Note: The data used in the induced innovation papers comes from my dissertation, *Induced Innovation, Energy Prices, and the Environment*. The following chapter from my dissertation describes the data in detail.

Chapter 2

The Energy Patent Dataset

One of the major contributions of this dissertation is the creation of a dataset of energy patents in the United States from 1970-1994. Despite the theoretical advances of the induced innovation literature during the 1960's and 1970's, sufficient data to test the hypotheses were unavailable. Data on R&D expenditures were then, as they are now, unavailable for specific types of research. In addition, the computerization of patent data, which makes the construction of this data set possible, has occurred only over the past ten years. Previous tests of the induced innovation hypothesis were mostly indirect tests. These tests focused on the results of innovation -- actual use of factors -- rather than the innovation process itself.

By comparison, this study takes advantage of improved data sources, especially in the realm of patent data, to develop a direct test of the induced innovation hypothesis. A database of over 40,000 U.S. patents related to energy is assembled. This chapter discusses the creation and contents of the energy patent dataset. Analysis of the trends in the data is postponed until chapter 4.

I. Patent Data

When a patent is granted in the United States, it is given a U.S. classification number. There are over 300 main classification groups, and over 50,000 subclassifications. The first step in assembling the data set was to identify subclassifications which pertained to energy efficiency.

Using resources from the Department of Energy and from the academic sciences, several areas of research in the energy field were identified. Descriptions of these technologies were matched up with U.S. patent subclassifications. Technologies for which no clear subclassifications existed were eliminated. The resulting set of subclassifications was then grouped into 24 distinct technology groups. The data set includes all patents granted in these subclassifications in the United States from 1970 to 1994. General background information on these technologies is provided in section II. The technology groups, and the classifications included in each, are listed in the appendix A. They include 13 groups pertaining to energy supply, such as solar and wind energy, and 11 relating to energy demand, such as methods of reusing industrial waste heat.

Two sources of patent data were used to assemble the database. The main source of patent data for this project is the MicroPatent CD-ROM database of patent abstracts. The MicroPatent database contains every U.S. patent issued from 1975-1994. This data set includes all of the information that is found on the front page of a patent, including the date of application, date of grant, name of the inventor and his or her organization, the nation of the patent holder, and citations to previous patents. In addition, since the MicroPatent database does not extend far enough into the past to encompass the first energy crisis of 1973, additional lists of patents in our target classes have been obtained from the Classification and Search Support System (CASSIS) available from the U.S. Patent and Trademark Office. Unfortunately, for these patents the additional data found on the MicroPatent database is not available.

Using these data sources, all patents in the 24 technology groups were identified. For the purposes of this paper, only patents granted to Americans are included, since foreign inventors are likely to be influenced by factors not included in the data described below. For each technology group, patents are sorted by the year of application. Several papers have found that patents, grouped by the date of application, to be a good indicator of R&D activity (see Griliches 1990 for a survey). Since a patent application is only made public when a patent is granted, the data since 1985 have been scaled up by using a distribution of the lag between patent application dates and patent grant dates for the patents in the sample. Because a large number of patents applied for in recent years have yet to be granted, and since recently granted patents have not had a chance to be cited yet, only patent applications through 1990 are used.[1] Table 2.1 provides the annual patent count in each of the technology groups from 1970 to 1993. Figure 2.1 illustrates trends in the data. Included for reference in these figures is an index of energy prices. The index provides the cost of energy of in 1987 dollars per million British thermal units (Btu). Note that for most of the technology groups, there is a jump in patent applications during the energy crises of the 1970's. Notable exceptions include fuel cells, the use of waste as fuel, and continuous casting. A more thorough discussion of the trends in the patent data is found in chapter 4.

II. Energy Technologies Studied

A. New Energy Technologies

Increasing energy prices can be expected to lead to two types of innovative activity. The first is research designed to increase the *supply* of energy available. Research directed at increasing the supply of energy may focus on better uses of existing energy supplies, such as new oil-drilling techniques or obtaining liquid fuel from coal, or instead may focus on developing entirely new sources of energy, such as solar or wind power. Since the ultimate goal of this research is to discern the effect of environmental policies such as Pigouvian taxes on innovation, the supply-side technologies chosen for examination are those which have positive environmental

---

[1] The adjustment factor for 1990 is only one percent.

side-effects as well -- they are not only new energy technologies, but are technologies which hold the promise of less pollution.

i. Coal Technologies

In the United States, coal is an abundant resource. Near the start of the energy crisis, known resources of coal in the United States were 1.7 trillion tons, with 437 billion tons being considered reserves, and 283 billion tons considered recoverable reserves. (*Pursuing Energy Options*, 1979). Thus, it is not surprising that one response to the rising energy prices of the 1970's would be to develop new uses for coal. Two technologies which were considered promising were coal liquefaction and coal gasification.

Coal liquefaction involves converting pulverized coal into synthetic liquid fuels. Hydrogen is added to the coal, so that the carbon/hydrogen ratio decreases, making the coal more similar to the more familiar petroleum-based fuels. Fuels from coal liquefaction would thus serve as substitutes for oil. In addition, coal liquefaction removes gaseous sulfur and nitrogen compounds from the coal, making the emissions less harmful than if coal is burned directly. Coal can be liquefied in one of two ways. Indirect liquefaction begins with coal gasification and then converts the gas into a liquid fuel. The Fischer-Tropsch technology, used in three coal liquefaction plants in South Africa, is the best known example of the indirect method. Conversely, direct liquefaction of coal converts the coal directly from a solid to a liquid. (U.S. Department of Energy, 1988) As with the indirect method, several different methods have been used in the liquefaction process.

In the United States, direct liquefaction is the most advanced of all the potential processes from producing liquid fuels from coal. As of the early 1990's, it was established that coal liquefaction was capable of providing fuel that would be cost-effective crude oil price of $35 per barrel. Current research and development efforts are focused on improving catalysts for more efficient liquefaction at lower temperatures and pressures. (U.S. Congress, Office of Technology Assessment, 1991b)

In coal gasification, solid coal is reacted with either air or oxygen and steam to create a combustible gaseous mixture of carbon monoxide and hydrogen. The coal gasification process can produce substitute natural gas (SNG); synthesis gas, which can be converted to liquid fuels or used to manufacture chemicals; and electricity, which is generated in gasification combined cycle systems. As with coal liquefaction, emissions of sulfur and nitrogen compounds are reduced. In addition, the basic technology can be applied to other fossil energy feedstocks, such as wood and biomass. (Department of Energy, 1988) During the 1970's, concerns over the supply of natural gas led to much R&D in coal gasification. Many of the R&D projects of the 1970's have been discontinued as concerns over the supply of energy have weakened. (OTA, 1991b)

ii. Solar Energy

Whereas coal technologies are attractive in the United States because of America's abundance of coal resources, renewable energy technologies are attractive because their source is infinitely supplied. Once the technology is developed for making use of a renewable resource, exhausting the supply is not a worry. Examples of renewable resource are solar energy, wind energy, and geothermal energy. We begin by looking at solar energy.

Energy from the sun can be used either directly as a source of heat or indirectly to generate electric power. To generate electricity, reflective solar collectors are used to concentrate the heat and light of the sun. Various types of collectors include the parabolic trough, the central receiver, and the parabolic dish. With the parabolic trough, sunlight is concentrated onto a fluid-filled pipe, heating the fluid. A heat exchanger then converts the heat from the fluid into steam. The steam can be used to power an electric turbine. Of the three types of collector technologies, this is the only one currently in widespread commercial use. The second type of collector is the central receiver. This is a field of heliostats (reflective mirrors) which focus the sun's energy at a tower, where it is converted into electricity. Finally, the parabolic dish system uses mirrors, often set up like a radar disc, to focus collected sunlight. The concentrated sunlight is extremely hot and can be used to generate electric power. (OTA 1991b)

There are several areas of R&D needed for solar power. Technologies which can store the energy collected during the day for use at night are a top priority. (Idaho National Engineering Laboratory, *et al*., 1990) As a result, I have included a set of classifications related to photoelectric batteries. In addition, research to lower the cost of the receivers, as well as improved methods of heat exchange, are important to the success of solar energy (*Pursuing Energy Supply Options*, 1979).

Photovoltaics present another opportunity for the utilization of solar power. Photovoltaic (PV) cells are used to convert sunlight directly into energy. The cells are made of thin semiconductor layers such as silicon. When exposed to sunlight, these cells produce an electric current. Modules of the cells can be put together to generate power, making PV technology particularly useful for remote areas (Idaho National Engineering Laboratory, *et al*., 1990). R&D efforts for photovoltaics focus on new materials to use in the fuel cells (U.S. Department of Energy, 1985b) Photoelectric cells are included in classification 250/203.4.

Because of the large number of patent classes related to solar energy, I have broken them down into four sets, each related to the usage of the technologies. The first is a general category of solar energy patents, which includes such items as collecting heat from solar energy and the use of solar energy to generate power. The second set is for solar cells. The third set is for batteries used to store solar energy. The final set relates to the process of manufacturing solar energy devices.

iii. Wind Energy

Another useful renewable energy technology is energy from the wind. Wind power is used to rotate a turbine, which in turn rotates a shaft connected to a generator, producing power. Of all the renewable technologies currently being pursed in the U.S., wind power is the closest to being economically competitive in the bulk power market. R&D into wind technologies helped to lower the cost of electricity produced from wind from $1.50 per kilowatt hour (kWh) 25 years ago, to 12¢/kWh 10 years ago (U.S. Department of Energy, 1985b), to 7 to 10¢/kWh by the early 1990's (Idaho National Engineering Laboratory, *et al.*, 1990). However, much of this drop in costs can be attributed to standardization of procedures, mass production of equipment, and improved siting of wind farms.

Wind power has achieved its greatest successes in the United States. In 1989, the U.S. capacity for electricity generated by wind was 1,520 megawatts (MW). The total capacity for the entire world was just 1,760 MW. Over eighty percent of the world's wind-generated electricity is produced in California. (OTA, 1991a) Nonetheless, the potential for further expansion of wind energy is high. A 1985 study by the Electric Power Research Institute projected that the market potential for wind could reach 21,000 MW by the end of this century (EPRI, 1985). It is projected that with additional R&D, electricity produced from wind power could sell for 3.5¢/kWh in the next 20 years. Much of the gains from R&D will come from improvements in the design of wind turbines to allow them to better adjust to changing wind speeds and direction. (OTA, 1991b) *iv. Geothermal Energy*

Geothermal energy is generated from the heat of the earth. There are four types of geothermal resources: hydrothermal, geopressured, hot dry rock, and magma. Hydrothermal resources consist of hot water and steam close to the earth's surface. The steam is used to generate electric power. Hydrothermal resources are the only type of geothermal energy currently being used to produce electricity commercially (National Renewable Energy Laboratory, 1992). Geopressured resources consists of water and dissolved methane which exists under conditions of high pressure. It is found in the Gulf Coast region of the United States. Hot dry rock resources take advantage of the naturally hot rock formations at accessible depths in the earth's crust. A pair of wells are drilled, and connected by fractures in the rocks. Water is pumped down one well, circulated through the rock formation, and pumped up through the other well. The heat is converted to energy on the earth's surface. Magma systems make use of extremely hot molten rock, or magma. The temperature of such rock is often above 1000º Celsius. Although much of the earth's magma is deep in the crust, and thus inaccessible, it is believed that some magma can be recovered from volcanoes. R&D for geothermal technologies focuses on drilling techniques and technologies to help determine the validity of a potential site. (*Pursuing Energy Supply Options*, 1979, Idaho National Engineering Laboratory, *et al.*, 1990, and National Renewable Energy Laboratory, 1992).

v. Biomass

The last renewable energy resource which will be examined is biomass. Biomass energy sources are those organic materials other than fossil fuels that are used for energy. Among the many potential sources of biomass energy are wood, agricultural crops, animal wastes, municipal solid wastes, and sewage sludge. The use of such wastes can serve as useful means for industry to reduce its energy costs. For example, about 65 percent of all wood consumed for energy is consumed by the lumber, pulp, and paper industries. In addition, the use of municipal wastes as a fuel source has the added advantage of reducing the strain on overused landfills (OTA, 1991b). The research needs for biomass vary depending on the material used as a source of fuel. For analysis in this paper, I have included classifications which contain the burning of waste as a source of fuel, and a classification which uses the burning of waste gases, such as furnace gas, as fuel.

vi. Miscellaneous Renewable Resources

Finally, I have included two smaller classifications of renewable resources. The first is Ocean Thermal Energy Conversion (OTEC). OTEC uses the temperature differences between surface and deep ocean water to generate energy. (U.S. DOE, 1985b) Ocean Thermal is still a relatively untested technology. No commercial sites have been tested to date. The only sites in the U.S. that are considered to be potentially useful for ocean thermal energy are coastal areas in the Gulf of Mexico and Hawaii. Internationally, Norway, Britain, an Japan have done R&D aimed at using the energy from ocean tides and waves to generate electricity. However, no such research has been attempted in the U.S. Finally, I include the general classification of natural heat. This includes the generation of power using natural heat in ways not previously discovered, such as solar, geothermal, or OTEC.

vii. Fuel Cells

The final supply-side classification is for fuel cells. Fuel cells do not make use of renewable energy, but rather allow for more efficient use of fuels such as natural gas, petroleum, and coal. Their primary advantage is that they are modular, allowing for greater flexibility than large power plants. Fuel cells produce electricity with an electrochemical reaction between hydrogen and oxygen, with the hydrogen typically supplied by a hydrocarbon fuel. In a power plant using fuel cells, a fuel processor extracts hydrogen from the fuel. They hydrogen is then fed into a fuel processor. Since the power produced is direct current (DC), a power conditioner is then used to convert the power to alternating current (AC). (OTA 1991b)

The primary focus of fuel cell R&D is to increase the efficiency of the cells. Fuel cells currently in use usually use phosphoric acid as the electrolyte, but newer technologies are being developed which hold promise for lowering costs. One technology showing promise is the molten carbonate fuel cell, which operates on single-carbon fuels such as methane or methanol. These are expected to increase the efficiency of fuel cells by about 25%. (U.S. DOE, 1985b)

B. Technologies to Improve Energy Efficiency - Process Innovations

The previous section dealt with the supply-side reaction to increased energy prices -- what new technologies could be developed to increase the available supply of energy? We now turn to the demand side. Unlike final consumption goods, the consumption of energy itself does not yield utility; rather, it is the goods or services that result from the consumption of energy. Thus, higher energy prices should lead to a desire to get more out of each unit of energy -- to increase energy efficiency. This section will discuss the various energy-efficient innovations examined in this paper. Note that by no means is this an exhaustive list of energy-efficient innovations. It is merely intended as a sample of areas in which innovation might occur.

Energy efficient innovations can be one of two types. Either they are innovations to the process of manufacturing a final good (*process innovations*) or they are goods which are intended to be sold to consumers or other firms (*product innovations*). Most of the technologies in this section are process innovations.

Industrial uses of energy make up a substantial portion of U.S. energy consumption. In 1990, U.S. industry consumed 25 quadrillion Btu (quads) of fuel and electricity - a little over 30 percent of all energy use in the United States. Of this, 17 quads was accounted for by the use of natural gas or petroleum. An additional 3.2 quads consisted of electricity consumption. Industry spent a total of $108 billion on energy in 1990 (OTA, 1993). However, the 1990 figures represent substantial gains in efficiency. In 1980, 30.6 quads of energy were used, which accounted for 39% of all U.S. energy consumption. Energy intensity fell from 28,300 Btu per dollar of industry output in 1980 to nearly 14,000 Btu per dollar of industry output in 1990.

In addition, energy use varies greatly across sectors. Petroleum refining, chemicals, primary metals, pulp and paper, food, and ceramics and glass accounted for 74% of total industrial energy use in 1988. In some cases, energy use is high because the output of the industry is high - food and oil and gas extraction are examples. In other industries, both output and the energy intensity is high. Such industries are petroleum refining, steel, organic chemicals, and paper. Most energy R&D is concentrated in these energy intensive industries. Table 2.2 presents data on energy consumption in selected industries in 1971, 1981, and 1991.

The following section includes descriptions of the industrial technologies chosen for analysis in this study. They include a mixture of technologies chosen for specific industries and technologies with a more general usage. Industry-specific technologies could not be chosen for all of the energy intensive industries, because in some of these industries there are a broad range of energy uses, making it difficult to focus on individual technologies. For example, the chemical industry makes a diverse range of products such as rubber, plastics, soaps, paints, industrial gases, fertilizers, and pharmaceuticals. Obviously, different technologies to conserve energy would be needed in the production of these various products.

i. Steel

Primary metals accounted for 12 percent of all industrial energy consumption in 1988. Of this, most energy was consumed by the steel industry. Coal is the major energy source for the steel industry. (OTA, 1993) There are two predominant processes for the production of steel: the integrated process, which combines blast furnaces and basic oxygen furnaces, and the non-integrated process, which uses electric arc furnaces. Both of these consume large amounts of energy. Newer processes, such as direct reduced iron and continuous casting, have gained prominence in recent years. Of these, continuos casting is notable for its potential energy savings. (Direct reduced iron actually increases the amount of energy used, but produces steel without the intermediate step of molten raw steel, and has the advantage of using mostly natural gas, rather than coal).

The integrated process begins with iron ore, coking coal, and limestone. First, the coal is heated in coke ovens to rid it of volatile gases, leaving the residue called coke. The coke, limestone, and iron ore pellets are fed into a blast furnace, which produces molten pig iron. Finally, the pig iron is charged in the basic oxygen furnace to produce raw, molten steel. The molten steel undergoes further processing to make the final product.

The non-integrated process begins with scrap steel being fed onto an electric arc furnace. High-voltage electric power is used to create an arc along the scrap materials, producing intense heat which melts the scrap and removes impurities. The molten steel which results again goes through further processing to make the final product (EPRI, 1994).

The major energy saving innovation in steel making is continuous casting. Continuous casting was first patented in 1865. However, it did not become commercially viable until the early 1960's. Most new steel plants today are continuous casting plants. The use of continuous casting has increased from 42 percent of world steel production in 1983 to 64 percent in 1991. (EPRI, 1994) As mentioned above, the molten metal initially produced must be processed further to get the final steel product. Earlier methods required first pouring the molten metal into ingots that were then rolled into slabs, blooms, or billets in mills. Continuous casting simplifies the process by taking the molten metal and converting it directly into solid steel. Energy is saved both because the energy-intensive intermediate steps are eliminated and because the final yield is increased. Total energy savings average about 3.33 million Btu per ton of steel continuously cast. Less scrap is produced, and less raw materials are needed. Thus, there are several cost saving advantages to the continuous casting of steel. However, since energy savings are one of the largest potential gains, we should expect R&D on continuous casting to increase when energy prices increase. In fact, the number of continuous casting plants increased dramatically during the energy crisis of the 1970's (OTA, 1980).

ii. Aluminum

The production of aluminum is electricity-intensive. Aluminum uses more electricity than any other industry in the U.S. The production of aluminum begins with bauxite, which refined to extract the alumina. This is usually done via the Bayer process. Next, is the aluminum smelting stage, in which aluminum is produced from the alumina by electrolysis. This is by far the most energy-intensive part of the process. In 1983, 175 million Btu of energy were required to produce one ton of primary aluminum ingot. Of this, 3.2 percent was consumed at the bauxite stage, 16.3 percent to refine the alumina, and 80.5 percent for smelting. Of the energy used in smelting, 75 percent is energy used for electrolysis. As a result, better understanding of the electrolytic process is a main goal of the research and development plans of the U.S. Department of Energy.

Aluminum smelting results in *primary aluminum*, which is usually forged or cast into ingots. In addition, scrap aluminum can be used to produce ingots. This is known as *secondary aluminum*. Secondary aluminum requires much less energy to produce (11.4 million Btu per ton) (OECD 1983). Secondary aluminum is generally substitutable for primary aluminum, and its use has been rising. In 1970, 20 percent of aluminum used in the United States was secondary aluminum; this figure had risen to 30 percent by 1984. The growth of secondary aluminum depends on two factors: 1) the amount of old scrap available, which depends on how much aluminum was used earlier, and what it was used for (for example, beverage cans are recycled quickly; aluminum siding lasts for many years) and 2) the price of primary aluminum (Peck, 1989). Once the ingots are formed, procedures such as casting, hot and cold rolling, and extrusion are used to transform them into usable forms for industry, such as aluminum sheets, rods, and wires. Depending on the process used, this requires only 2 to 6 percent of the energy required to produce the primary ingot (OECD 1983).

The technologies used in the aluminum industry have been available for over a century. The Bayer process for extracting alumina was developed in 1888. Electrolysis is almost always done by the Hall-Heroult smelting process, which was developed in 1886. Throughout the history of the industry, technological change has occurred as improvements in the existing processes, rather than as the development of new processes. For example, energy requirements per pound of aluminum produced fell by about 1 percent per year from 1947 to 1972. From 1972 to 1980, energy requirements fell by about one-half percent per year (Peck 1989).[2] The energy shocks of the 1970's did encourage some R&D into new aluminum processes; however, there has been little success in developing any alternatives. (Peck 1989)

Because electrolysis is by far the main consumer of energy in the aluminum process, and since past history shows that most improvements come as improvement to the Hall-Heroult process, rather than new processes, I will focus on patent class 204/67 -- electrolysis for production of aluminum. In addition, I include patents for one alternative production method which is considered promising -- reducing aluminum oxide using carbothermic processing rather than electrolytic reduction. Carbothermic processing is currently widely used in the production of iron and steel. With research to better understand the basic chemical reactions involved, carbothermic processing can be used as an alternative to electrolytic reduction (U.S. DOE 1985a, 1987). Patent class 75/10.27 contains patents for the carbothermic reduction of aluminum.

iii. Paper Manufacturing

The pulp and paper industry is the fourth largest energy consuming industry. The first step of paper production is cooking wood in a sodium or ammonia-based liquor. This allows the fibers of the wood to separate. The fibers are then packed and transported to the paper mill. After the fibers go to the paper mill, they are woven into sheets of paper. At this stage, the water content of the paper is about 60 percent. The paper is then dried until the water content falls to 7 percent. This is the most energy intensive part of the paper manufacturing process.

Although the paper making process is energy intensive, much of the energy used is generated by the industry itself. The waste liquor from the cooking of the pulp can be used to produce heat. In addition, before the wood is cooked, it must be stripped of its bark. The waste bark can also be used as fuel. In 1989, about 56 percent of the industry's energy came from self-generated and waste fuels. This figure was up from 40 percent in 1972. (OTA, 1993) I have

---

[2] Energy efficiency improvements slowed during the 1970's because many of the technological improvements are used only in new smelters. Construction of new smelters declined in the U.S. during the 1970's. (Peck, 1989)

included two classifications of patents pertaining to the recovery of waste liquor for use as a power source in this study.

iv. Waste Heat Recovery

Industrial processes produce much heat which is never used. Recovery of this waste heat would allow for substantial energy savings. There are three types of waste heat: industrial process waste steam and heat, power plant reject heat, and heat generated from miscellaneous sources (Reay, 1979) Waste heat can be classified as high, medium, or low-temperature waste heat. High-temperature waste heat, that above 1200º Fahrenheit, and medium-temperature waste heat, which is between 450º and 1200º F, can be used to produce process steam. Heat exchangers are used to transfer this heat from one stream to another, so that it can be reused. Low-temperature waste heat, that below 450º F, is not hot enough to extract work from the heat itself, but it can be used with a heat pump for mechanical work. A 1981 study concluded that there were one to three quads of low-temperature waste heat recoverable in the U.S., and 1.5 to three quads of medium and high temperature waste heat. (DOE, 1987)

Several classifications of patents contain innovations relating to the recovery of waste heat. I have grouped the classifications into three main groups. The first deals with the use of waste heat itself. The second group contains patents for heat exchange. Finally, I include a group of patents pertaining to heat pumps.

a. Heat Exchange

To recover waste heat, heat exchangers are used to transfer heat from one fluid stream to another. The fluids between which the heat is transferred can either be gas or liquid. Major types of heat exchangers are gas-to-gas, gas-to-liquid, and liquid-to-liquid. Heat exchangers have several applications. They can be used to preheat the combustion air for furnaces or ovens, to preheat liquid or solid feedstocks, to generate steam, or to transfer waste heat to a secondary source. (Hu, 1983) A 1986 study indicated that 2.5 quads of energy could be saved by enhanced heat exchanger technology (DOE, 1987)

b. Heat Pumps

Often, the available heat which can be recovered is not hot enough to be of direct use. This is particularly true for liquid effluents. However, the heat can still be of use if its temperature is raised. Heat pumps are used to perform this task. The basic process of a heat pump is simple. Heat is received at a low temperature via a fluid. The fluid is heated and vaporized. The vapor is compressed in a compressor. The work required to compress the vapor raises the temperature of the vapor. The vapor then flows through a condenser, where the added energy is released and the vapor is again condensed into a liquid. Heat pumps use the same basic principles as refrigeration devices, except that they work in reverse. (Reay, 1979; Hu, 1983)

v. Stirling Engines

Stirling engines are high-efficiency, closed cycle heat engines. They are expected to reach efficiencies of 40 to 50%. They could potentially use a wide variety of fuels. Although they are not yet viable for commercial use, with further R&D they could be used for cogeneration in industrial plants. Cogeneration is the production of electrical or mechanical power and process heat from the same primary fuel. Traditional power sources produce only one or the other.

vi. Insulated Windows

Significant amounts of energy are consumed due to heat losses through windows. About 25% of heating and cooling requirements in buildings are due to windows. This accounts for about 5% of total energy use in the United States (Gellner and Nadel, 1994). A material's resistance to heat is measured by its *R*-value. Higher *R*-values signify better insulating qualities.

A normal single-glazed window has a rating of *R*-1. For comparison, an insulated wall would have a rating of *R*-11 or higher. Adding a second pane of glass can increase the rating to *R*-2. Transparent, low-emissivity materials, such as tin oxide, can be added to the inner surface of one of the panes to help reflect heat back into the home. This could increase the *R*-value to *R*-3. Filling the space between the panes of glass with a gas such as argon or xenon can increase the rating to *R*-5. (Office of Technological Assessment, 1991a)

Market shares of energy-efficient windows have increased dramatically over the past 20 years. In 1974, double or triple glazed windows comprised 37% of window sales. This figure increased to 87% by 1991. Low-emissivity coatings began to enter the market in 1984. By 1991, they were used in about 33% of residential windows. (Gellner and Nadel, 1994) For this project, I have included patent classifications for treated windows, glazing strips, double paned windows, and windows with internal spacing.

vii. Compact Fluorescent Lightbulbs

Compact fluorescent lights (CFL's) are high-efficiency lightbulbs designed to work in fixtures with a standard screw-in base. CFL's have thin fluorescent tubes that are bent several times to allow the lamp to fit in the same small spaces that an ordinary lightbulb would. CFL's offer potential savings of 66-78% over standard incandescent lightbulbs. In addition, they have a rated life that is approximately 10 times greater than incandescent bulbs. Assuming that a compact fluorescent bulb costs $14 to purchase, the value of energy savings over the life of the bulb is approximately $0.017 per kWh for commercial buildings, and $0.026 per kWh for residential uses. (Gellner and Nadel, 1994)

Compact fluorescent lightbulbs were developed in the early 1970's, and first marketed in 1978. A keyword search of the MicroPatent database revealed no patent classes which were heavily comprised of CFL patents. However, since this is such a new technology, extending the database for CFL's before 1975 was not important. Thus, compact fluorescent patents were simply identified by a keyword search on the MicroPatent database.

REFERENCES

Electric Power Research Institute (1985), *Early Market Potential for Utility Applications of Wind Turbines*, prepared by Science Applications International Corp.

Electric Power Research Institute (1994), *Economic Impact of Carbon Taxes: Detailed Results*, prepared by Charles River Associates and DRI/McGraw-Hill.

Gellner, Howard and Steven Nadel (1994), "Market Transformation Strategies to Promote End-Use Efficiency", *Annual Review of Energy and the Environment*, 19, 301-346.

Griliches, Zvi (1990), "Patent statistics as economic indicators," *Journal of Economic Literature*, 28, 1661-1707.

Hu, S. David (1983), *Handbook of Industrial Energy Conservation*, Van Nostrand Reinhold Co., New York.

Idaho National Engineering Laboratory, *et al*. (1990), "The Potential of Renewable Energy: An Interlaboratory White Paper," March 1990.

National Renewable Energy Laboratory (1992), "Conservation and Renewable Energy Technologies for UTILITIES: Office of Utility Technologies Program Overview.

OECD (1983), *Aluminum Industry: Energy Aspects of Structural Change*, Paris.

Office of Technology Assessment (1993), *Industrial Energy Efficiency*, Washington, D.C.

Office of Technology Assessment (1991a), *Changing by Degrees: Steps to Reduce Greenhouse Gases*, Washington, D.C.

Office of Technology Assessment (1991b), *Energy Technology Choices: Shaping Our Future*, OTA-E-493, Washington, DC, U.S. Government Printing Office, July.

Office of Technology Assessment (1980), *Technology and Steel Industry Competitiveness*, Washington, D.C.

Peck, Merton J., ed. (1989), *The World Aluminum Industry in a Changing Energy Era*, Resources for the Future, Washington, D.C.

Pursuing Energy Supply Options: Cost Effective R&D Strategies, hearing before the Joint Economic Committee, 1979.

Reay, D.A. (1979), *Industrial Energy Conservation*, 2nd edition, Pergamon Press, Oxford.

U.S. Department of Energy (1985a), *Guidelines for DOE Long Term Civilian Research and Development*, *Volume V, Demand*.

U.S. Department of Energy (1985b), *Guidelines for DOE Long Term Civilian Research and Development*, *Volume VI*, *Supply*.

U.S. Department of Energy (1987), *Energy Conservation: Multi-Year Plan FY 1989-93*.

U.S. Department of Energy (1988), Office of Coal Technology, Fiscal year 1988 Program Plan.

APPENDIX A – U.S. patent classifications related to energy

Guide to definitions: The first phrase is the main classification. For example, class 208 contains patents for Mineral Oils: Processes and Products. These are followed by the various subclassifications, listed in descending order of precedence.

Supply Technologies:

Coal Liquefaction:

208/400-435	Mineral Oils: Processes and Products/By treatment of solid material (e.g. coal liquefaction)

Coal Gasification:

48/200	Gas: Heating and Illuminating/Processes/Coal, oil and water
48/201	Gas: Heating and Illuminating/Processes/Coal and oil
48/202	Gas: Heating and Illuminating/Processes/Coal and water
48/210	Gas: Heating and Illuminating/Processes/Coal
48/71	Gas: Heating and Illuminating/Generators/Cupola/Coal, oil and water
48/72	Gas: Heating and Illuminating/Generators/Cupola/Coal and oil
48/73	Gas: Heating and Illuminating/Generators/Cupola/Coal and water
48/77	Gas: Heating and Illuminating/Generators/Cupola/Producers/Coal
48/98	Gas: Heating and Illuminating/Generators/Retort/Coal, oil and water
48/99	Gas: Heating and Illuminating/Generators/Retort/Coal and water
48/100	Gas: Heating and Illuminating/Generators/Retort/Coal and oil
48/101	Gas: Heating and Illuminating/Generators/Retort/Coal

Solar Energy:

60/641.8-641.15	Power Plants/Utilizing natural heat/Solar
62/235.1	Refrigeration/Utilizing solar energy
126/561-568	Stoves and Furnaces/Solar heat collector for pond or pool
126/569-713	Stoves and Furnaces/Solar heat collector
126/903	Stoves and Furnaces/Cross-Reference Art/Solar collector cleaning device
126/904	Stoves and Furnaces/Cross-Reference Art/Arrangements for sealing solar collector
126/905	Stoves and Furnaces/Cross-Reference Art/Preventing condensing of moisture in solar collector
126/906	Stoves and Furnaces/Cross-Reference Art/Connecting plural solar collectors in a circuit
126/910	Stoves and Furnaces/Cross-Reference Art/Heat storage liquid

Solar Cells:

250/203.4	Radiant Energy/Photocells: circuits and apparatus/Photocell controls its own optical system/Following a target/Luminous target/Sun

Solar Energy -- Batteries:

136/206	Batteries: Thermoelectric and Photoelectric/Thermoelectric/Electric power generator/ Solar energy type
136/243	Batteries: Thermoelectric and Photoelectric/Photoelectric
136/244-251	Batteries: Thermoelectric and Photoelectric/Photoelectric/Panel
136/252-265	Batteries: Thermoelectric and Photoelectric/Photoelectric/Cells

Solar Energy -- Manufacturing Solar Materials:

29/890.033	Metal Working/Method of manufacture/Catalytic device making/Solar energy device making
437/2	Semiconductor Device Manufacturing: Process/Making device responsive to radiation

Fuel Cells:

429/12-46	Chemistry: Electrical Current Producing Apparatus, Product, and Process/Fuel cell, subcombination thereof or method of operating

Wind:

290/44	Prime-Mover Dynamo Plants/Electric control/Fluid-current motors/Wind
290/55	Prime-Mover Dynamo Plants/Fluid-current motors/Wind
416/132B	Fluid Reaction Surfaces (i.e., Impellers)/Articulated resiliently mounted or self-shifting impeller or working member/Sectional, staged or non-rigid working member/windmills
416/196A	Fluid Reaction Surfaces (i.e., Impellers)/Lashing between working members or external bracing/Connecting adjacent work surfaces/Non-turbo machine (windmills)
416/197A	Fluid Reaction Surfaces (i.e., Impellers)/Cupped reaction surface normal to rotation plane/Air and water motors (natural fluid currents)

Geothermal energy:

60/641.2 -641.5	Power Plants/Utilizing Natural Heat/Geothermal

Using waste as fuel:

110/235-259	Furnaces/Refuse incinerator
110/346	Furnaces/Incinerating refuse
431/5	Combustion/Process of combustion or burner operation/Burning waste gas, e.g. furnace gas, etc.

Ocean Thermal Energy Conversion (OTEC)

60/641.7	Power Plants/Utilizing natural heat/Ocean Thermal Energy Conversion (OTEC)

Renewable Energy -- General:

60/641.1	Power Plants/Utilizing natural heat
60/641.6	Power Plants/Utilizing natural heat/With natural temperature differential

Demand Technologies:

Waste heat:

122/7R	Liquid Heaters and Vaporizers/Industrial/Waste heat
7A	Liquid Heaters and Vaporizers/Industrial/Waste heat/Steel converter
7B	Liquid Heaters and Vaporizers/Industrial/Waste heat/Additional burner
7C	Liquid Heaters and Vaporizers/Industrial/Waste heat/Waste sulfate
7D	Liquid Heaters and Vaporizers/Industrial/Waste heat/Carbon monoxide
60/597-624	Power Plants/Fluid motor means driven by waste heat or by exhaust energy from internal combustion engine

Heat exchange:

62/4	Refrigeration/Intermediate fluid container transferring heat to heat absorber or holdover/Flow line connected transfer fluid supply and heat exchanger
62/79	Refrigeration/Processes/Exchanging heat between plural systems, e.g., disparate
62/513	Refrigeration/Refrigeration producer/ Heat exchange between diverse function elements
62/515-528	Refrigeration/Refrigeration producer/Evaporator, e.g.,. heat exchanger
165	Heat Exchange

Heat Pumps:

62/238.7	Refrigeration/Disparate apparatus utilized as heat source or absorber/With vapor compression system/Reversible, i.e. heat pump
62/324.1-325	Refrigeration/Reversible, i.e., heat pump

Stirling engine:

60/517-526	Power Plants/Motor operated by expansion and/or contraction of a unit of mass of motivating medium/Unit of mass is a gas which is heated or cooled in one of a plurality of constantly communicating expansible chambers and freely transferable therebetween

Continuous Casting:

148/541	Metal Treatment/Process of modifying of maintaining internal physical structure (i.e. microstructure) or chemical properties of metal, process of reactive coating of metal and process of chemical-heat removing (e.g., flame-cutting, etc.) or burning of metal/With casting or solidifying from melt/Iron(Fe) or iron base alloy/Continuous casting
148/551	Metal Treatment/Process of modifying of maintaining internal physical structure (i.e. microstructure) or chemical properties of metal, process of reactive coating of metal and process of chemical-heat removing (e.g., flame-cutting, etc.) or burning of metal/With casting or solidifying from melt/Aluminum (Al) or aluminum base alloy/Continuous casting
164/263	Metal Founding/With product severing or trimming means/Associated with continuous casting means
164/268	Metal Founding/With coating means/associated with a continuous or semicontinuous casting means
164/415	Metal Founding/Means providing inert or reducing atmosphere/In continuous casting apparatus
164/416	Metal Founding/Including vibrator means/In continuous casting mold
164/417	Metal Founding/Combined/Including continuous casting apparatus

164/418-444	Metal Founding/Means to shape metallic material/Continuous or semicontinuous casting
164/445-446	Metal Founding/Starter bar
164/447-448	Metal Founding/Product supporting or withdrawal means for continuous casting apparatus
164/449.1-450.5	Metal Founding/Control means responsive to or actuated by means sensing or measuring a condition or variable (i.e., automatic control)/Control of feed material enroute to shaping area/Responsive to material level/In continuous casting apparatus
164/451-455	Metal Founding/Process/With measuring, testing, inspecting, or condition determination/Of continuous or semicontinuous casting
164/459-491	Metal Founding/Process/Shaping liquid metal against a forming surface/Continuous or semicontinuous casting
164/502-504	Metal Founding/Including means to directly apply magnetic force to work or to manipulate or hold shaping means/In continuous casting apparatus
164/505-509	Metal Founding/Means to directly apply electrical or wave energy to work/In continuous casting apparatus
164/154.4	Metal Founding/Control means responsive to or actuated by means sensing or measuring a condition or variable (i.e., automatic control)/Responsive to position or spatial dimension/Responsive to rate of change/Continuous casting
164/154.5	Metal Founding/Control means responsive to or actuated by means sensing or measuring a condition or variable (i.e., automatic control)/Responsive to position or spatial dimension/Continuous casting

Manufacture of aluminum:

75/10.27	Specialized Metallurgical Processes, Compositions for Use Therein, Consolidated Metal Powder Compositions, and Loose Metal Particulate Mixtures/Processes/Electrothermic processes (e.g., microwave, induction, resistance, electric arc, plasma, etc.)/Carbothermic reduction of Aluminum (Al) compound
204/67	Chemistry: Electrical and Wave Energy/Processes and Products/Electrolysis/Synthesis/From fused bath/Metals/Aluminum

Use of Black Liquor in Paper Manufacturing

162/31	Paper Making and Fiber Liberation/Processes of chemical liberation, recovery or purification of natural cellulose of fibrous material/With regeneration, reclamation, reuse, recycling or destruction of digestion fluid/Flames combustion
162/47	Paper Making and Fiber Liberation/Processes of chemical liberation, recovery or purification of natural cellulose of fibrous material/With heat recovery

Insulated windows:

52/172	Static Structures (e.g., Buildings)/Transparent panel; e.g., window, with treatment means/Hygroscopic material; e.g., internal drier
52/776	Static Structures (e.g., Buildings)/Window or window sash, sill, mullion, or glazing/Attaching means securing a pane to a sash member or to another pane/Solid three-sized glazing strip
52/788	Static Structures (e.g., Buildings)/Composite prefabricated panel comprising: separate mechanical fastener; means for support securement; disparate edging or stiffener which, in a multi-ply panel, extends outwardly of a major or edge face; or spaced sheets with inturned edge-forming flanges/Sandwich or hollow with sheetlike facing members/Parallel, transparent panes, (e.g., double glass window panel, etc.)
52/790	Static Structures (e.g., Buildings)/Composite prefabricated panel comprising: separate mechanical fastener; means for support securement; disparate edging or stiffener which, in a multi-ply panel, extends outwardly of a major or edge face; or spaced sheets with inturned edge-forming flanges/Sandwich or hollow with sheetlike facing members/Internal spacer

Compact Fluorescent Lightbulbs:

Note: no classification could be found for these. Patents for compact fluorescent lightbulbs were found by a keyword search on the MicroPatent database. Because this is a relatively new technology, it was not necessary to extend the search before 1975 by using the EPO tape.

Table 2.1 – Summary Patent Data

Privately Held U.S. Patents

Sorted By Year of Application

Year	Coal Liquefaction	Coal Gasification	Solar Energy	Solar Batteries	Fuel Cells	Wind Power	Geothermal Energy	Waste as Fuel	Waste Gas as Fuel	OTEC	Renewable Energy – General	Waste Heat	Heat Exchnage – Refrigeration	Heat Exchange – General	Heat Pumps	Stirling Engine	Continous Casting	Aluminum – Carbothermic	Aluminum – Electrolysis	Black Liquor	Insulated Windows	CFL
1970	42	14	6	18	43	2	3	63	4	0	1	17	11	425	0	13	84	2	8	4	5	0
1971	37	24	5	17	46	8	4	53	5	1	2	18	13	423	2	13	115	0	9	2	3	0
1972	27	16	10	13	33	7	5	52	12	0	0	21	11	340	8	12	67	1	10	3	8	0
1973	28	20	36	23	28	4	3	52	14	0	0	12	18	346	4	9	63	2	9	2	7	0
1974	51	38	104	27	26	20	22	49	7	2	1	28	15	382	7	17	48	2	4	2	12	2
1975	45	31	218	63	38	37	17	29	13	3	7	26	20	418	8	11	46	2	2	3	17	0
1976	107	42	321	89	32	24	15	32	11	9	4	34	18	450	20	17	43	2	11	0	11	0
1977	88	45	367	117	52	29	14	34	14	3	7	29	19	505	17	11	37	3	10	3	9	1
1978	114	53	333	142	42	39	15	41	6	7	5	16	22	479	32	12	40	0	8	3	9	7
1979	77	32	295	119	40	33	11	40	9	6	5	27	31	462	24	11	45	1	11	1	3	10
1980	97	38	278	112	54	34	15	50	4	7	3	25	13	443	21	18	44	4	15	3	13	3
1981	100	27	208	119	54	37	14	44	3	3	1	23	22	382	30	21	43	1	12	1	8	4
1982	82	25	151	93	74	28	12	58	7	2	1	31	11	377	18	30	49	1	16	2	12	4
1983	74	22	102	74	47	23	12	50	4	2	1	22	10	317	11	21	61	2	14	1	7	6
1984	70	15	104	86	39	13	2	44	4	1	1	24	9	338	8	19	62	2	12	2	6	9
1985	34	18	85	80	54	9	5	46	6	0	0	17	15	286	14	13	46	0	10	3	4	2
1986	20	10	42	73	72	11	4	61	3	1	0	13	23	323	15	13	80	6	5	1	12	1
1987	12	16	35	54	65	9	6	83	8	2	0	13	17	297	11	19	39	0	6	0	11	5
1988	14	10	44	63	54	6	4	69	2	0	2	26	24	315	5	10	58	0	5	4	9	4
1989	22	14	33	42	51	6	6	84	10	0	0	24	22	311	14	12	38	0	5	3	20	6
1990	16	9	26	41	60	6	4	102	5	1	2	24	27	337	18	18	33	0	5	2	18	3
1991	10	4	32	48	49	15	4	98	12	0	0	19	35	391	22	11	38	0	6	2	7	5
1992	12	5	27	53	61	13	11	93	9	2	1	25	28	428	14	12	33	0	1	6	16	12
1993	8	2	23	20	58	10	2	60	17	0	0	22	13	350	17	5	31	2	3	2	2	7

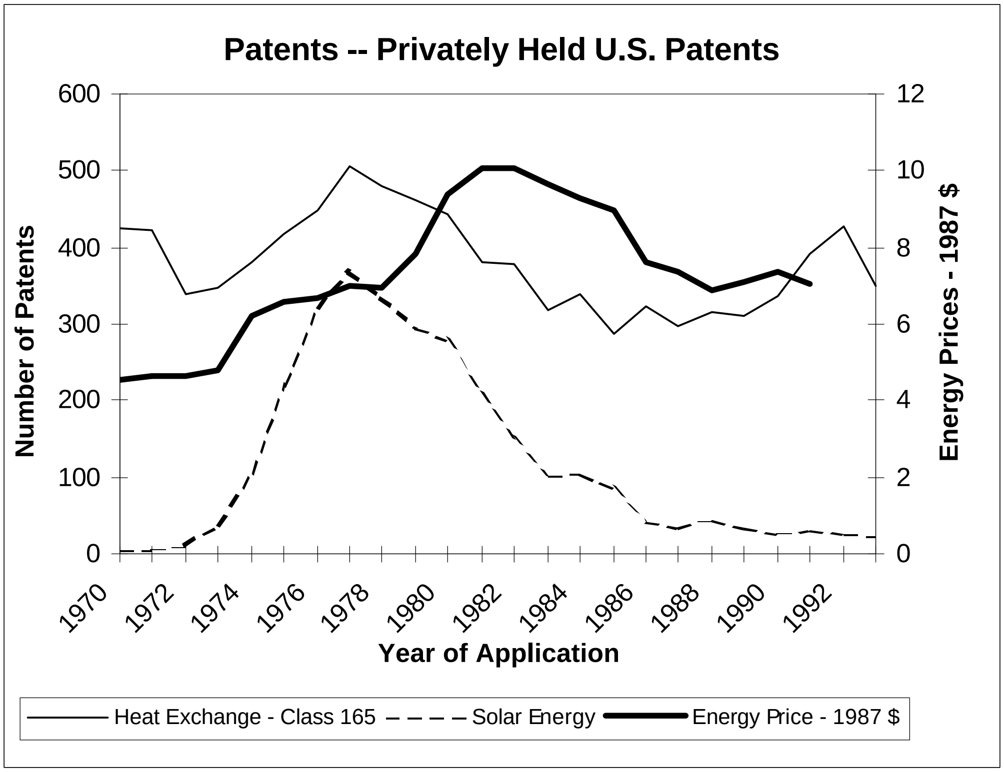
Table shows the number of successful patent applications in each technology field by U.S. inventors.
As discussed in the text, data after 1985 have been scaled up to include applications not yet acted upon by the U.S. Patent Office.

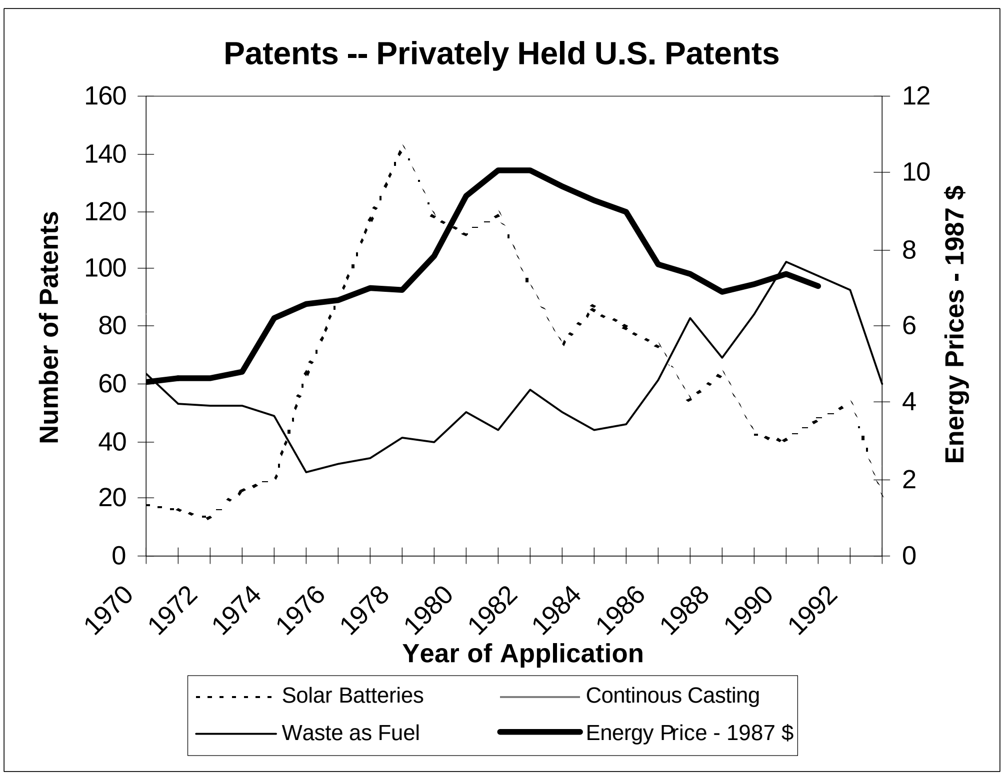
Table 2.2 -- Energy Use for Selected Industries

		Real Energy Consumption (millions of 1987 $'s)			Energy Intensity (Real Energy/Real Value Added)		
Industry	**SIC**	**1971**	**1981**	**1991**	**1971**	**1981**	**1991**
Food	20	3,916	4,534	4,597	0.05	0.05	0.03
Paper	26	4,289	4,970	5,184	0.13	0.13	0.10
Chemicals	28	8,028	10,389	8,174	0.10	.012	0.06
Petroleum Refining	29	3,836	4,214	4,176	0.17	0.26	0.18
Stone, Clay, and Glass	32	3,932	4,027	3,194	0.13	0.14	0.10
Primary Metals	33	10,225	10,765	7,008	0.18	0.21	0.17
Steel	3312	6,064	5,741	2,951	0.22	0.27	0.21
Aluminum	3334	1,101	1,539	1,266	0.53	0.65	0.70

Source: Calculated from data in NBER Manufacturing Productivity Database
NOTE: Energy intensity is millions of dollars of energy consumption
per million dollars of value added.
Both figures are in 1987 dollars.

Figure 2.1 – Patent Applications

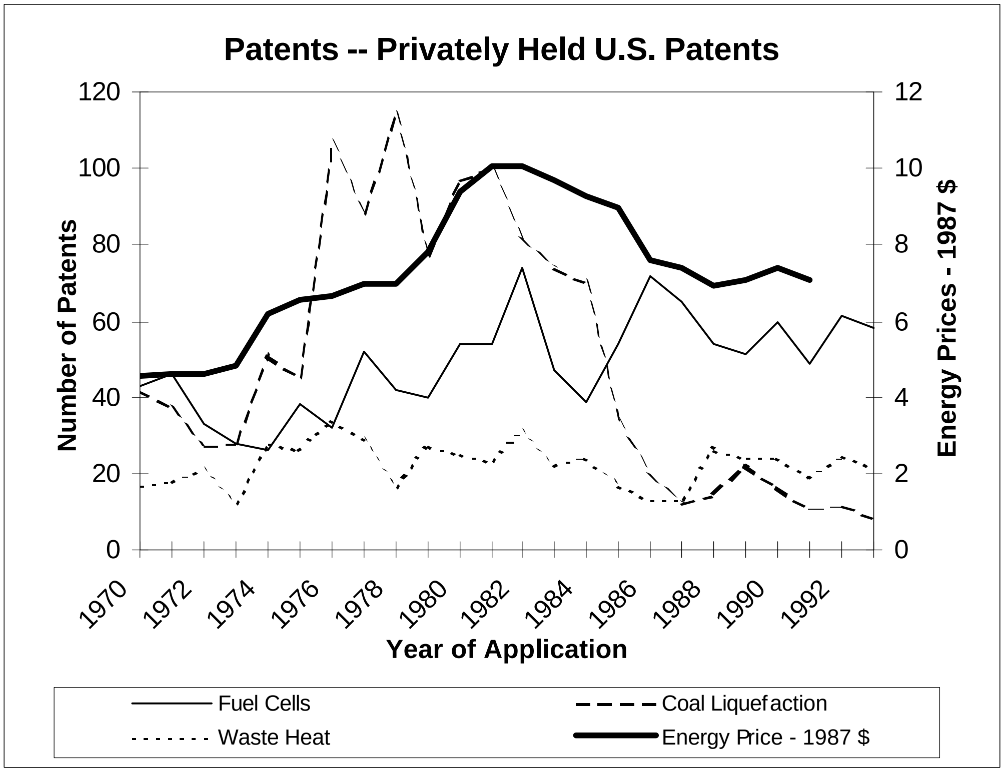


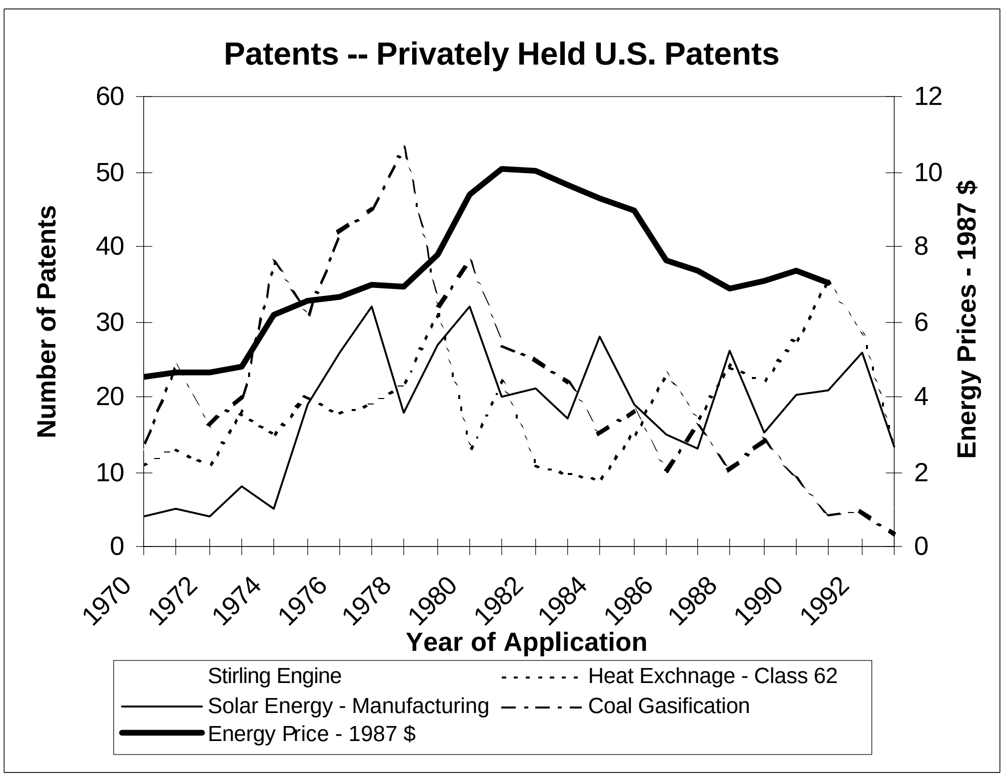


NOTE: Energy prices are the cost per million Btu of energy consumption, in 1987 dollars.

Figure is continued on next page

Figure 2.1 – Patent Applications (continued)

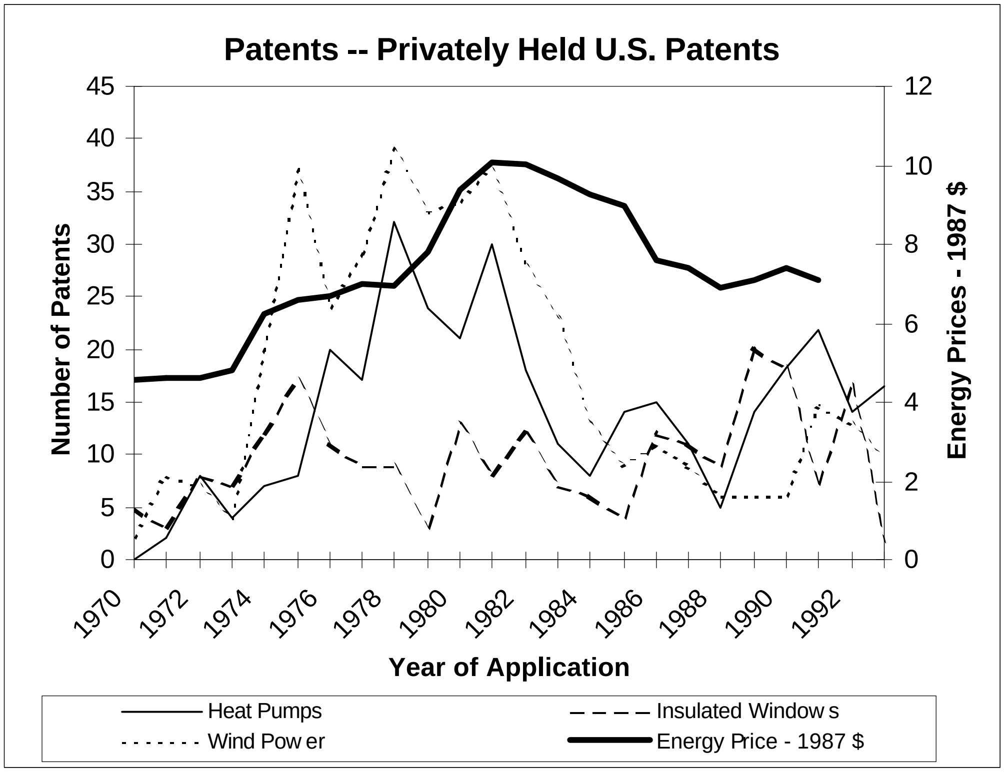


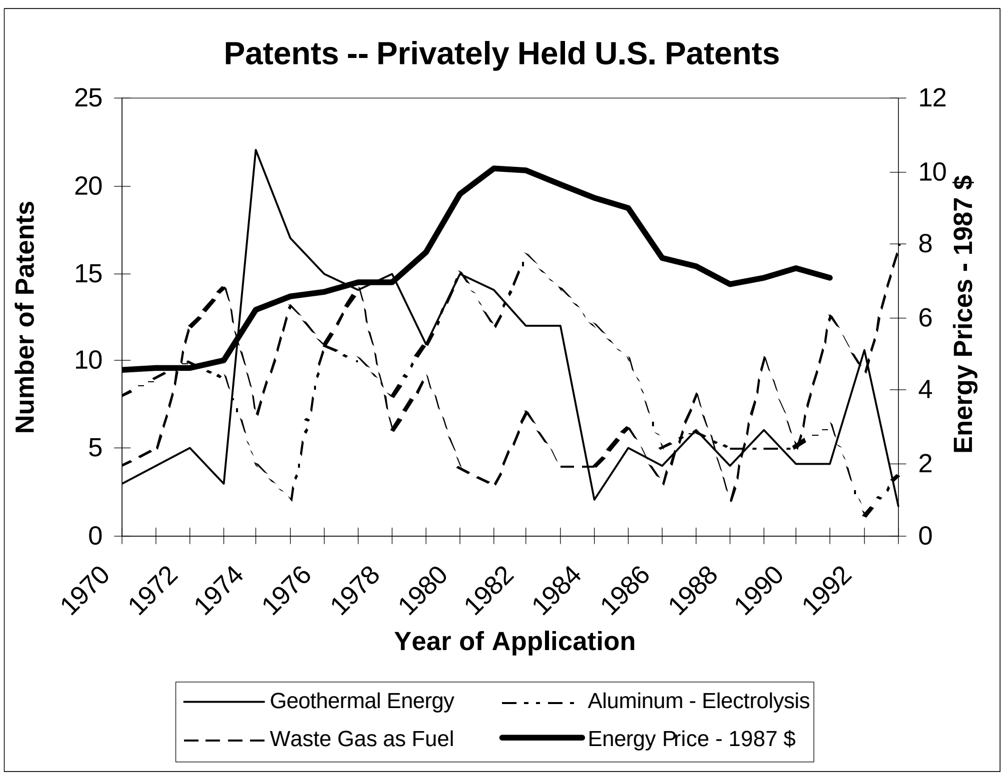


NOTE: Energy prices are the cost per million Btu of energy consumption, in 1987 dollars.

Figure is continued on next page

Figure 2.1 – Patent Applications (continued)

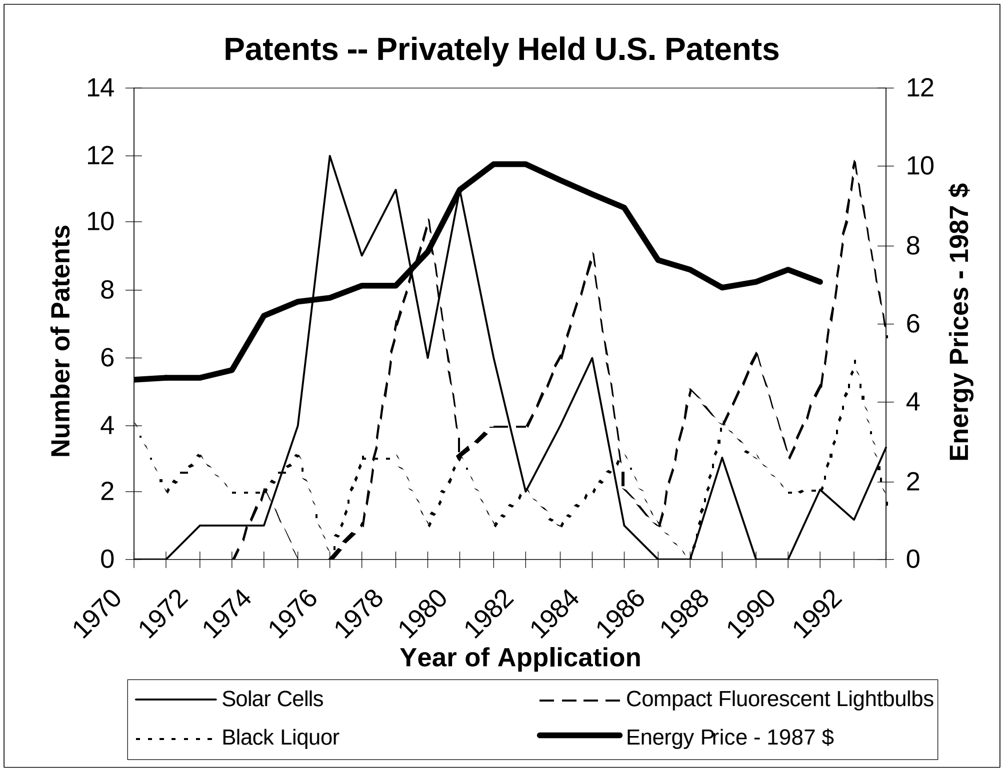


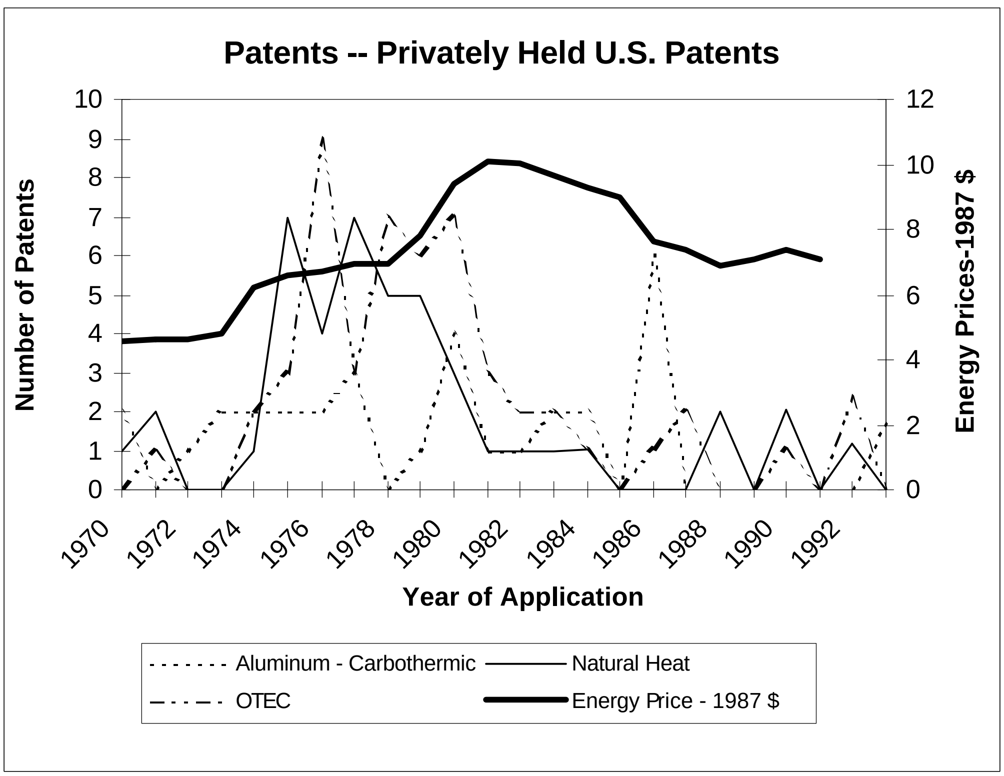


NOTE: Energy prices are the cost per million Btu of energy consumption, in 1987 dollars.

Figure is continued on next page

Figure 2.1 – Patent Applications (continued)





NOTE: Energy prices are the cost per million Btu of energy consumption, in 1987 dollars.