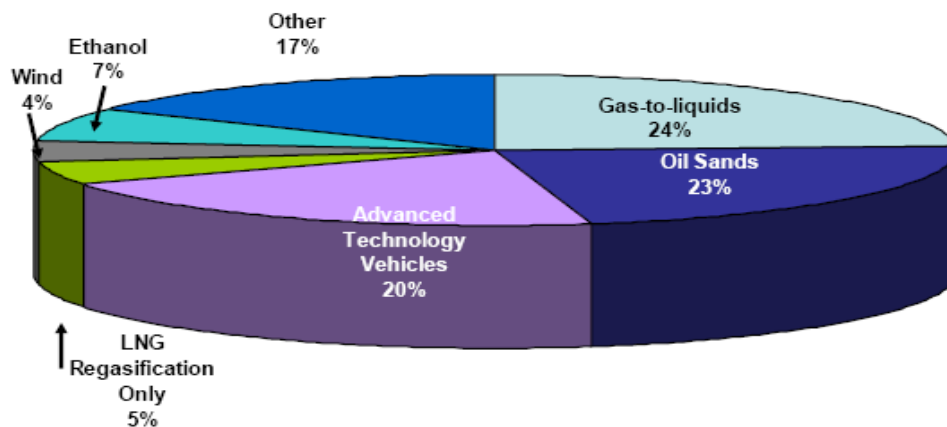
Six Leading Technology Investments During 2000 to 2007

The six leading technologies for private and public sector investment (*Figure ES-2*), as measured by expenditure, are gas-to-liquids (24 percent); oil sands (23 percent); advanced-technology vehicles (20 percent); ethanol (7 percent); liquefied natural gas, or LNG⁶ (5 percent); and wind (4 percent).⁷

⁶ We have included only investments in domestic LNG regasification facilities. The global LNG market would also include ships and liquefaction facilities in foreign locations, which are estimated to be valued at nearly \$200 billion.

⁷ Percentages may not add to 100% due to rounding.

Figure ES-2
Leading Emerging Energy Investments In North America
2000-2007



Source: Data Compiled from 350+ Annual Company Reports for 2000-2007, and the U.S. Department of Energy, Energy Information Administration

Major forecasts of U.S. and global energy supply by the Energy Information Administration (U.S. Department of Energy), and for the world by the International Energy Agency (Organization for Economic Co-Operation and Development), continue to place carbon-based fuels in the forefront for supplying the world's energy needs over the forecast period. The preponderance of frontier hydrocarbon investments, composing roughly 60 percent of the \$188 billion total, reflects a continuing primary role for oil, gas, and coal in the North American energy mix, at least over the next several decades. However, even given the preponderance of frontier hydrocarbon investments, there is substantial and important activity in end-use and non-hydrocarbon technologies.

Major Changes Since Last Report

Oil and gas companies, other private sector companies, and the Federal government continue to invest in emerging energy technologies in the North American market. Since the last report that covered investment from 2000-05⁸, total investment in these technologies has increased by approximately \$53 billion in 2006-2007. Overall, investment has grown by approximately 40 percent, from \$134.7 billion to \$187.8 billion. Significant growth has occurred in wind, biodiesel and nuclear though investment in other

⁸ Bradley, Robert, Tanton, Thomas, et al.: *Oil and Gas Industry Investments in Alternative Energy, Frontier Hydrocarbons and Advanced End-Use Technologies*; May 2006.

technologies increased as well. Table ES-1 lists, by technology, the investments made over the two time periods, and then gives the percentage increase in investments in the later period over the former period. Overall, the 2006-07 oil and gas industry investments are estimated to have increased by \$23 billion over the 2000-05 level. Comparable figures for other private industry and the Federal government are \$26 billion, and \$3 billion, respectively.

Table ES-1
Comparison of 2000-2005 and 2006-2007 Investment Levels
All Investor Groups, \$millions

Technology	2000-2005 Investment	2006-2007 Investment	2006-07 Investment Divided by 2000-05 Investment
Nuclear	\$193	\$1,325	6.9
Biodiesel	\$278	\$913	3.3
Geothermal	\$337	\$941	2.8
Hydrogen Fuel Cells	\$1,322	\$2,980	2.3
Shale Oil	\$160	\$476	3.0
Ethanol	\$5,401	\$7,684	1.4
Solar Electric	\$647	\$666	1.0
Gasification	\$2,750	\$2,600	0.9
Heavy Oil	\$2,967	\$2,600	0.9
Cogeneration (CHP)	\$3,786	\$2,115	0.6
Advanced-technology vehicles	\$26,009	\$11,600	0.4
Biomass	\$991	\$856	0.9
Wind	\$5,579	\$2,823	0.5
Oil Sands	\$33,600	\$9,300	0.3
Landfill Gas	\$1,273	\$229	0.2
Gas-to-liquids	\$40,450	\$5,200	0.1
Liquified natural gas	\$8,941	\$800	0.1
Total	\$ 134684	\$ 53108	0.40

Oil and Gas Industry Investments In Alternative Energy, Frontier Hydrocarbons and Advanced End-Use Technologies: An Update

Introduction

This report updates the 2006 report *Oil and Gas Industry Investments in Alternative Energy, Frontier Hydrocarbons and Advanced End-Use Technologies* by adding data for the years 2006 and 2007 to its emerging energy technology database. More specifically, publicly available information on investments made by the U.S. oil and gas industry, other U.S. industries, and the Federal government, in the North American market over the 2000-2007 period, are assessed in this report.⁹

Part I: Meeting Future Energy Demand

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 19 percent over the 2006 to 2030 period, or about 0.7 percent annually. (**Figure 1**) This increase is projected *after* accounting for a predicted improvement in energy intensity (energy usage per real dollar of GDP) of 1.7 percent per year.¹⁰ To meet the 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 79 percent in 2030, moderately changed from 85 percent in 2006.¹¹

The International Energy Agency (IEA) projects more than a 50 percent rise in global energy consumption between 2005 and 2030, a roughly 1.8 percent annual increase led by developing countries, many of which are expected to significantly increase energy consumption due to rising per capita incomes and population growth.¹² (**Figure 2**) Similar to the forecast for the U.S., fossil fuels are estimated to fill roughly 82 percent of the projected global primary energy demand in 2030.

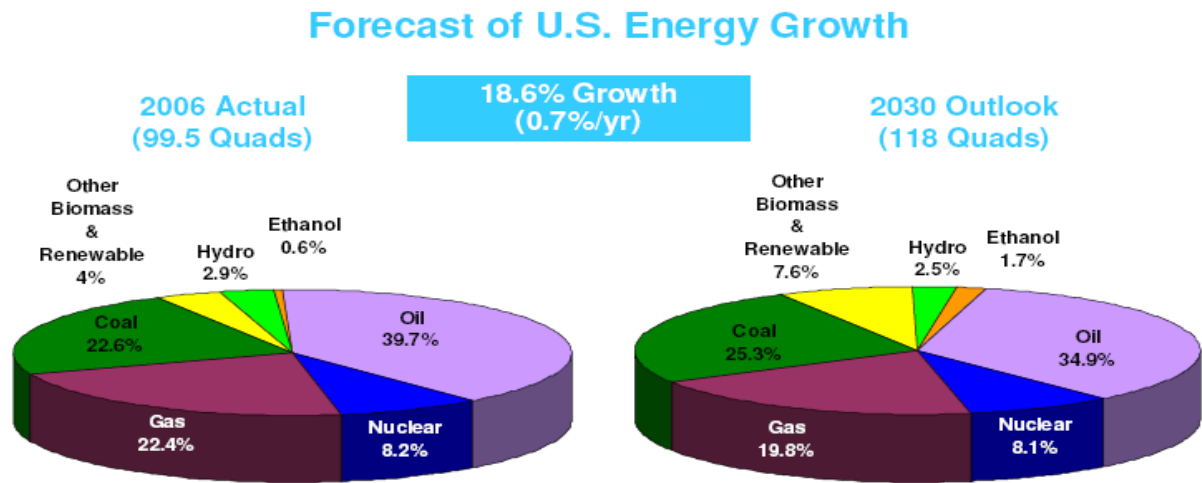
⁹ Estimates include some investment by foreign-owned companies operating in the U.S.

¹⁰ U.S. Energy Information Administration, *Annual Energy Outlook 2008 (Revised Early Release)* available at [EIA-Annual Energy Outlook 2008 \(Revised Early Release\)](#), June 2008.

¹¹ Ibid. Percentages in Figure 1 may not add to 100% due to rounding.

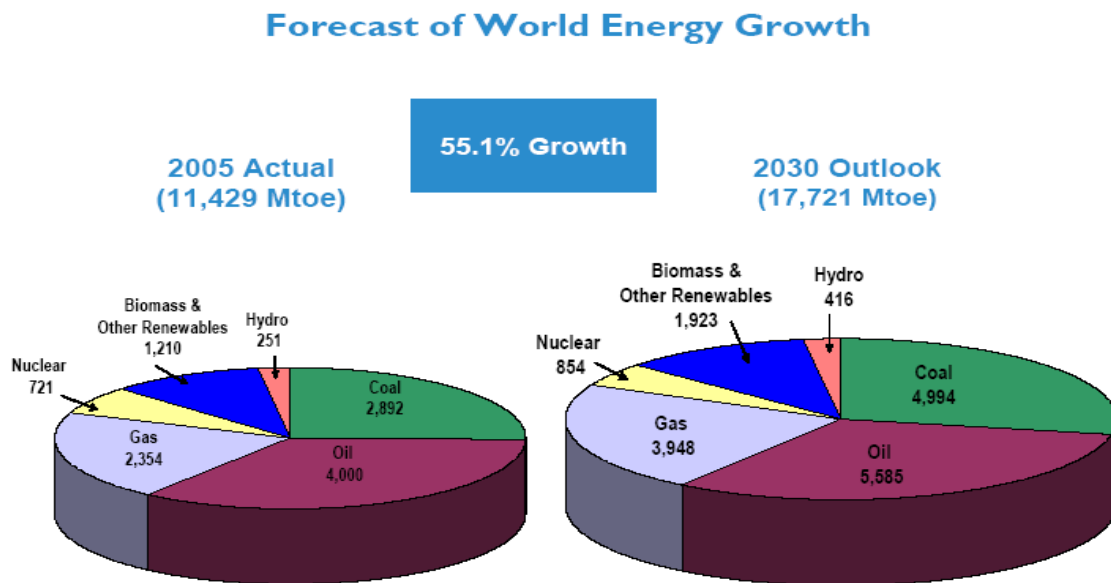
¹² International Energy Agency, *World Energy Outlook 2007* (Paris: Organization for Economic Co-operation and Development). Totals in Figure 2 may not add to precise sum of components due to rounding.

Figure 1



Source: EIA, AEO 2008

Figure 2



Source: IEA, World Energy Outlook 2007

Part II: Emerging Energy Technologies

Sixteen *emerging* energy technologies have been examined in this study over the 2000 to 2007 period.

Each is congruent with U.S. energy policy by either:

- Significantly increasing North American hydrocarbon supplies thereby increasing energy security (gasification including hydrogen production, gas-to-liquids, oil sands, heavy crude);
- Providing additional new non-hydrocarbon energy supply options using alternative feedstocks (ethanol, biodiesel, and other biomass sources); or
- Globalizing a regionally limited natural gas market to reduce risks associated with supply and price (LNG).

The emergence of these technologies not only increases the supply of energy and/or improves environmental performance in the future, it also provides a larger backstop of energy sources and, thus, a more diversified energy portfolio.

These technologies (**Figure 3**) have been grouped into three categories: *frontier hydrocarbon*, (six technologies), *non-hydrocarbon* (seven technologies), and *end-use* (three technologies).

Figure 3
Emerging Energy Technologies

Frontier Hydrocarbon	Non-hydrocarbon
Gasification (inc. hydrogen and coal to liquids)	Biomass/Biorefineries
Gas to Liquids	Ethanol and Biodiesel
Heavy Oil Conversion	Geothermal
Liquified Natural Gas (LNG)	Landfill Digester Gas
Shale Oil Development	Nuclear Power
Oil Sands Production	Solar electric
	Wind Power

End Use
Advanced Technology Vehicles
Cogeneration (CHP)
Fuel Cells (inc. hydrogen usage)

“*Frontier Hydrocarbon*” technologies (category 1) include: gasification of coal or petroleum coke (but not direct combustion), gas-to-liquids (GTL), heavy oil (both enhanced oil recovery and refining thereof), liquefied natural gas (LNG), oil sands, and shale oil. Biomass gasification is included in biomass/biorefining, as a precursor to ultimate use.

GTL converts methane (natural gas) to higher molecular weight hydrocarbons ranging from light gases to waxes or diesel fuel. *GTL* investments include use of natural gas that would otherwise be flared (e.g. natural gas associated with crude oil in remote areas) or stranded (isolated areas) and other beneficial uses. Companies with commercial interests have made advances in hardware design, catalysts, and operating conditions that have improved *GTL* economics. Certain governments, such as Qatar, have assisted in developing and implementing *GTL* as a component of long-term strategies.

Oil sands are heavy forms of petroleum. It is a vast additional source but requires very capital-intensive extraction techniques driven in large measure by their high viscosity. Oil-sands production in Canada has grown to 2.7 million barrels per day (b/d) in 2007, and a forecast output by 2020 of 4.5-5 million b/d.¹³ As conventional oil reserves continue to mature, the share of production from oil sands and other heavier types of oil, e.g. shale oil, will likely grow in significance.

Gasification is a thermal process for converting solid materials (e.g. coal or petroleum coke) into a synthetic gas, which can then be used directly in power generation or converted to liquid or hydrogen fuels. Newer gasification technologies will likely include carbon capture and ultimate sequestration. Gasification can also be performed with biomass materials but, in this study, this application is considered a non-hydrocarbon technology and included in the biorefining category.

Liquefied natural gas (LNG) is natural gas that has been super-cooled to a liquid. The conversion from a gas to a liquid dramatically reduces the volume of gas for cost-effective transport by tanker (where transport via conventional natural gas pipelines is cost prohibitive or not feasible). The global transport of LNG provides a means for natural gas to become a much more broadly traded international commodity and increases the potential natural gas supply available to the U.S.¹⁴

“Non-hydrocarbon” technologies (category 2) include any energy form that is not a fossil fuel/hydrocarbon energy source. This category includes: wind energy conversion (including turbine manufacturing facilities built in North America), solar to electric, geothermal (electric and direct use for industrial application), landfill gas, nuclear power, biomass and biorefinery, biodiesel, and ethanol production. Biodiesel and ethanol use technologies (e.g., vehicles) are included in the end-use category.

Ethanol is produced by the fermentation of various sugars, primarily from corn and sugar cane. Significant fossil fuel use is involved in corn-based ethanol production both for growing the corn and in

¹³ Canadian Association of Oil Producers, http://www.capp.ca/default.asp?V_DOC_ID=688

¹⁴ For more information on LNG, refer to the briefing papers and knowledge base incorporated in the CEE’s online *Guide to LNG in North America*, www.beg.utexas.edu/lng.

producing the ethanol. Most ethanol for fuel is produced in Brazil or the United States. There is no extensive global commodity trade for fuel ethanol, though Brazil continues exploring export opportunities. Technological advances may allow cost-competitive ethanol production from cellulosic materials in the longer term.

Biomass projects also use plant materials to produce energy—in this case electricity from direct combustion. Bio-refineries produce a broad slate of products from plant materials, including energy and fuels, plastics, pharmaceuticals and animal feeds. Biodiesel is an increasingly important sub-group of this technology. Biodiesel is produced by chemically altering oils (e.g., soybean oil) into diesel fuel substitutes. Another sub-category of biologically derived petroleum substitutes are called biobased products or bioproducts.

“*End-use*” technologies (category 3) include stationary fuel-cell applications, transportation applications (e.g., fuel cell, electric hybrid, and flex-fuel vehicles), and cogeneration—regardless of fuel source. Most of the ethanol is combusted in traditional motor vehicles, not flex-fuel or advanced vehicles. Most fuel cells ultimately use hydrogen, although the primary fuel may be fossil or non-fossil (e.g., natural gas that is reformed or electrolytic hydrogen).

Advanced-Technology Vehicles, as the name suggests, use both petroleum and non-petroleum based fuels (or mixtures) or fuel-cell technologies. Automakers, engine manufacturers, and oil and gas companies continue to actively develop 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 when compared to the separate production of electricity and heat. These facilities range from very small units in commercial buildings to large units at petroleum refineries.

Methodology

This analysis was carried out in several steps. The first was an identification of major categories of emerging energy sources, and the associated technologies. Second, a database of investments was constructed by emerging energy technology category and by investor type. The database was compiled from a review of over 350 company annual reports, federal budget documents, and other public sources, beginning with the database constructed for the 2006 report by the Institute for Energy Research, *Oil and Gas Industry Investments in Alternative Energy, Frontier Hydrocarbons and Advanced End-Use*

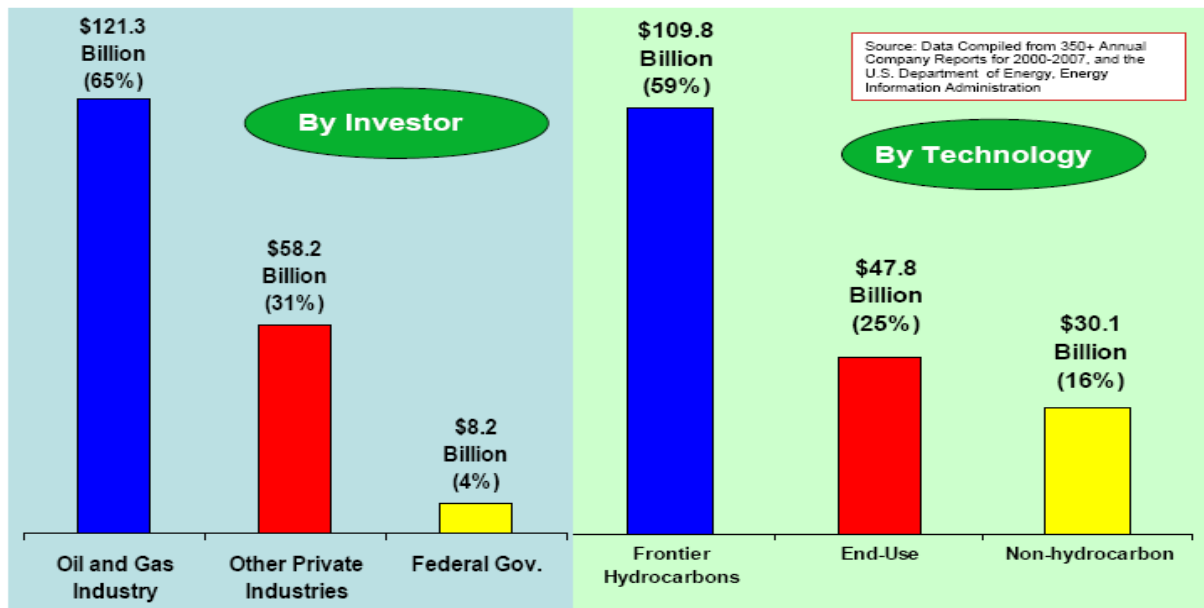
Technologies (2006). If an investment amount for a relevant technology was specified in a source document it was included in the database. All investments were tabulated in nominal dollars. Third, each investment was reviewed to determine if it should remain in the database, be prorated, or otherwise 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 ships, and liquefaction facilities in foreign locations, which are estimated to be valued at nearly \$200 billion.¹⁵ Ships and liquefaction facilities were not included here as they, to a large extent, fall outside the area of the North American market.

¹⁵ Bradley, R., Tanton, T., et.al., *Oil and Gas Industry Investment in Alternative Energy, Frontier Hydrocarbons, and Advanced End-Use Technologies*, May 2006

Part III: Emerging Energy Technology Investments

U.S. based companies¹⁶ and the Federal government invested approximately \$188 billion from 2000 to 2007 on emerging energy technologies in the North American market, far outdistancing non-conventional energy development over the post World War II period.¹⁷ The U.S. oil and gas industry invested \$121.3 billion, 65 percent of the \$188 billion total, principally in frontier hydrocarbon development, although significant investments were also made in end-use and non-hydrocarbon technologies. Other private industries invested an estimated \$58.2 billion or 31 percent of the total. During the same six-year period, the Federal government invested in a wide array of emerging energy technologies, with expenditures of approximately \$8.2 billion, or 4 percent of the total (*Figure 4*).¹⁸

Figure 4
Emerging Energy Investments in North America 2000-2007
(Total Investment=\$188 billion)



Consistent with the energy outlook by EIA and IEA, investments in frontier hydrocarbons are estimated to account for \$109.8 billion (59 percent) of the total of \$188 billion over the 2000 to 2007 period¹⁹. The

¹⁶ U.S. based companies include both U.S. companies and foreign-owned companies operating in the U.S.

¹⁷ The largest prior efforts involved synthetic liquid fuels. A Federal program from 1944 through 1955 totaled \$106 million, which in today's dollars would be around \$850 million. More than \$20 billion was allocated for synthetic fuel research and development from 1974 to 1985, but less than one half of that was actually spent before the Federal programs were terminated (Robert Bradley, *Oil, Gas & Government: The U.S. Experience* [Lanham, MD: Rowman & Littlefield, 1996], pp. 574, 576-83).

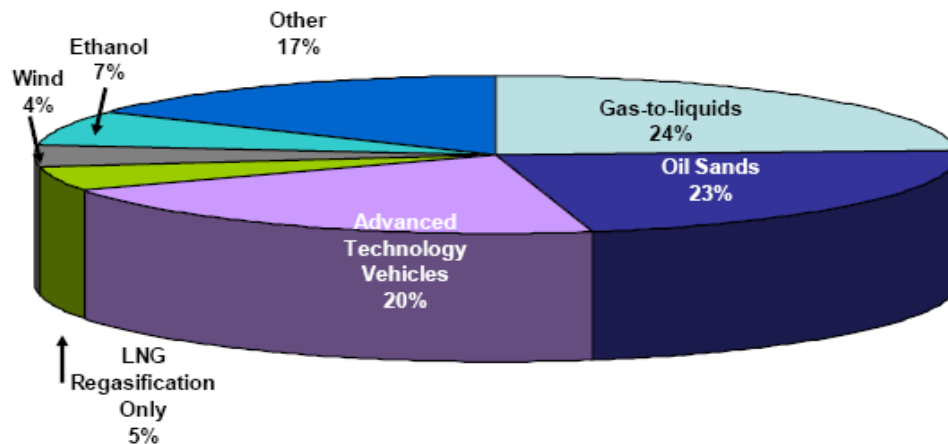
¹⁸ State and local alternative-energy investment would add approximately \$2 billion to this total on the public-sector side. <http://www.dsireusa.org/>

¹⁹ The investment shares estimated herein are also consistent with U.S. DOE/EIA forecasts of energy demand for other energy types, e.g. renewables.

balance of *emerging* energy technology investment over this study period is estimated to be: end-use technologies (\$47.8 billion, 25 percent) and non-hydrocarbon investment (\$30.1 billion, 16 percent).

The six leading technologies over the study period for private and public sector investment (**Figure 5**), as measured by expenditure, are gas-to-liquids (24 percent); oil sands (23 percent); advanced-technology vehicles (20 percent); ethanol (7 percent); liquefied natural gas, or LNG²⁰ (5 percent); and wind (4 percent).²¹

Figure 5
Leading Emerging Energy Investments In North America
2000-2007



Source: Data Compiled from 350+ Annual Company Reports for 2000-2007, and the U.S. Department of Energy, Energy Information Administration

Oil and Gas Industry Investments from 2000 to 2007

The leading technology investor—the *U.S. oil and gas industry*—and the leading technology area—*frontier hydrocarbons*—are related. Oil and gas industry investments in this area sum to \$103.9 billion, 86 percent of their \$121.3 billion total investment over the study period. The ability of major oil companies to upgrade oil sands and heavy oil into refinery feedstock, and to turn waste and residue hydrocarbons (gasification, hydrogen production) into high-value products, are natural extensions of their expertise. Developing hydrocarbons is a core competency relative to non-hydrocarbon and end-use

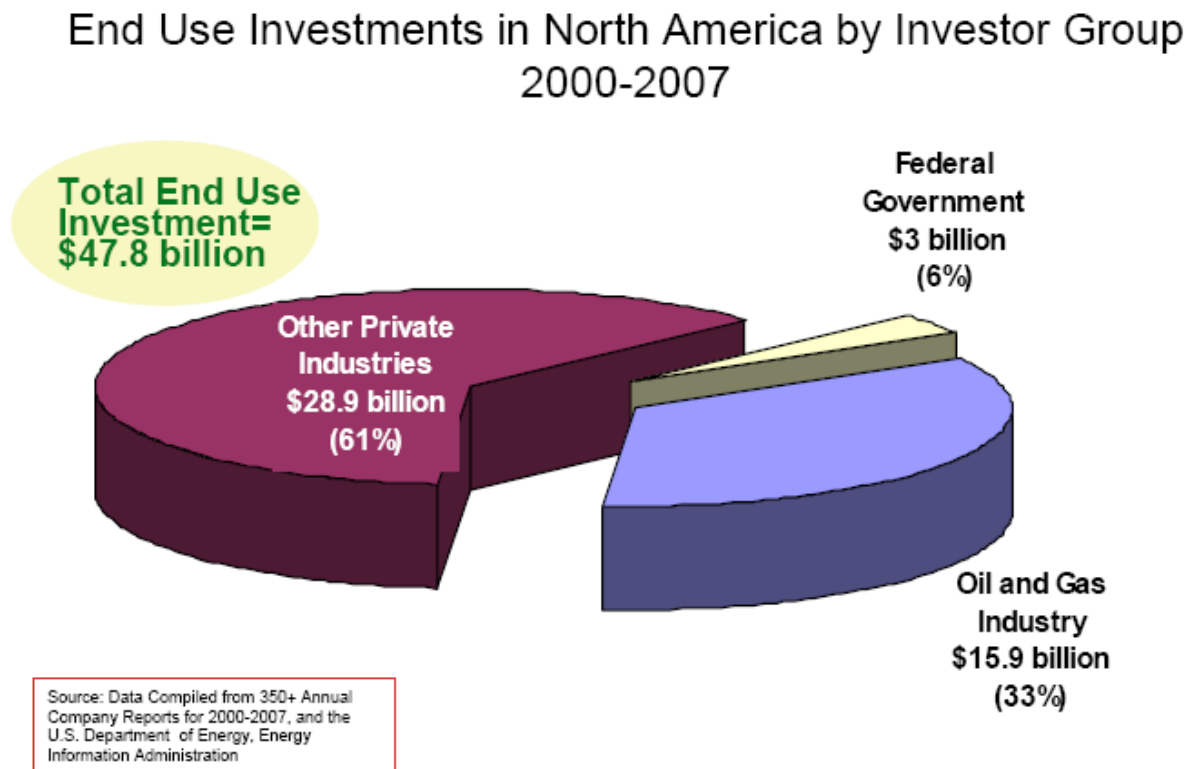
²⁰ We have included only investments in domestic LNG regasification facilities. The global LNG market would also include ships and liquefaction facilities in foreign locations, which have an estimated value of nearly \$200 billion. We've previously estimated that roughly \$30 billion of this total could be allocated to the U.S. market.

²¹ Percentages may not add to 100% due to rounding.

technologies. Yet, U.S. oil and gas industry investments go beyond frontier hydrocarbons. The investment of oil and gas companies in end-use and non-hydrocarbon technologies, in relation to total investment in these areas, is shown in the next two figures.

Oil and gas companies have invested approximately \$15.9 billion on *end-use* technologies, mostly for efficiency improvements through combined heat and power (cogeneration) and for advanced technology for vehicles using fuel-cell technology or advanced batteries. It is significant to note that this \$15.9 billion investment in end-use technologies represents 33 percent of the estimated total amount (\$47.8 billion) spent by U.S. companies and the Federal government in this area (**Figure 6**).

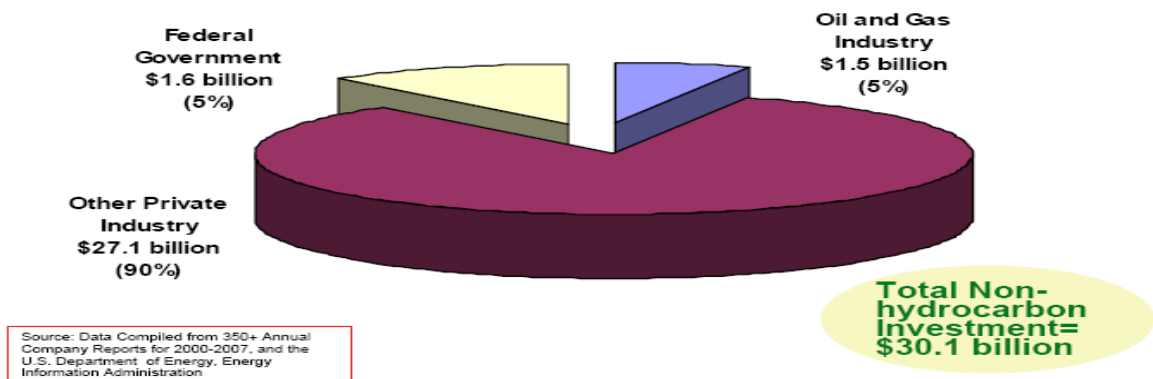
Figure 6



Non-hydrocarbon investment by the U.S. based oil and gas companies is estimated at \$1.5 billion, representing 5 percent of the total industry and Federal investment of approximately \$30.1 billion (**Figure 7**). The data over the study period indicates that the top investment is in wind, followed by investments in solar, geothermal, and landfill digester gas.

Figure 7

**Non-hydrocarbon Investment in North America by Investor Group
2000-2007**

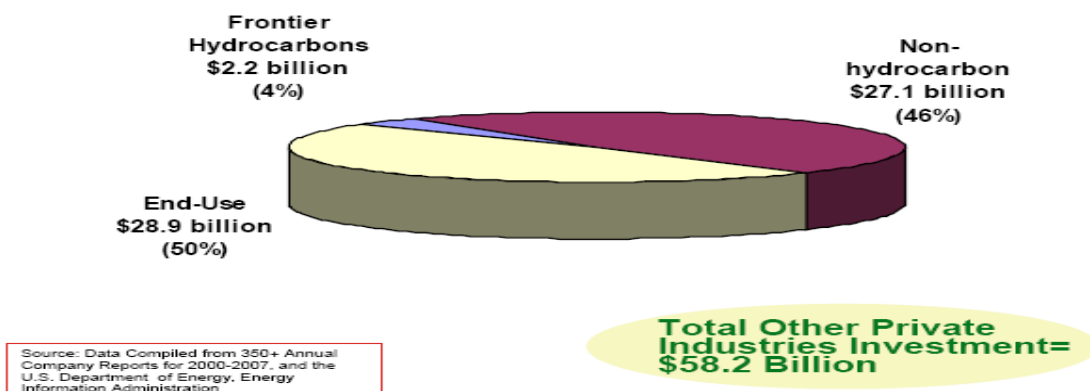


**Other Private Industries and Federal Government Investments
from 2000 to 2007**

Other private industries (**Figure 8**) have accounted for an estimated \$58.2 billion of the \$188 billion total estimated investment. Other private industries lead the way in (1) the *end-use* market (mostly automotive companies investing in advanced-technology vehicles), and (2) the *non-hydrocarbon* market (mostly agricultural firms in the ethanol market, independent power producers in the electricity market, and manufacturing firms in the wind and solar markets).

Figure 8

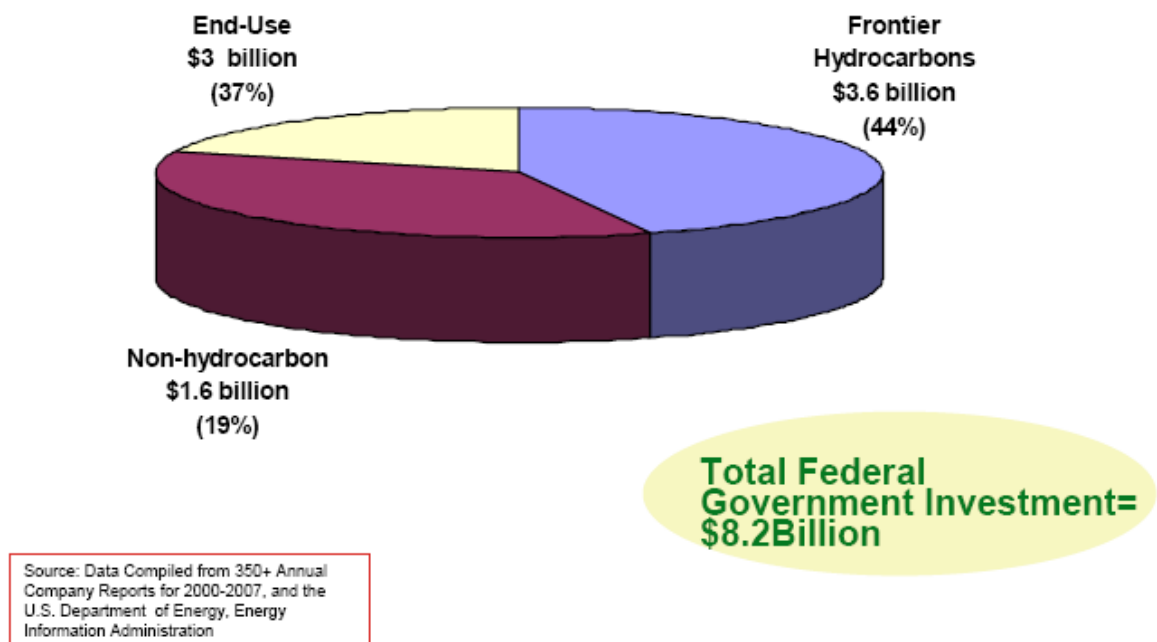
**Emerging Energy Investment in North America
2000-2007
Other Private Industries**



The *Federal government* (**Figure 9**) has been the most diversified investor, supporting all seventeen technologies. Total estimated expenditure in the years 2000-2007 of \$8.2 billion has been spread between *frontier hydrocarbons* (primarily coal gasification, gas-to-liquids research, and heavy oil studies), non-hydrocarbons (primarily ethanol, wind, nuclear and solar) and end-use (primarily cogeneration and lighting technologies) . While the level of spending may seem low compared to the private sector, seed-money investments by government can leverage significant private sector follow-on investment.

Figure 9

**Emerging Energy Investments in North America
2000-2007
Federal Government**



Finally, it is important to recognize that aggregate investment levels for each technology are, and should be, consistent with the development status of that technology. More mature technologies will naturally see higher levels of investment than technologies earlier in the development cycle. The technologies included here are at different stages in their development cycle as indicated in part by relative expenditures. The distribution of investments can be expected to shift as different technologies mature or market conditions change.

Appendix A

Technology Categorization, Assumptions, and Limitations

Categorization of technologies

The intent of constructing this database is to identify major investments by industry sector and government in primary energy sources and technologies that will diversify and expand available energy supplies. For display purposes, specific technologies have been grouped into one of three categories: frontier hydrocarbons; non-fossil; and end-use (regardless of fuel choice). The following identifies how technologies were categorized, recognizing that several technologies may easily fit into more than one category.

“*Frontier Hydrocarbon*” technologies (see **Figure 3**, category 1) include: gasification of coal or petroleum coke, gas to liquids (GTL), heavy oil (both enhanced oil recovery and refining thereof), liquefied natural gas (LNG), oil sands, and shale oil. Biomass gasification is included in biomass/biorefineries, as a precursor to ultimate use.

“*Non-hydrocarbon*” technologies (category 2) include any energy form that does not first rely on a fossil energy source. This category includes: wind energy conversion, solar to electric, geothermal (electric and direct use for industrial application), land-fill gas, nuclear power, biodiesel and ethanol production. Biodiesel and ethanol use technologies (e.g., vehicles) are included in the end-use category.

“*End-use*” (category 3) technologies include stationary fuel-cell applications, transportation applications (fuel cell, electric hybrid, and ethanol), and cogeneration. Most fuel cells ultimately use hydrogen, although the primary fuel may be fossil or non-fossil (e.g., natural gas that is reformed or electrolytic hydrogen).

Technology names are not always consistent between companies (e.g., “tight sands” may be used by one company and “unconventional gas” by another). Our best judgment was used to assign projects and expenditures to specific technologies and categories; we believe this does not affect the data base for the purposes intended and do not believe that further disaggregation is warranted.

Many of the companies included in our investment data search are multi-national corporations (MNC). It was not always possible to distinguish investments made in the U.S. from investments made elsewhere. Investments made in globally traded commodities were included if, in our judgment, they served to expand energy supply available to the U.S.

Cost Assumptions

Estimates of investment amounts for each technology, e.g. facility capital costs or research and development expenditures, were arrived at either from listings of individual projects and their costs, or from corporate expenditures for a technology area.

Project-level costs estimates were not always available. In those cases, we estimated project costs based on average project costs from other sources as explained below. Individual projects may cost more or less

than the average. For several of the technologies, actual costs are more broadly distributed around the average. We believe the estimated costs used here are representative of the included technologies. Estimates were especially important for ethanol production, biodiesel production, wind farms, and cogeneration.

The cost of constructing *ethanol production* facilities was estimated based on cost for a particular size (~20 million gallons per year at \$22 million) and is likely not representative for sizes dramatically larger, nor for the few facilities using non-corn feedstocks²². Furthermore, no cost allocation has been done for the co-products of ethanol (e.g., cattle feed, protein isolates, etc.) Lastly, some existing ethanol production facilities do not have associated cost estimates, and are not included here, because they came on line prior to the period of interest.

Cogeneration (combined heat and power, CHP) plants were estimated to cost between \$800-2200/kW, depending on size.²³ No cost allocation was assigned for the thermal portion of CHP/cogeneration plants.

Wind farms were estimated to cost, on average, \$800/kW, although since 2005 costs have risen substantially²⁴.

Lastly, the capital cost of *biodiesel production* plants was estimated based on the work of Frazier, Barnes and Associates²⁵ as shown in Table A-1 below.

Table A-1
Estimated Capital Cost of Biodiesel Production Plants

Plant Size (million gallon/yr)	0.5	3	15	30
Capital Cost	\$950,000	\$3.4 Mill	\$9.6 Mill	\$15 Mill
Source: Frazier, Barnes and Associates; http://www.agecon.uga.edu/~caed/biodieselrpt.pdf				

Research and Development activities in alternative fuels, hydrogen, and fuel cells has been undertaken primarily through various research consortia and “partnerships” (e.g., California Fuel Cell partnership), which may have included several to many participants and investors. Investors included energy companies, as well as automobile companies. Available documentation does not provide delineation of contributions by funding source or category.

Several technologies may be termed “enabling” technologies and applicable across various feedstocks. Investments by individual companies in enabling technologies were assigned to the application claimed.²⁶

For capital projects, interest during construction and other financing costs are not included; for projects with long lead times (4–5 years) this expense can be significant and may represent ~20–25 percent of total costs.

²² EIA - Biofuels in the US Transportation Sector; www.eia.doe.gov/oiaf/analysispaper/biomass.html

²³ Source: *Electricity Market Module of the National Energy Modeling System 2008*, DOE/EIA-M068(2008). Estimates for plants greater than 50 MW=\$800/kw; 20–50 MW= \$1000/kw; 5–20MW=\$1400/kw; 1–5 MW=\$1800/kw; <1MW=\$2200/kw.

²⁴ Ibid.

²⁵ <http://www.agecon.uga.edu/~caed/biodieselrpt.pdf>

²⁶ For example, advances to Fisher Tropsch conversion are useful for both gas-to-liquids as well as coal gasification, to produce transportation fuels (as well as bio-refineries using a thermal platform). If a company made investment in FT to convert flared gas to liquids, the entire investment was assigned to GTL.

Investment amounts are shown as-spent or as-planned in the year claimed and not corrected for inflation.

Some projects in multiple technology areas were sold to new owners during the period of 2000–2005. The sale or transfer costs of projects were not considered net or “new” investment in this study.

Appendix B

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(note: Some corporate names have changed during the period 2000-2007 due to mergers and/or acquisitions; current names are used below)

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