MH
Project Number: 0311
Division # 42 MH-0311

ALTERNATIVE RENEWABLE ENERGY SOURCES

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Nathan G. Meryash

Brian G. Cordes

Michael P. Lynch

Scott L. Proulx

Christopher J. Kruszeski

Date: March 4, 2004

Approved:
Professor Mayer Humi, Advisor

Abstract

This project considered the imminent depletion of the world's fossil fuel supply. Impacts of fossil fuel usage on the environment and humanity have been studied in depth. Alternative, environmentally friendly, sustainable energy sources, primarily wind and solar, were investigated as possible solutions. The economic and technical feasibility of implementing these sources and their potential impact on the energy market were researched. A system dynamics model was developed to simulate the relationships between the essential factors affecting the global energy market.

Table of Contents

Table of Figures

Executive Summary

Time is running out; there is no question as to whether fossil fuel supplies are finite. Over the last century the world has become increasingly addicted to fossil fuels, especially oil. Aside from electricity, heat and transportation; millions of products that society has come to depend on are not only made with the energy from fossil fuels, they are made out of them as well. As the peak of oil production nears (or as some believe may have already occurred), the resulting battle for remaining resources will undoubtedly lead to war, depression and the ultimate collapse of civilizations as they exist in their current state. Without immediate action, this will become a reality in the not so distant future.

What would happen if oil production were to peak tomorrow? From that moment on, oil supply would fall increasingly below a rapidly growing demand. At first it may not result in closed petroleum stations and rationing, however the cost of electricity, gasoline and heat, would curve steeply upward; thus making petroleum an energy source that is less and less economically viable. Frank Hubert correctly predicted that oil production in the United States would peak just 10 years before it did in 1982. That same geologist has predicted global oil production to peak as early as this year. New oil discoveries have been steadily declining for decades and have forced an increasing dependence on Middle Eastern resources. The prospects for natural gas are not much better and coal, the most primitive and dirty of the fossil fuels will eventually come in short supply as well.

This paper provides an in-depth analysis of the current energy situation, a critical assessment of the potential associated with possible alternative energy technologies, and

a detailed evaluation concerning possible energy policies based on the potential success of their implementations. An in depth look is taken at everything from conservation and efficiency of energy usage to production with a focus on alternative energy sources. Two renewable energy sources in particular, wind and solar maintain the focus of this report as they have been identified as proven, economically viable sources, with the greatest immediate growth potential. In brief this paper addresses two key target areas, current energy production and future energy production. An attempt is made to better understand the situation using a system dynamics model, of which conclusions and recommendations are made for industry and policy makers.

0- Introduction

The Interdisciplinary Qualifying Project experience at WPI entails a true opportunity to apply the skills acquired in ones major to real world problems. We have combined the skills of two Mechanical, one Mathematics, and two Electrical Engineering students to develop a solution to an impending energy crises fostered by the world's dependence on fossil fuels. We have used our collective skill set to examine the scientific aspects of energy production in detail to develop a better understanding of existing and future technologies involved in energy production. The IQP enables us to not only apply our newly acquired knowledge; it enables us to have a better understanding of how our careers can have a positive impact on the needs of society.

Nathan Meryash

The means by which we obtain and manage energy to serve our needs will undeniably become a field of great reform in the near to immediate future. I believe the efforts involved in radically adapting our technology to make use of alternative sources of energy from a failing system of fossil fuel dependence will present us with one of the most exciting periods of change our society has ever seen. I choose this project as it gives me an opportunity to help define the problems and possible solutions associated with our existing and future energy infrastructure. In the United States we all depend on oil to power our homes, our hospitals, our offices, our vehicles, etc… Thus a shift away from that model will mean a significant change for all of us or a very noticeable one at the very least. This project covers an important topic as energy has a direct and substantial impact on everyone. As we make changes in our infrastructure, the expertise of those with an electrical engineering background will be called upon to a great extent, thus I anticipate I will find myself a part of this massive undertaking on numerous occasions over the course of my career.

Scott Proulx

I found this IQP to be interesting. The idea of figuring out a way to provide enough energy to the United States by using alternative energy sources that were environmentally safe appealed to me. I was motivated to work hard on this project because it involves a topic that affects the future of the world. I wanted to produce a quality paper so that when people read it they get ideas of what can be done to solve the problem. This IQP ties in nicely with my studies because one of the areas I am studying is the transporting of electricity, which is a major aspect of using renewable energy. This ties into my career goals because I would like to get a job in electrical engineering that helps solve our energy problem.

Chris Kruszeski

I decided to do my IQP on Renewable Energy Sources because I saw the depletion of fossil fuels as a problem that won't go away and something that needs to be dealt with or else we will be faced with major difficulties. I thought it would be interesting learning new ways of creating energy and solving the problem with fossil fuels. This project kept my attention and I was compelled to work hard because I wanted to try and produce something that would help the energy needs I the future.

This IQP has to do with mechanical engineering because every industry where a mechanical engineer is used needs energy and fuels to run the mechanical devices. Once fossil fuels are depleted and there are energy shortages the mechanical engineering field and many others with have major difficulties. This IQP fits into my career goals because if this situation isn't solved before we run out of fuels there will not be many companies that could afford to run and in return many job shortages.

Michael Lynch

Renewable Energy Sources was an IQP that caught my attention. It mainly interested me, because I could clearly see how the problem of depleting fossil fuels affected society. Also, this affects the entire world, not just a certain region or country. The experience gained from this IQP can easily be applied in the professional world. First of all, working on this project has improved my teamwork skills. Another skill it has helped, is problem solving. Through our research we were able to justify the need to increase the use of renewable energy. This ability can be useful in many professions. This IQP can relate to my major, Mechanical Engineering, as well. It mainly comes into play during the design and construction of renewable energy plants. For example, a wind turbine would need a certain structural stiffness, along with gears that turn with the turbine.

Brian Cordes

I think what attracted me to this IQP were both the magnitude and the immediacy of the problem it detailed. Considering our current energy situation, we as a society need to reach some structured resolution concerning the avoidance of this impending energy crisis. Specifically, this is making a combined effort to create new energy technologies that will eventually phase out our dependence on fossil fuels.

As a mathematics major, I felt a particular interest in attempting to understand the dynamics behind many of the functional relationships concerning energy parameters. By using the knowledge that I gained from my education, I hoped to elaborate upon these detailed relationships as a way of expressing the problem at hand.

My interest in attempting to both understand and solve this problem leads me to believe that I will deal with it in the future. During the course of my education and my career, I hope to continue to research into this problem.

We chose this IQP because it involves gathering information and developing a solution for the energy crisis, which is rapidly growing problem in the world today. This is a subject that will influence the daily lives of everyone. It ties into the studies of the two electrical engineers because it involves handling of energy in its electrical form. The studies of the two mechanical engineers will be impacted by this because the majority of materials used and the power comes from fossil fuels. It also presents opportunities design more efficient wind mills and solar panels that will make renewable energy feasible. The math major on this project was most useful when it came time to develop a model. The model allows us to see how all of the various things tie in together, whether it be presenting a solution or showing how quickly our current fossil fuels will deplete. We hope our work will be used as a resource to help plan and implement new energy solutions.

1- Problem Statement: The Argument for Renewable Energy

Energy is what sustains our civilization. It is the basis for all things that we use and require in order to survive. Whether this is in the form of heat or electricity or food, energy is what allows our appliances and us to function.

While modern society consumes a significantly greater amount of energy than it used to, energy has always been needed. Originally animals were used to provide energy necessary for transportation and farming / food production. In addition humans would need to use more of their own energy in order to sustain themselves or in other words everything had to be done by hand. Towards the end of the 19th century, humans discovered that the quality of life could be greatly improved by using machines that run off of fossil fuels. Further developments since then have yielded more and more technology that could replace the duties of human labor. These breakthroughs have enabled a multitude of new frontiers for society, increasing individual productivity and greatly improving the quality of life. Unfortunately, these fossil fuel powered wonders do not have an infinite supply of energy nor are they free of other negative externalities.

Energy production is dominated by the consumption fossil fuels.

> **"Fossil fuels – coal, oil and natural gas -- currently provide more than 85% of all the energy consumed in the United States, nearly two-thirds of our electricity, and virtually all of our transportation fuels."**
> **– United States Department of Energy**

Over the last thirty years, society's dependence on energy produced by fossil fuels has grown rapidly. From 1970 to 2002, consumption of energy produced by fossil fuels increased from 63.52 to 83.49 Quadrillion Btu (EIA, 2002). Predictions are that this trend of increasing dependence will continue in the future. However, the continued dependence on fossil fuels presents a major problem.

It is well known that the natural formation of fossil fuels is a process that requires many millions of years to complete. Due to the extreme disparity between the consumption of fossil fuels by our civilization and the natural reintroduction of fossil fuels into the environment, fossil fuels are essentially a limited resource. As a demonstration of this, consider the following assessment. If oil consumption increases at the same annual rate of 2.3% over the next century with a baseline consumption of 27.34 BBOE (an approximation much less than what is to be expected), the recoverable reserves, which are estimated at 1017 BBOE[1], will be depleted by 2025. Even if recoverable reserves were five times this amount, they would only last an additional fifty years[2].

As reserves are depleted and recovery becomes more and more difficult, energy costs will continue to rise. Between 1970 and 1997, expenditures relating to energy production steadily increased in nearly every area. Total petroleum expenditures increased by a factor of five from 47,942 to 266,595 million nominal dollars[3]; natural gas expenditures changed by nearly an entire order of magnitude from 10,891 to 91,769 million nominal dollars[4]; and total coal expenditures increased from 4,594 to 27,522 million nominal dollars[5].

Elevated costs will drive energy prices to extreme levels and the majority of the world will not be able to afford electricity and heating. Between 1970 and 1997, prices

[1] Oil and Gas Journal, 1999
[2] Klass, D., 2003. "A Critical Assessment of Renewable Energy Use in the USA". Energy Policy 31
[3] EIA, 1997
[4] EIA, 1997
[5] EIA, 1997

increased as a direct result of the increased costs. The average price of petroleum based energy increased from 1.72 to 7.82 nominal dollars per million Btu[6]; the average price of coal based energy increased from 0.37 to 1.31 in nominal dollars per million Btu[7]; and the price of natural gas based energy increased from 0.59 to 4.62 in nominal dollars per million Btu[8].

Numerous arguments can be made concerning the possible fallout from these predictions. Scarce resources could fuel military conflict concerning possession of established reserves. Energy shortages could cause wide spread famine and inevitably the contraction of the world's population to only half a billion people. Although these scenarios are hypothetical in nature, they are representative of the one result that cannot be avoided. If we continue to depend on fossil fuels to meet our energy demands, we are faced with the undeniable fact that some day in the not too distant future, limited reserves will reduce energy production capacity to the point where we will be incapable of meeting our energy demand. If this does indeed occur, it would cause the collapse of our civilization.

Thus we are faced with the task of solving this problem.

The concern is how can we address this problem? Consider the option of developing technologies to synthetically manufacture the fossil fuels required to meet our energy demand. For many reasons, this will not work. This method is inefficient because the energy required to synthetically produce these fuels is greater than the energy produced by the consumption of such fuels. Also, it is theoretically impossible to sustain the desired rate of synthesis due to the massive energy demand of society. Last, fossil

---

[6] EIA, 1997
[7] EIA, 1997
[8] EIA, 1997

fuel consumption produces high levels of pollution. Continued use is extremely unhealthy to our planet. It should become obvious from these considerations that in some shape or form, fossil fuels must be replaced.

It is important to understand that fossil fuels serve numerous additional purposes in industry aside from energy production. Although oil is primarily used to produce fuels that power transportation vehicles, it is heavily used in industry as a key component in the manufacturing of a wide array of materials ranging from plastics to tires to chemicals. Similarly, coal is a main component in the production of steel and natural gas is used heavily in the chemical industry. Thus, it must be noted that solving our energy problems will not completely address our dependence on fossil fuels. But, the first step in this process is the change of our energy market.

We must shift our energy dependence from the consumption of fossil fuels to the consumption of sustainable resources. Considering the group of possible energy sources, the most practical options are those of wind energy and solar energy. However, the key issue is: how can this be accomplished? This IQP focuses specifically on this issue.

The goal of this IQP is to determine an efficient and effective policy detailing the guidelines for energy production in the future so as to resolve the current and impending problems surrounding society's dependence on fossil fuels.

This paper provides an in-depth analysis of the current energy situation, a critical assessment of the potential associated with possible alternative energy technologies, and a detailed evaluation concerning possible energy policies based on the potential success of their implementations.

2- Fossil Fuels

The energy used by society today is derived from three main resources which; are coal, oil, and natural gas. Each resource has its' own unique uses and individual problems associated with there usage. The problems arise with obtaining, transporting and using the fossil fuels. The fossil fuel industry is faced with increasingly difficult challenges from an increase in consumption, decline in supply, obtaining of resources, and environmental problems.

The industrial revolution brought about many advances in technology and helped turn the industrial world into what is it today. Around this time, in the early 19^{th} century, fossil fuels began to be more widely used. Coal was the first fossil fuel to be exploited on a large scale. It was mainly used in the commercial introduction of electricity. Since the Second World War there has been a significant increase in the usage of oil. Approximately 40% of the global fossil fuels used in the early 1970's were oil. Starting in the 1960's natural gas became increasingly popular due to the fact that it is more efficient. The reliance on fossil fuels that began with the technological advances from the industrial revolution is still prominent today.

Oil is one of the most valuable recourses currently being used by society. The consumption rates of oil have been on the rise for the last decade, this trend is expected to continue with the increased development of third world countries and technological advances that will raise the energy demand. The problem with the growing consumption rates is that the inability of production to maintain pace. After a few decades there is projected to be a decline in the discovery of new reserves; which will significantly reduce the longevity of oil. Analysts have collected statistics on oil and simulated models that predicted the approximation for when the oil reserves would be totally depleted. As a result of the advanced technology untapped reserves have been located and the new refineries available they might now useful.

An increasingly more popular fossil fuel is natural gas. Rates at which natural gas is being consumed are rising faster than other fossil fuels. The amount of natural gas that is being consumed can currently be filled. However, with the continued increase in consumption the maximum amount that can be produced will not meet the demand. Obtaining natural gas is a complex process. Due to this, there are numerous reserves that have yet to be explored. Studies on natural gas have been performed to try and accurately predict when it will run out.

Coal is the most widely used fossil fuel in not only the United States, but the entire world. The majority of electricity generated is from coal power plants. Coal is so widely used due to the fact that it was one of the first fossil fuels to be used on a large scale. The abundance of coal also contributes to its high amount of consumption.

Naturally there are problems with coal, as with any other fossil fuel. This is the main argument for renewable energy. Although projected to last a long time, coal will eventually run out. Another problem to consider with coal is that it is the most polluting fossil fuel. Sulfur dioxide, and carbon dioxide are the two biggest contributors to pollution from coal emissions.

Fossil fuels have a direct affect on the environment. In order to create energy from fossil fuels, they must be burned. This process emits various gases into the atmosphere. These gases, usually called greenhouse gases, can affect major parts of the environment. The quality of air and water can also drastically decrease due to the air pollutants. CO_2 emissions are the most common, and contribute most to the pollution. More and more states and countries are taking the initiative to reduce emissions, whether from cars, power plants, or factories. Emissions are being reduced; however, they are still present due to fossil fuels.

2.1 Oil

2.1.1 World Oil Consumption

Oil is the least available fossil fuel; however it is the most valuable. Each year the world requires more and more oil. The world oil consumption grew in 2002 by about 300 thousand barrels per day, this was scattered evenly among the industrialized nations and the developing nations. The increase in the oil consumption is partly because the crude oil prices were $22 to $28 per barrel, which is with in the range preferred by producers in the Organization of Petroleum Exporting Countries (OPEC). OPEC made substantial modifications as to how to produce and provide crude oil by controlling the oil production of the associated countries, in the 1970's. The result was the First Oil Shock in 1973-1974, which permanently changed the economics of international oil markets, the direction of energy usage, and dependence on oil for industrialized nations[9].

The initial result of controlling oil production in the export countries was the increase in crude oil price from $2 per barrel to $13 per barrel. Similarly, refined products and processed commodities became more expensive. Considering the sudden decrease in the amount of exported oil, shortages and supply problems occurred

---

[9] Energy Information Administration, Short-Term Energy Outlook, April 2003, www.eia.doe.gov/emeu/steo/pub/contents.html

frequently. Since then, OPEC members have had the most control over the world's energy markets. By controlling oil production, many OPEC countries have greatly increased their revenues from crude oil sales. In contrast, the countries that heavily depended on foreign oil experienced economic setbacks. Obviously, in the countries that depended on importing oil, for instance the United States, there were considerable price increases[10].

The world oil demand is expected to grow by about 1.2 million barrels per day in 2003. Through 2020, the change in crude oil consumption rates is expected to increase from a low of 1.4 to a high of 2.9 percent. This prediction agrees with the belief that the largest fraction of the world's energy will be due to crude oil, which is expected to increase by 59 percent between 1999 and 2020. This is expected despite the dramatic increase in crude oil prices early in 2003. The increases in prices were a combination of two things, they are the strike against the Chavez regime which; resulted in a drop in Venezuela's oil exports and the other reason was the price volatility that was created by the war in Iraq[11]. The world oil prices for 2003 are expected to remain at $30 per barrel. The price per barrel of oil is expected to soften in 2004; however this might not occur if OPEC maintains its current success in market management through production cutbacks. The prices could fall if the other OPEC members follow through with their agreement to increase production in order to replace the oil lost by Iraq and Venezuela. If the non-OPEC nation continue to increase their production to the expected 1.4 million barrels per day, then it will be easier for oil prices to drop. The future project for oil prices by the

[10] Radler, "Worldwide Reserves Increase as Production Holds Steady," Oil & Gas Journal, December 23, 2002.
[11] P.I. Vasquez, "Tensions Rise in Venezuela; Groups Plan Nationwide Strike," The Oil Daily, October 4, 2002.

International Energy Outlook show a decline in prices to $23.27 per barrel in 2005 leading to a .7 increase per year leading to $26.57 per barrel in 2025.

The worldwide oil demand is projected to reach 119 million barrels per day by 2025, requiring an increment to world production capability of more then 42 million barrels per day over current capacity. The OPEC nations are expected to be the major suppliers of the increased production; however the non-OPEC nations are expected to remain competitive in the market. There are four major factors that contribute to the projections made by the International Energy Outlook. Factor one is the dramatic increase in oil prices from 2002 to 2003 as a result of the Venezuelan labor strike and the war in Iraq. The second factor is the deepwater exploration and development initiatives that are expected with the offshore Atlantic Basin, this will emerge as a major source of oil production in Latin America and Africa. Another factor is the economic development in Asia. This is crucial to the long-term growth of oil markets because the increased oil demand would great a demand and strengthens the economic ties between the Middle East and the Asia markets. The last major factor is the projection of the competition between OPEC and non-OPEC over the sources of supply, so between oil and other sources of energy such as natural gas[12].

[12] "Egypt—Oil and Gas," World Markets Energy Online, September 25, 2002, www.worldmarketsanalysis.com.

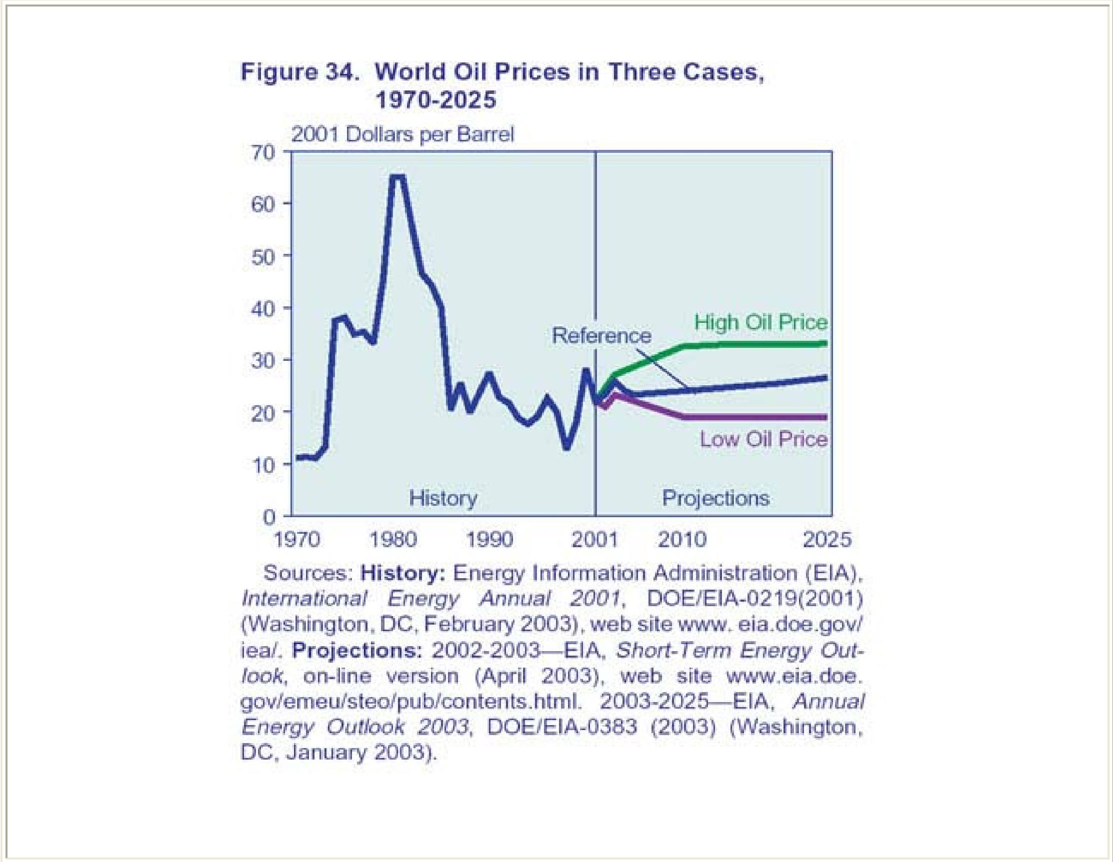


Figure 1: World Oil Price

This graph demonstrates three different trends. The reference trend is the projected one; it is a combination of the high oil prices and low oil prices. The high and low oil prices show what it would be like if the price stayed constant.

World oil demand is projected to grow to 119 million barrels per day by 2025. Over the forecast period, oil remains the fuel of choice in the transportation sector worldwide, and almost three-quarters of the projected increase in oil demand from 2001 to 2025 comes from the transportation sector. Global economic growth, the main driver of oil demand growth, is expected to average 3.1 percent per year. The highest rates of economic growth from 2001 to 2025 are expected in developing Asia, led by China and India at 6.2 percent and 5.2 percent. The developing countries' share of world oil demand is projected to increase from 36 percent in 2001 to 43 percent in 2025, with a corresponding drop in the industrialized countries' share from 57 percent in 2001 to 50 percent in 2025. The largest regional increases in oil demand are projected for North America and developing Asia. The smallest increase is projected for Western Europe, where transportation is more mature and population growth is relatively slow[13].

The picture below shows the break down of consumption by region and by the amount of million barrels per day consumed. It shows the consumption from 1970 until 2001 and below that it shows the consumption from 2001 to 2025. As stated it shows that North America and developing Asia will consume the most oil.

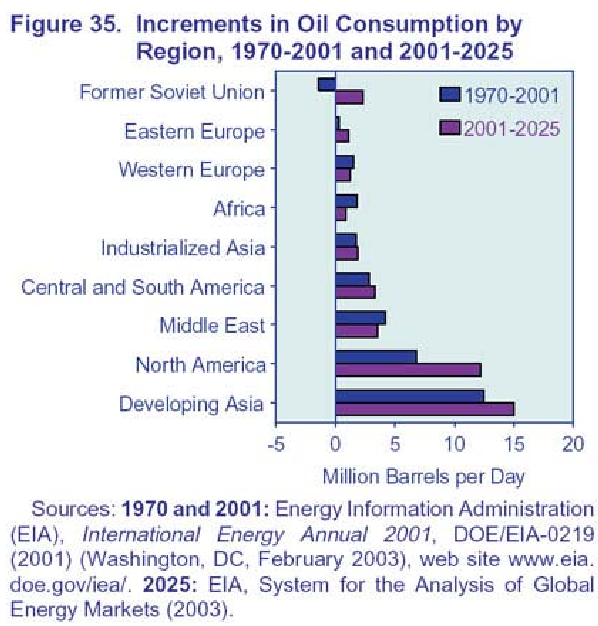


Figure 2: Oil Consumption by Region

North America is the largest consumer of oil in the world accounting for more then one fourth of the total demand in 2001. The United States continues to depend more

13 Petroleum Economics, Ltd., World Long Term Oil & Energy Outlook, London, UK, June 2002.

and more on foreign oil as time goes by. US oil imports accounted for nearly 55 % of crude oil consumption in 2000, which constitutes a 9% increase since 1992. On average, the daily oil imports in the US were 6.9, 8.0, and 11.4 million barrels in 1980, 1990, and 2000, respectively. The oil demand in the United States is projected to grow by 1.7 percent per year to 29.2 million barrels per day in 2025, which is up from 19.6 million barrels per day in 2001. Oil consumption in the transportation sector represents 66 percent of North America's total oil demand. North America's oil markets strongest growth is projected for gasoline. In the past another major area for growth in America's oil market was jet fuel; however that has changed in the wake of the recent airline troubles. The growth in America's oil demand will impact the demand for oil in Mexico. The close economic ties with the United States led to the projected increase in Mexico's oil demand. Mexico is project to demand 4.1 million barrels per day in 2025 and increase from 1.9 million barrels per day in 2001. The oil demand in Canada is expected to grow to 2.4 million barrels per day in 2025 as a result of the growing transportation sector[14].

In industrialized Asia, oil demand is expected to grow more rapidly in Australia and New Zealand than in Japan. Oil use in Australia and New Zealand is projected to grow by 2.3 percent per year, from 1 million barrels per day in 2001 to 1.7 million barrels per day in 2025, reflecting higher expectations for population growth and economic expansion. In Japan, the projected increase averages only 0.8 percent per year, from 5.4 million barrels per day in 2001 to 6.5 million barrels per day in 2025. In 2002, Japan's oil demand fell for the third consecutive year. Demand for fuel oil by large industries and electric utilities continued to fall as a result of Japan's prolonged economic recession. The projected growth of oil in Western Europe is the complete opposite of that for

[14] DRI•WEFA, World Overview, Lexington, MA, September 2002.

Australia; Western Europe is only supposed to have a growth of .4 percent a year, growing to 15.3 million barrels per day in 2025[15].

The total oil demand in the Former Soviet Union and Eastern Europe is projected to reach 8.8 million barrels per day in 2025. The lack of oil resources in Eastern Europe, in contrast to the abundance of coal, has limited the share of oil in the energy mix to an estimated 26 percent in 2001. Oil demand in Eastern Europe is mainly for use in the transportation sector and is projected to grow by 2.5 percent per year, to 2.5 million barrels per day in 2025, rising to about 29 percent of total energy consumption[16].

The oil demand in the developing world is projected to reach 50.7 million barrels per day by 2025. Developing Asia has managed to avoid the global slump of 2001 because of regional economic growth, consumer confidence, low interest rates, and progressive liberalization of trade. This led to a prediction of developing Asia's oil demand to reach 28.9 millions barrels per day in 2025. China is one of the developing nations whose demand for oil is continuing to climb. The increase in demand for oil results from the increase in motorization and switching away from coal and other traditional noncommercial fuels in the residential sectors. India is the other developing nation who is project to have major increase in it's' demand for oil. 70 percent of the projected increase in the oil demand results from the transportation sector. The Indian government is spending a lot of money fixing roads and building new roads. The projection for oil demand in India is 5.5 million barrels of oil for 2025[17].

---

[15] World Market Research Center, China Automotive, London, UK, September 4, 2002, www.wmrc.com.
[16] www.sciencedirect.com
[17] "Country Report: India", World Markets Energy Online, August 7, 2002, www.worldmarketsanalysis.com.

The oil demand in the Middle East is projected to grow at an average annual rate of 2.1 percent to 8.9 million barrels per day in 2025. In Saudi Arabia, the transportation sector and massive petrochemical sector have been driving the rapid growth in oil demand. Direct burning of crude oil in the power generation sector takes place in Saudi Arabia; there are plans to eliminate this by 2015. Iran is the other major consumer of oil in the Middle East. One third of the oil consumed by Iran is used domestically[18].

Central and South America is a region that is expecting an increase in it's' oil demand to 8.5 million barrels per day in 2025. Presently oil accounts for one half of the region's total energy use. This is expected to change with the new large-scale hydropower opportunities that are expected to develop. The projection is for a slow decline in the oil's share down to 45 percent in 2025, this is mainly due to competition from natural gas in the industrialized sector[19].

2.1.2 World Oil Production

The International Energy Outlook projects that the world oil supply in 2025 will exceed the 2001 level by 41 million barrels per day. Increase in production are expected from both OPEC and non-OPEC producers. Over the last hundred years, about 539 billion barrels of oil have been manufactured outside the United States. The world expects about 39 percent of the total expected increase in production to come from non-OPEC areas. Worldwide only the Middle East region has registers no decline in drilling activity during 1998. Onshore drilling fell more sharply than offshore drilling; offshore drilling has sustained levels better then 80 percent of capacity. The 61 percent increase in

---

[18] "Egypt—Oil and Gas," World Markets Energy Online, September 25, 2002, www.worldmarketsanalysis.com.
[19] "Inching Forward with the IMF," Business Monitor International: Latin American Monitor, September 2002.

petroleum demand over the next two decades will be met by an increase in production by members of OPEC. OPEC production in 2025 is projected to be more than 25 million barrels per day higher then 2001. The graph below shows that the OPEC areas will lead the oil production come 2025. Currently and in 2010 the rest of the world is projected to supply more oil then the OPEC areas. In time this changes because OPEC areas have considerable more oil[20].

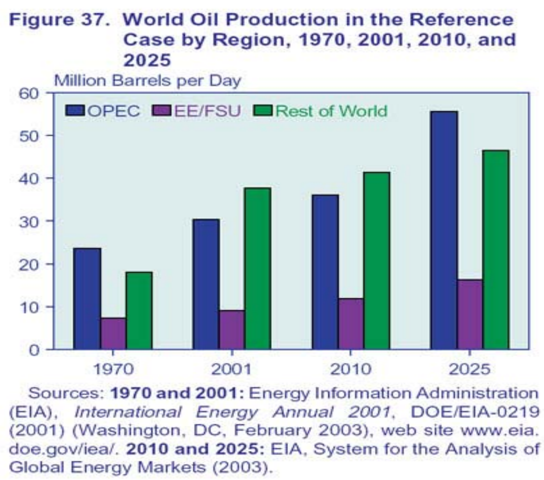


Figure 3: World Oil Production

The sizable increase in petroleum demand is thought to be able to be covered by the OPEC members with large proved reserves. OPEC suppliers are projected to grow at an annual rate of 2.5 percent through 2025. OPEC capacity utilization is expected to increase to 95 percent by 2015 and will remain there through 2025. With the Persian Gulf producers enjoying a reserve to production ratio that exceeds 89 year, capacity expansion is clearly feasible. Persian Gulf OPEC producers can expand capacity at a cost that is a small percentage of the projected gross revenues. Venezuela has the greatest potential for

[20] Energy Information Administration, Long-Term Energy Outlook, April 2003 on-line version, www.eia.doe.gov/emeu/steo/pub/contents.html.

capacity expansion and could increase production by more than 1 million barrels per day to 4.2 million barrels per day by 2005; however the current political climate could impact it. OPEC members outside the Persian Gulf are expected to increase their production despite their higher capacity expansion cost[21]. Nigeria has considerable offshore production potential.

The non-OPEC areas supply from proved oil reserves is expected to increase steadily to 62.8 million barrels per day in 2025. Production from Norway is expected to continue its increase and peak at about 3.4 million barrels per day. The United Kingdom is expected to have an increase in production during the middle of the decade and reach its peak production of 2.5 million barrels per day. Deepwater fields are expected to contribute to non-OPEC's production of oil. The Philippines is expected to be a major producer of oil recovered from deepwater fields. Canada is expected to contribute to the oil production by adding 500,000 barrels per day from the frontier area offshore projects and oil from the tar sands. The resource rich Caspian Basin region has created lots of optimism for the non-OPEC area because it is considered to have the most potential fro oil production in the long-term. The non-OPEC production potential is based on the parameters of finding rates, numbers of exploration wells, reserve-to-production ratios, and advances in both exploration and extraction technologies, and sensitivity to changes in the world oil prices. The results of these show a projected increase in the output of non-OPEC areas by an additional 6.6 million barrels per day in 2010[22].

---

[21] P.I. Vasquez, "Tensions Rise in Venezuela; Groups Plan Nationwide Strike," The Oil Daily, October 4, 2002.
[22] Radler. "Worldwide Reserves Increase as Production Holds Steady," Oil & Gas Journal, December 23, 2002.

The projected numbers show that there is a high demand for oil in the world today. Based on the current reserves the world oil demand should be able to be fulfilled. After a few decades pass not meeting the oil demand will not change unless unexpected supplies of oil are found. The industrialized nation places too much emphasis on oil without oil their economies will take major hits. The world needs to start looking for alternative energy supplies so that when the oil supply has diminished the majority of the world won't crumble. The projected number until 2025 show the world oil demand increasing annually. While the data on oil depletion shows a decrease in oil supplies and oil production annually. The combination of these to things doesn't great a positive outlook for the future. Steps need to be taken to lead the world away from its heavy reliance on oil.

2.1.3 Oil Predictions

There is a growing debate over the possibility of a peak in global oil production and when the world's oil supply will run out. There are a few different theories on when oil will be depleted; the major ones come from Hubbert, Campbell, and Laherrere. The three have some similar ways of approaching their predictions but disagree with other aspects of it.

Hubbert is a Shell Oil Company geoscientist; he originally developed a bell curve to model the annual production of oil and gas in the US. He then created a bell curve to model the production and ultimate recovery of the world's oil. Hubbert's curve has validity because he first used his curve to correctly predict the oil production of the lower 48 states in 1970. In his current model he predicts, along with association for the study of peak oil (ASPO) and the London based Oil Depletion Analysis Center that the peak will occur no later then the turn of this decade. They also predict that once the peak is reached and the fall off occurs the downside will be steep and created unprecedented energy price spikes. Hubbert's curve is based on two driving forces, the amount of oil that can be recovered and historical records of depletion. The primary flaw in Hubbert's- type model is a reliance on the world's ultimately recoverable resources numbers instead of the dynamic variable that takes into account the growing knowledge and technologies. The picture below is a picture of Hubbert's current model of the US oil production. As you can see he believes that the US reached its peak of oil production in the 1970's and has been on the decline ever since[23].

"So long as oil is used as a source of energy, when the energy cost of recovering a barrel of oil becomes greater than the energy content of the oil, production will cease no matter what the monetary price may be." – Dr. Hubbert

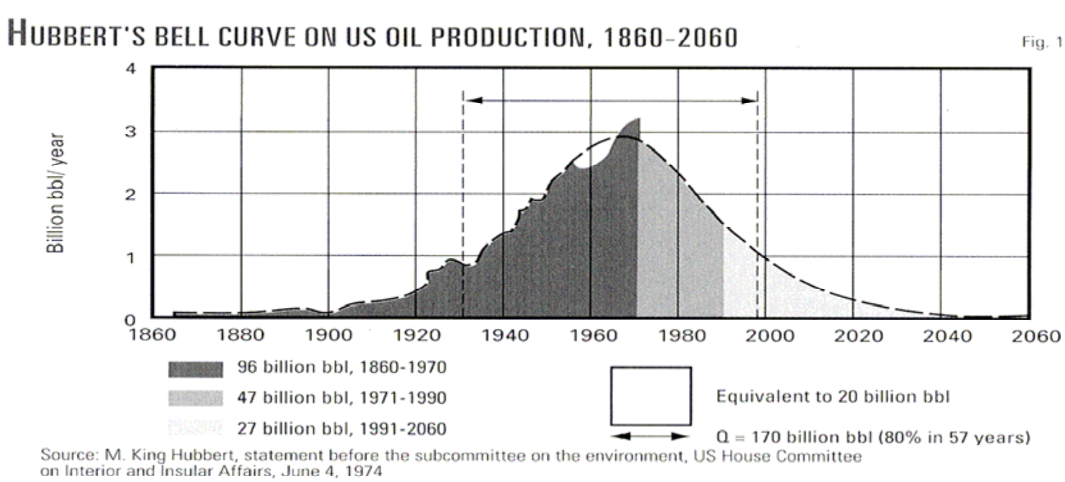


Figure 4: Hubbert's Bell Curve

[23] Deffeyes, Kenneth S., Hubbert's Peak: The impending world oil shortage, Princeton, N.J., Oxford: Princeton University Press, 2003.

Campbell and Laherrere have similar prediction to one another however they are somewhat different from Hubbert's predictions. Laherrere believes in including populations and economics into his peak oil model. He finds more relevance with energy per capita data. The latest model of Laherrere projected the ultimate oil recovery to total 3 trillion bbl, with the total production of all petroleum liquids peaking at 90 million b/d near 2010. Laherrere points out that there are inconsistencies in his model because not all of the countries reports on their oil reserves are accurate. The OPEC nations have reported that their reserves increased by 50% this was done in order to reach higher quotas. They claimed that they found 300 billion bbl of oil over that period when in fact it was less then 10 billion bbl. Laherrere estimates that the amount of recoverable resources of conventional petroleum remaining is 1.1 trillion bbl[24].

The Campbell model shows that oil production is flat until 2010, there it commences into a long term terminal decline at about 2 % a year. The data he collected shows that the heavy oil is expected to grow slowly over the next few years with predominate supply coming from Canada and Venezuela. The Deepwater oil is mainly in the Gulf of Mexico and in the south Atlantic, this is thought to peak at about 8 million b/d by 2010. Campbell claims that the peak of the conventional oil may have been passed in 2000, he also claims the peak of all liquids will come in 2010 and hydrocarbons around 2015[25].

Campbell's model was created based on a seven step process he derived. Step one is to look at past annual production input from the data published annually by the Oil &

---

[24] B. Campbell, "Hard at Work: Independents Plan To Go the Extra Mile," The American Oil & Gas Reporter, January 2001.
[25] B. Campbell, "Hard at Work: Independents Plan To Go the Extra Mile," The American Oil & Gas Reporter, January 2001.

Gas Journal. Step two is to look at the proved reserves as published by the Oil & Gas Journal. The third step is to adjust any values that seem inconsistent. Step four is to take the adjusted value and multiply it by a factor to deliver Assessed Reserves, which is a "best" estimate of future production from known fields. Proved Reserves refer to the estimated future production from wells in current developments as reported for financial and sometimes political purposes, which may or may not equate with what the fields will actually deliver over their full life-span, namely the Assessed Reserves the fifth step it to take the assessed Ultimate and input into the model. In step six the midpoint value is calculated (Ultimate/2) to determine the future depletion method, which is broken down into two cases. In Post-Midpoint cases, future production as calculated at the Current Depletion Rate is applied. Whereas in Pre-Midpoint cases, production is modeled to increase at between 0 and 5% to Midpoint, depending on local circumstances, and then depleted at the Midpoint Depletion Rate. Since Midpoint in most such countries is within a few years, the assessed rate of increase is not critical. The last step is to take into account several other parameters relating to drilling activity, giant fields, and discovery trends[26].

---

[26] B. Campbell, "Hard at Work: Independents Plan To Go the Extra Mile," The American Oil & Gas Reporter, January 2001.

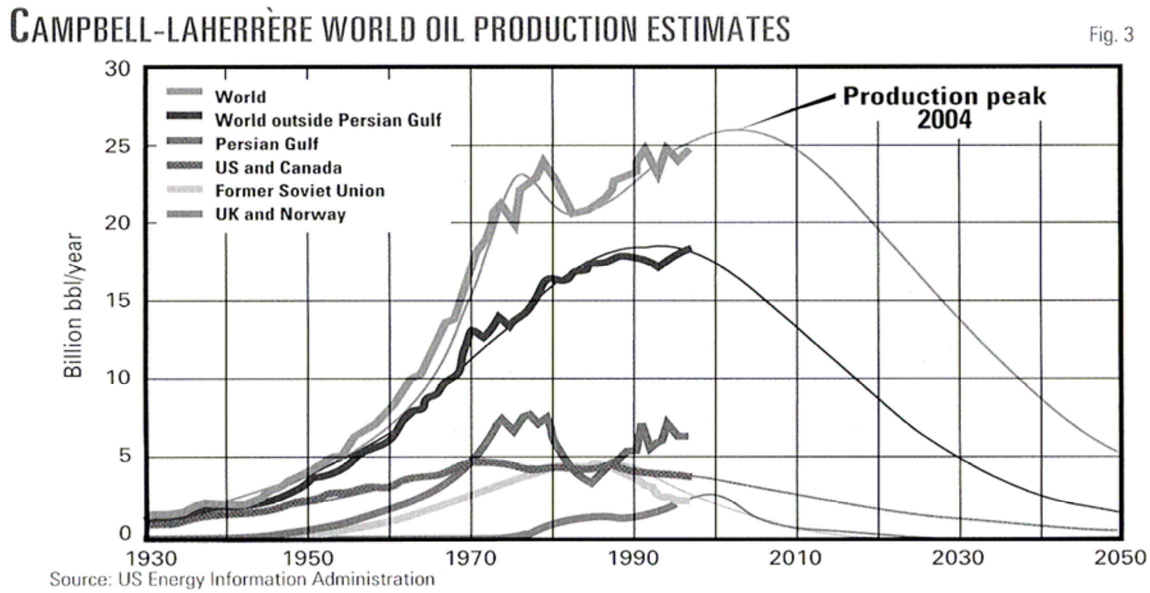


Figure 5: World Oil Production Estimates

This is a graph of Campbell's and Laherrere's prediction for oil depletion. They break it down into categories so that you can see how much each region has. As this shows the Persian Gulf has the majority of the world's oil reserves.

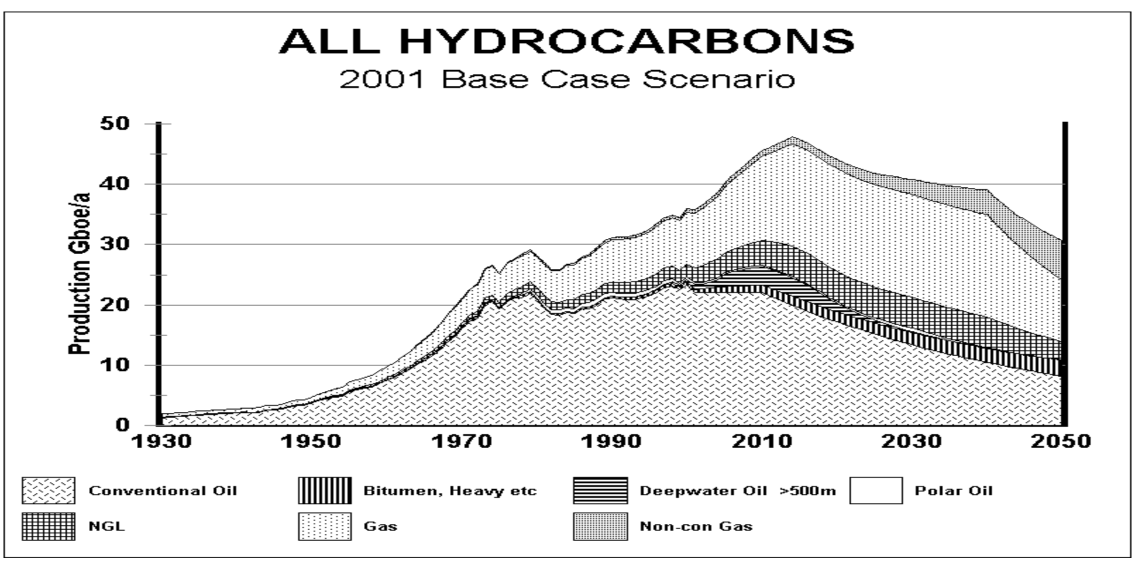


Figure 6: Hydrocarbons

This is a break down by Campbell of how much of each type of hydrocarbons is left and when it will run out. As the graph shows Campbell believes that the hydrocarbons will peak around 2010.

The association for the study of peak oil (ASPO) has designed a data set that will model regular oil depletion. The ASPO breaks their model down into four major areas. The first area is the post midpoint country; these are countries that are considered to have produced more then half their total regular oil production and it is assumed to decline at the current depletion rate. Pre midpoint countries are the second areas. These countries' oil production is considered to be flat at the midpoint and will remain that way unless circumstances dictate other wise at which it will decline at the midpoint depletion rate.

The most crucial group is the group called the swing countries. This group together holds about half of the world's remaining regular oil. They are assumed to exercise a swing role near the peak, making up the difference between the world demand and what the other countries can produce under the model. The last factor into the ASPO model is the regular oil scenario. This scenario shows that demand is assumed to be flat until 2010; this is due to recurring recessions and price spikes. The Middle East swing role is assumed to end in 2010 when the demands upon those countries will exceed their practical capacity. World production is thereafter assumed to start its terminal decline at that current depletion rate[27].

Considering these results with the predictions that global oil demand will increase in the future, and the fact that since 1983 oil consumption has increased, it is highly likely that "there will be shortages, problems with supply, and substantial cost increases for

[27] Association for Study of Peak Oil, http://www.peakoil.net/iwood2003/MatSim.html.

crude oil”. The OPEC effect and diminishing crude oil supplies will most likely have harmful affects on the economies of countries dependent on imported oil[28].

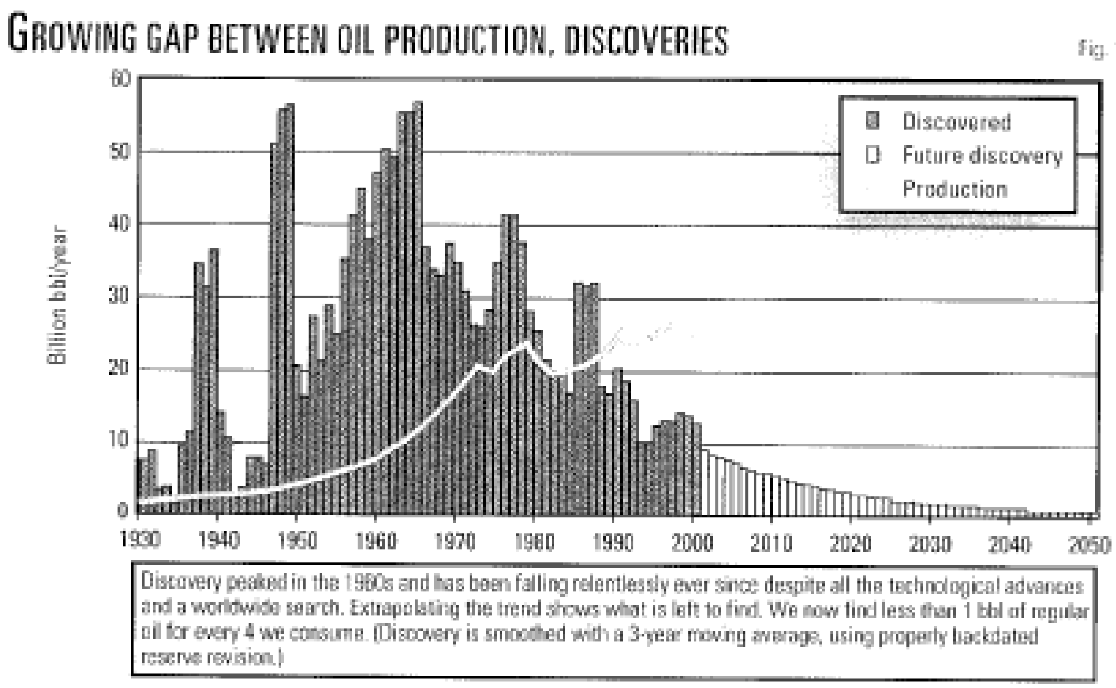


Figure 7: Gap between Oil Production and Discoveries

Source: B. Campbell, “Hard at Work: Independents Plan To Go the Extra Mile,” The American Oil & Gas Reporter, January 2001.

This graph shows the past discoveries of oil and shows the ASPO predictions for future discoveries. As the graphs shows the future discoveries look bleak compared with those of the past. It predicts that the world will run out of oil shortly after 2050.

The following graph gives an estimation of the remaining reserves over the next hundred years, if the annual growth rate remains the same:

---

28 Klass, D., 2003. A Critical Assessment of Renewable Energy Use in the USA.Energy Policy, 31 (pp. 353 – 367)

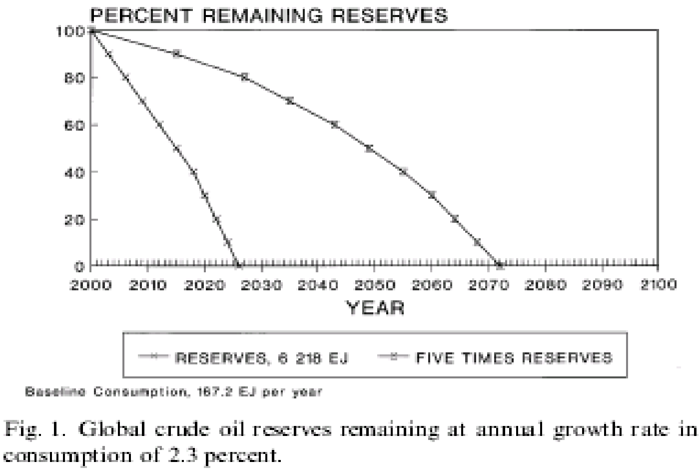


Figure 8: Percent Remaining Reserves

Source: Klass, D., 2003. "A Critical Assessment of Renewable Energy Use in the USA". Energy Policy 31.

2.1.4 Oil Refining

Oil refiners will soon face trying times. The main concern is the decreasing amount of oil. Since oil is running out, refiners must start drilling in new places, and mining deeper than before. To do this, refineries must be updated.

As companies drill in new places, they will find different types of crude oil. Some analysts generally believe that crude or feedstock slate will be heavier and contain more sulfur than the feedstock slate most refineries are getting now. This means that the overall quality will be lower. The projected increase in the extra heavy crude oil can be seen in the graph (Fig. 9) [29].

[29] Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 20.

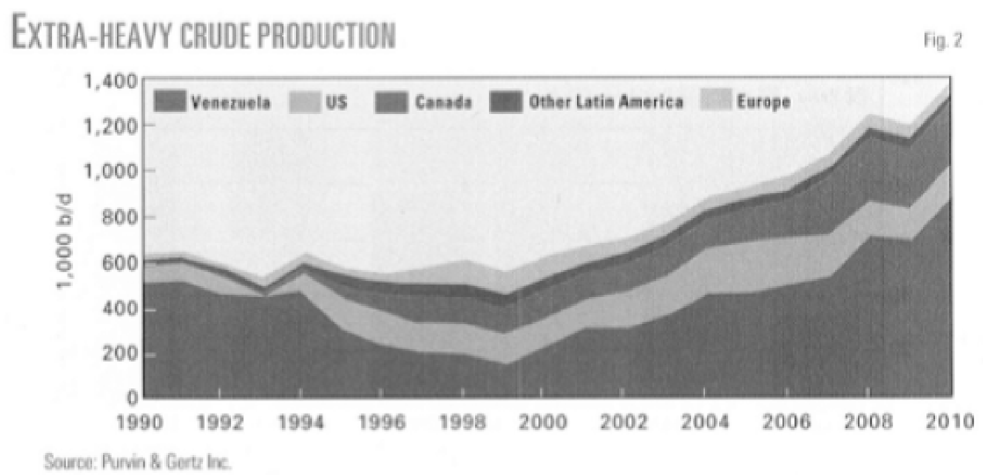


Figure 9: Heavy Crude Production

Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 21

Not all future crude oil will be heavier. Some of it may be lighter, or of the consistency of current crude oils but have corrosive characteristics. This is noted by a high total acid number (TAN). Pervin and Gertz, Inc. have estimated the amount of high TAN crude oil will increase by 2 million barrels per day in the next decade. The graph (Fig. 10) shows the estimated growth of high TAN crude oil[30].

[30] Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 20.

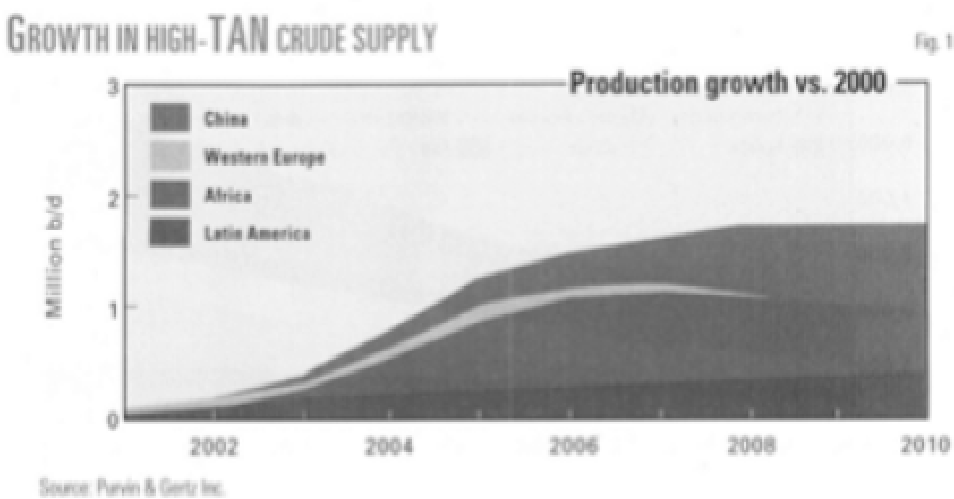


Figure 10: Growth in High TAN crude supply

Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 20.

Analyst Aaron Brady believes the biggest challenge in the future will be anticipating which type of oil to expect. He predicts that there is mostly medium to heavy crude oil in North America. The companies that invest in deep conversion capacity would benefit the most. However, he also states that there is still light crude oil in places such as North and West Africa, as well as the Caspian. Brady speculates that there will continue to be light crude oil from those areas[31].

Some refiners are worried that may have trouble with the different types of crude oil they will encounter. They will have to analyze the crude more extensively. Refiners will have to look for the usual things that can cause problems. Those main things are

[31] Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 22.

organic acids and chlorides. Research on different types of sulfur compounds will need to done.

Another issue to deal with is the region from which the crude oil is gathered (Fig. 11). Currently due to the export infrastructure, there is an abundant amount of crude oil in the former Soviet Union that has not been used. Cooperation of the Russian government and oil companies can ensure a significant amount of oil for the world in the next decade[32].

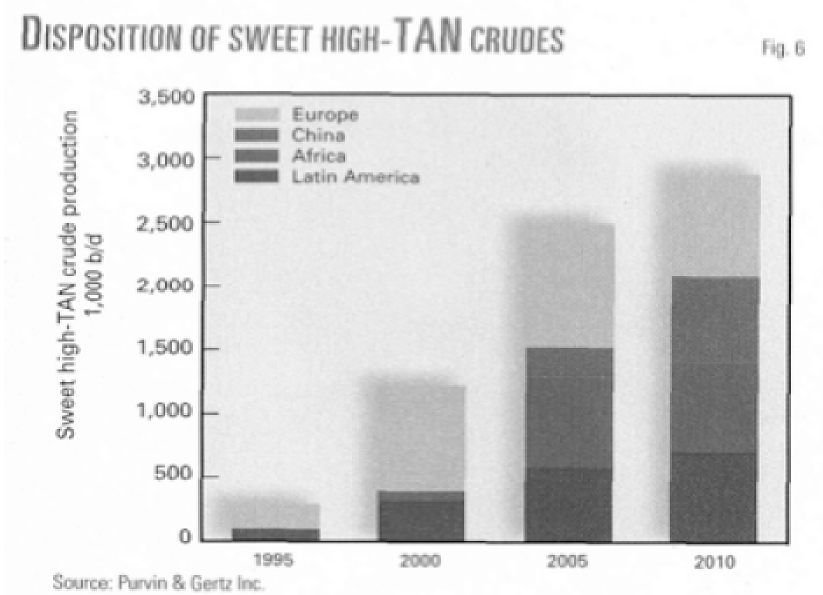


Figure 11: Disposition of Sweet High TAN crudes

Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 24

European refiners face an interesting issue as well. The demand for oil and gasoline is declining. However, the demand for diesel fuel is on the rise. The problem is

[32] Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 23.

that most of the crude that European refiners get is light. Light crude is better for gasoline and oil, while the heavier crude slates are better used for diesel.

North America is dealing with the fact that it will have to rely more and more on foreign oil markets. For example, refiners in the west coast of the US have had declining supplies from Alaska and California. They've had to replace that with Latin American and Middle Eastern crude oil. One problem with foreign oil is the quality may not be as good. Another is cost, and the means of transporting it.

Accommodating the heavier crudes will provide another challenge to oil refiners. They will be required to increase the conversion capacity. This is true especially since a supply-demand imbalance is predicted (Fig. 12).

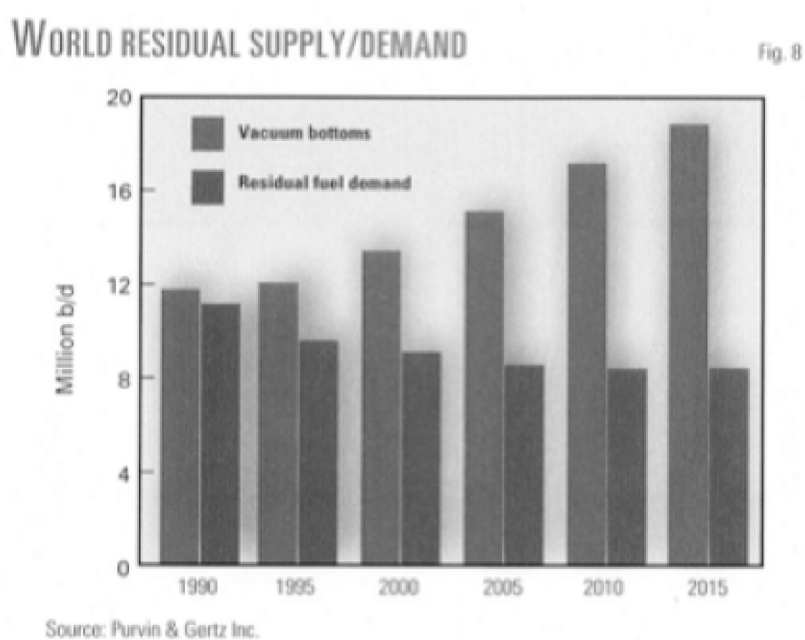


Figure 12: World Residual Supply/Demand

Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 26.

Concerns about sulfur amounts in crude oil are high among refiners. Many parts of the world have set goals for desulfurization in the next few years, in order to have virtually sulfur-free fuels (Table 1).

SULFUR LIMITS IN SELECTED DEVELOPED COUNTRIES Table 3

	2002	Target level	Target date
	ppm		
US			
Gasoline	500	30	2005
Diesel, on-road	500	15	2006
Diesel, off-road	3,500	15	2008-10
Canada			
Gasoline	150	30	2005
Diesel	500	15	2006
Germany			
Gasoline	50	10	2003
Diesel	50	10	2003
Other EU			
Gasoline	150	10	2009
Diesel	350	10	2009
Japan			
Gasoline	100	10	2008
Diesel	500	10	2008
Australia			
Gasoline	500	150	2005
Diesel	500	50	2006

Source: Sulphur Institute

Table 1: Sulfur Limits in Developed Countries

Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 32.

"The biggest challenges in desulfurization, besides dealing with a more severe operational mode…may be how to dispose of unwanted refinery streams," Brady said. "As product specs tighten, certain refinery streams have to be blended into lower grades as they are excluded from the premium product pools either though cut point or blending restrictions. High-sulfur distillate cuts, for example might get dumped in the fuel oil or high-sulfur heating oil pools [33]."

Two questions he asks are, "But what happens when the fuel oil market is shrinking dramatically? Worse, what happens when regulators target fuel oil sulfur content, as is being done in Europe?"

Contamination is also something to worry about when separating high and low sulfur fuels. If a tiny amount of sulfur from a higher sulfur fuel combines with the ultra low sulfur diesel, the entire batch of that diesel will go off spec, thereby ruining it. This could raise costs, as more careful processing will be needed.

The report shows that there is an increase in the world's petroleum reserves. The results indicate a 20 % increase in oil deposits and a 14 % decrease in natural gas deposits when compared to the prior evaluation:

Commodity	USGS 1994 Assessment[1]	USGS 2000 Assessment
Oil	539 billion barrels	649 billion barrels
Natural gas	915 BBOE[2]	778 BBOE
Natural gas liquids	90 BBOE	207 BBOE
Total	1544 BBOE	1634 BBOE

Table 2: USGS Assessment

There are many big challenges ahead for oil refiners in the next several decades. Being able to refine and process different types of crude oil is a major one. Along the same lines, they will be pressured to reduce or at least maintain the same prices, while the added research and processes will likely add to costs.

[33] Williams, Bob, "Refiners' future survival hinges on adapting to changing feedstock, product specs," Oil & Gas Journal, Aug. 11, 2003, pg. 33.

While some may believe oil can only be obtained from drilling, it is possible to produce it by other means. In fact, with very recently technological breakthroughs, oil can be made from anything. For some time now, it has been possible to transform crops such as corn in a gasoline like fluid known as methanol. However, this process has proved so far to be too costly and incapable of meeting the required volume necessary to serve the worlds need for oil. In the last few months, a new technology has been proven in Philadelphia in which virtually any form of waste can be transformed into oil via a mechanical and chemical reactor. The process is known as de-polymerization. De-polyermerization is a process that occurs in nature, as this is how the earth's oil supply has come to be. The difference between the newly developed artificial systems is that the process can be done in a matter of hours where as in nature; it takes several million years for material to decompose into crude. The company that holds the intellectual capital for the process, Changing World Technologies is constructing its first plant responsible for turning 200 tons of turkey by products into an assortment of useful products including 600 barrels of light oil each day.

While domestic oil production in the United States peaked back in 1981, studies have shown that natural gas production in the US has just peaked this year. Considering the fact that most new power plants in the US are natural gas turbines, this has posed serious imminent problems with not only gas and heating costs but with electric utilities as well.

As the production of "cheap" oil and gas hit their peaks, a great deal of attention will be paid to energy conversion processes capable of producing scarce fuels synthetically out of more abundant resources. One very recent discovery making headlines is a new process that is touted as being able to convert any non nuclear waste into high quality oil. A more widely known conversion process is that of coal liquefaction. There are a great deal of questions to be answered when considering synthetic fuel production, such as the cost competitiveness of synthetic fuels compared to traditional "cheap" oil and gas. Cost is the primary reason that the United States has become increasingly reliant on imported cheap oil as opposed to producing synthetic fuels from corn (methanol) or coal. Figure 2 represents the costs assessed in 1990 for various alternative fuels. Dependency on imported oil has remained the dominant source of fuel in transportation applications as these prices have not dropped significantly. As a reference, standard crude oil traded at an average of $27.71/barrel in September (2003)[34].

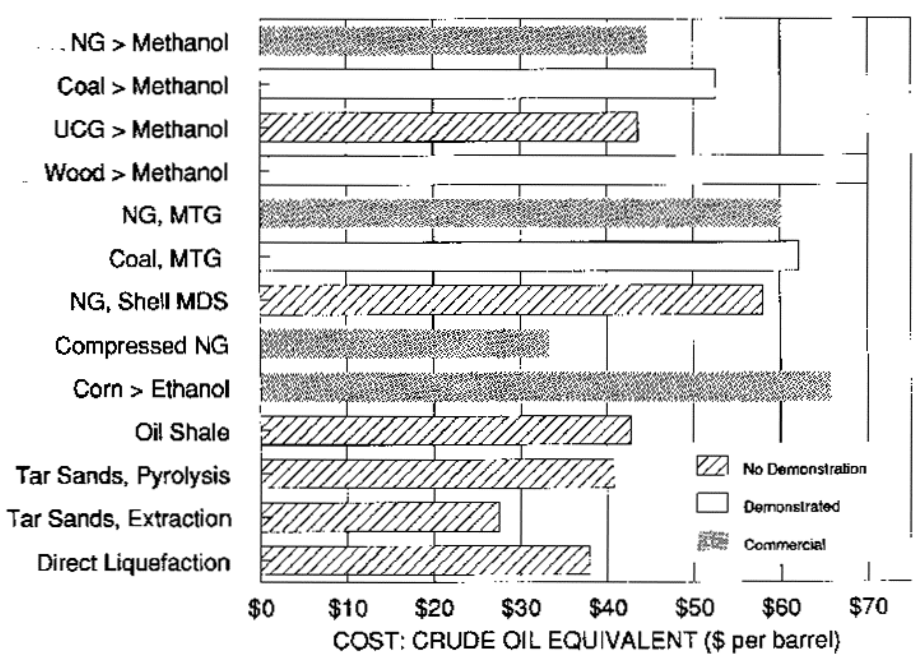


Figure 13: Crude Oil Equivalent Cost

Source 1990 Comparison of Synthetic Fuel Costs (National Research Council)

[34] US Energy Information, http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/weekly_petroleum_status_report/current/pdf/table14.pdf.

An older and more common energy conversion processes is coal liquefaction. There are two primary methods of converting coal into a synthetic liquid fuel; direct and indirect liquefaction. In the case of indirect liquefaction, the coal is first converted into synthetic natural gas (SNG) and is then converted by a conversion system known as the Fischer-Tropsch process to produce liquid fuel. According to the National Research Council, this particular process yielded an estimated efficiency of 50 – 55%. Or in other words 45 - 50% of the energy stored in the coal is consumed by the liquefaction process. The second method, direct liquefaction starts out similar to the indirect process where the coal is first converted into SNG. However in direct liquefaction the gas is further refined into pure hydrogen, which is used in a subsequent reaction to create an end product of clean liquid fuel. The liquid fuel generated by direct coal liquefaction retains an estimated 60% of the energy originally stored in the coal[35]. Considering the fact that in this procedure the coal must first be converted into hydrogen and then put through an additional process to yield liquid fuel, one may note that significant efficiency improvements could be obtained if vehicles were designed to run off of hydrogen directly. Department of Energy reports state that 65% of all US oil consumption is transportation related[36]. The ability for vehicles and other liquid fossil fueled equipment to run off of hydrogen directly would eliminate the need for the final process in direct coal liquefaction, thus eliminating the efficiency losses and costs associated with it. This idea is one that the Department of Energy pushed by the Bush administration is actively pursuing. The administration is pushing an initiative called the "FreedomCAR" initiative which aims to usher in the era of hydrogen fuel cell powered vehicles. Related initiatives

[35] National Research Council, Coal Energy for the Future, p11
[36] U.S. Department of Energy: Energy Efficiency and Renewable Energy http://www.eere.energy.gov/EE/transportation.html

by the administration support hydrogen and electricity being produced in a single coal powered co-production facility[37]. The administration's interests in pursuing coal and hydrogen obtained from it are encouraged by coal's relatively high availability within the US. One of the primary goals stated is to use this form of infrastructure to become independent of oil obtained from politically unstable regions.

The progress of all these initiatives and proposals will greatly impact any prediction model for how long fossil fuels will be available for. There are literally thousands if not an infinite number of factors that will undoubtedly play a role in determining the availability of fossil fuels. In summary factors are created for many different reasons, many relating to natural phenomena, some relating to politics, some relating to technology, etc… Factors that can be controlled by government and industry are often more unpredictable than their natural counterparts.

2.2 Natural Gas

Natural gas represented 24 percent of the energy consumed and 27 percent of the energy produced in the United States in 2000. The industrial sector was the largest user of natural gas for plant operations, cogeneration of electric power, and as an industrial feedstock. Natural gas is also the largest energy source consumed in the residential sector and the fastest growing energy source for electricity generation[38].

There are various ways to store natural gas. The most common method of natural gas storage is in underground geologic formations. Two other types of underground facilities are aquifer reservoirs and salt caverns. The rate at which it can be stored and

[37] http://www.ott.doe.gov/freedom_car.shtml
[38] Cedigaz, "Natural Gas Statistics for 2001: Cedigaz' First Estimates," The Year in Review, March 28, 2002.

withdrawal can occur varies dramatically for different geologic formations. Salt domes or beds usually can be emptied in 2 to 4 weeks and refilled in 4 to 8 weeks. Depleted oil and gas formations usually have much greater capacity than salt deposits, but their injection and delivery periods usually are much longer. Most depleted field storage facilities are designed to provide for withdrawals over the 151-day heating season and refilling over the 214-day non-heating season[39].

Since the natural gas high of the early 1970s, the U.S. natural gas consumption has declined to a low of 16.2 trillion cubic feet in 1986. Since then it has increased at an average annual rate of about 2.4 percent. In 2000, total natural gas consumption in the United States reached 22.8 trillion cubic feet, 4.8 percent higher than in 1999. This occurred while the industrial consumption declined and an increase in other sectors such as electricity generation and the residential and commercial sectors[40].

In 2000 the residential accounted for 24 percent of the end-use natural gas market, while commercial accounted for about 16 percent, 39 percent was accounted for by industrial, and 21 percent by electricity generation sectors. Consumption levels in the residential and commercial sectors are the most sensitive to temperature; those in the industrial sector the least. In these three sectors, natural gas use peaks in the winter period when heating loads are high. The electricity generation sector has a marked peak in the summer months when air conditioning demand is high and a second, smaller peak in the winter[41].

---

[39] Energy Information Administration, Natural Gas Monthly, Washington, DC, March 2001.
[40] Energy Information Administration, Natural Gas Monthly, Washington, DC, March 2001.
[41] B. Campbell, "Hard at Work: Independents Plan To Go the Extra Mile," The American Oil & Gas Reporter, January 2001.

The industrial sector consumes the greatest quantity of natural gas and shows the least monthly variation in gas consumption throughout the year. Industrial gas consumption fell by an average of about 1.9 percent per year from 1996 to 2000, this despite increases in manufacturing output each year. In 1996 the U.S. industrial sector consumed 8.7 trillion cubic feet of natural gas. Then a shift toward less energy-intensive industries occurred along with an overall increase in industrial energy efficiency resulting from the introduction of new capital equipment. Industrial gas consumption dropped to 8.3 trillion cubic feet in 1999 and 8.1 trillion cubic feet in 2000. From September through December 2000, natural gas consumption in the industrial sector was down by 8 percent from 1999 levels this was partly due to a drop in the manufacturing output[42].

The residential natural gas use grew by an average of 1.0 percent per year from 1996-2000. Several factors contributed to the increase. Newly constructed single-family homes increased in average size from 1,825 square feet in 1996 to 2,225 square feet in 1999 (22 percent), and in 1999 70 percent of those new homes used natural gas for space heating, compared with 47 percent in 1986. Residential natural gas consumption in 2000 was 4.3 percent higher than in 1999, largely due to the colder winter. About 70 percent of annual residential gas consumption occurs during the winter months, which represents just 41 percent of the calendar year. In the peak consumption month, residential consumption typically has reached or exceeded industrial consumption. Changes in gas prices affect the residential sector a lot however there is usually very little they can due about during the short-term change[43].

---

[42] Natural Gas Annual 1999, Washington, DC, October 2000.
[43] Natural Gas Annual 1999, Washington, DC, October 2000

The commercial natural gas market is only about two-thirds the size of the residential market. Winter temperatures affect consumption in the commercial sector, however only 62 percent of its total annual consumption occurs during the winter months. Commercial consumption has grown much faster than residential consumption since 1986, by about 2.7 percent per year on average, and the annual total in 2000 was about 7 percent higher than the average, this was in large part because of the colder winter[44].

From 1996 to 2000 the use of natural gas for electricity production grew by an average of nearly 11 percent per year, to 3.9 trillion cubic feet in 1999 and 4.4 trillion cubic feet in 2000. The natural gas share of U.S. electricity generation rose from 13.2 percent in 1996 to about 16 percent in 2000. The sharp increase in natural gas consumption for electricity generation since 1996 has resulted from increasing demand for electricity and from the growing use of gas in new generating plants. It is also helped bye the electric utility retail sales having increased by 2.4 percent per year on average since 1995[45].

Even with the high prices for natural gas in 2000, natural gas use by electric generators increased to assist in satisfying higher demand for electricity and to supplement low levels of generation from hydropower. While total net generation increased by 96 billion kilowatt-hours, conventional hydroelectric generation decreased by 44 billion kilowatt-hours, requiring a net increase from other sources of 140 billion kilowatt-hours. About half the increase came from coal, a third from natural gas, and about 17 percent from nuclear power. From 1995 to 1999 natural gas turbine and plants were the units of choice for new plant construction because of their relatively low costs,

---

44 Annual Energy Outlook 2001, Washington, DC, December 2000, www.eia.doe.gov/oiaf/aeo/.
45 Energy Information Administration, Natural Gas Monthly, Washington, DC, March 2001.

high efficiencies, and short construction lead times. Natural gas fired capacity in the United States increased by 21.4 gigawatts. The largest increase, 6.7 gigawatts, was in 1999. Another 21 gigawatts of gas-fired generating capacity were added in 2000[46].

Natural gas prices affect both the short and long-term domestic gas production. In the short term, price surges determine the degree at which it will be utilized. In the longer term, higher gas prices provide both the primary means and incentive to invest in additional projects to either maintain or expand productivity. The reduced gas drilling activity through April 1999 did not affect production immediately. The development of new wells is important. More than 30 percent of U.S. gas production in recent years has flowed from wells that are no more than 2 years old[47].

Although gas well completions have increased steadily since April 1999, production did not respond robustly enough to satisfy the expanding market demand, because the industry initially had to overcome the prior drilling slump. Despite this handicap, domestic production increased by about 0.7 trillion cubic feet in 2000, equivalent to about 66 percent of the increase in consumption from 1999 to 2000. Production could not increase sufficiently enough to meet rising demand, so prices were driven higher[48].

---

[46] Energy Information Administration, Natural Gas Monthly, Washington, DC, March 2001.
[47] Annual Energy Outlook 2001, Washington, DC, December 2000, www.eia.doe.gov/oiaf/aeo/.
[48] Natural Gas Annual 1999, Washington, DC, October 2000

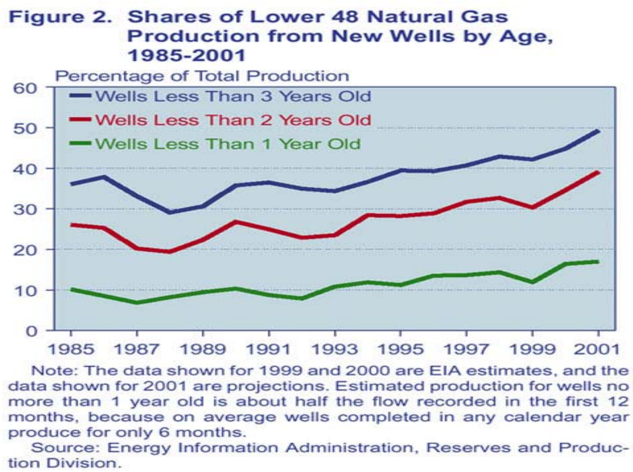


Figure 14: Production from New Wells

Natural gas well completions have outpaced oil well completions since 1993. Gas completions as a share of all successful oil and gas wells increased from 63 percent in 1998 to 72 percent in 1999. Overall, however, gas-drilling levels dropped by 13 percent between 1998 and 1999 because of low levels of cash available for investment in exploration and development. Despite a lower number of gas wells, natural gas reserve additions were higher in 1999 than in 1998, replacing 118 percent of dry gas production with new reserves[49].

[49] "Land Rig Drilling, Dayrate Boom, Produce Huge Profits for Industry," Natural Gas Week, April 30, 2001.

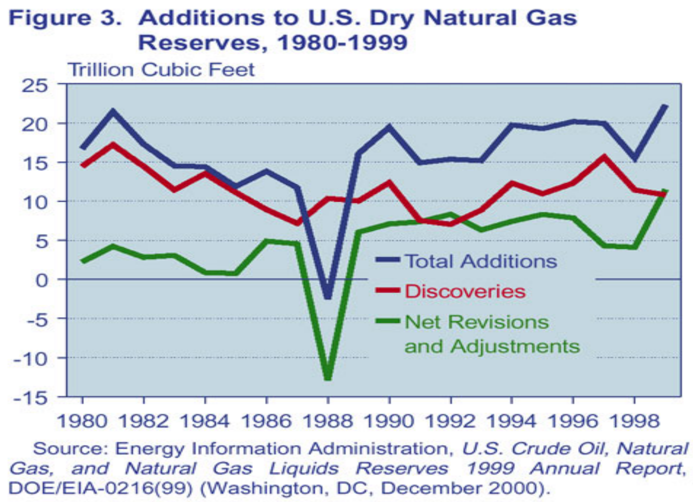


Figure 15: Dry Natural Gas Reserves

Analysis of the available data suggests that the natural gas industry behavior in 2000 was consistent with its practices of the past decade. In response to the natural gas price increases in 2000 there was an average of 720 rotary gas rigs in operation, a 45-percent increase from 1999. Gas rigs accounted for almost 80 percent of the total operating rigs. Between 1999 and 2000, both exploratory and developmental gas drilling increased significantly, by 31 percent and 45 percent, respectively. Drilling behavior is correlated with natural gas wellhead prices. Exploratory wells are wells drilled with the goal of finding new reserves. Developmental wells are wells drilled with the aim of producing from existing proved reserves. The two types of wells are vastly different in terms of their risk. In 2000, less than one-third of all exploratory wells were successful. In contrast, more than 85 percent of development wells in 2000 were successful[50].

[50] "Land Rig Drilling, Dayrate Boom, Produce Huge Profits for Industry," Natural Gas Week, April 30, 2001.

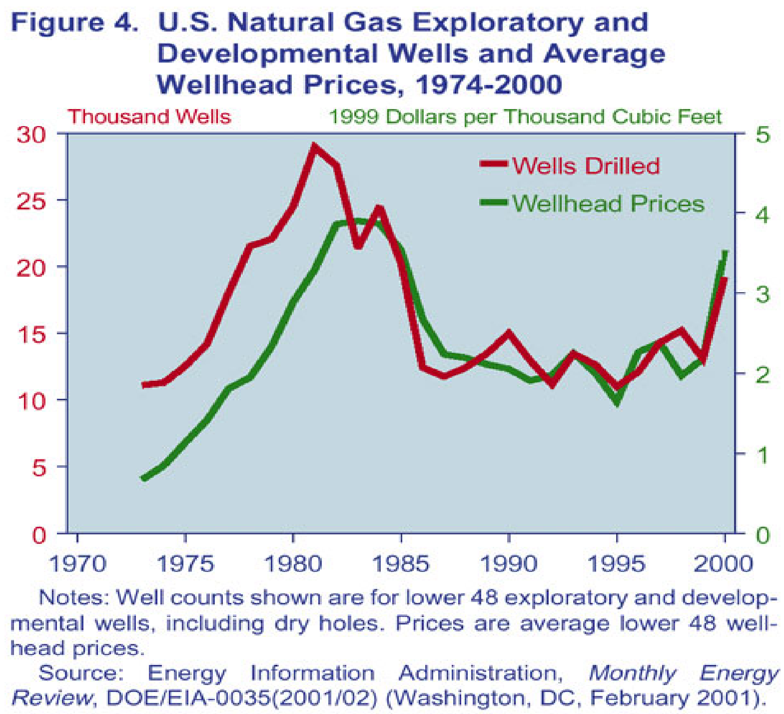


Figure 16: Natural Gas Well Prices

For the United States, international gas trade consists primarily of trade with Canada and Mexico. Net imports accounted for 16 percent of U.S. natural gas consumption in 2000. With tight domestic supplies and growing demand for natural gas, imports are an important source of supplemental supply. The United States is a net importer of natural gas from Canada, which provided approximately 94 percent of total U.S. imports in 2000. Net imports from Canada in 2000 totaled 3.5 trillion cubic feet, 5 percent more than in 1999. The weighted average price of gas imports from Canada in 2000 was approximately $3.90 per million Btu, almost 20 percent lower than the average city gate price in the United States. New pipeline capacity added in 2000 contributed to the continued growth in imports[51].

[51] Natural Gas Annual 1999, Washington, DC, October 2000

The following table shows the actual amount of imports in the second quarter of 2003 (April to June), as compared to the second quarter of 2002. The middle column is in Bcf (billion cubic feet)[52].

Canadian Imports	775.9	down 13%
LNG Imports	126.4	up 78%
Mexican Imports	-0-	same
Total Imports	902.3	down 6.5%
Canadian Exports	55.4	up 32.5%
Mexican Exports	79.4	up 18.5%
Japanese Exports	12.9	down 13.5%
Total Exports	147.7	up 19.5%

Table 3: Second Quarter Imports 2003

One method to reducing imports and meeting demand would be to increase the domestic supply. The following chart shows what would be needed from the US to meet the demand for natural gas.

[52] Department of Energy, Quarterly Report

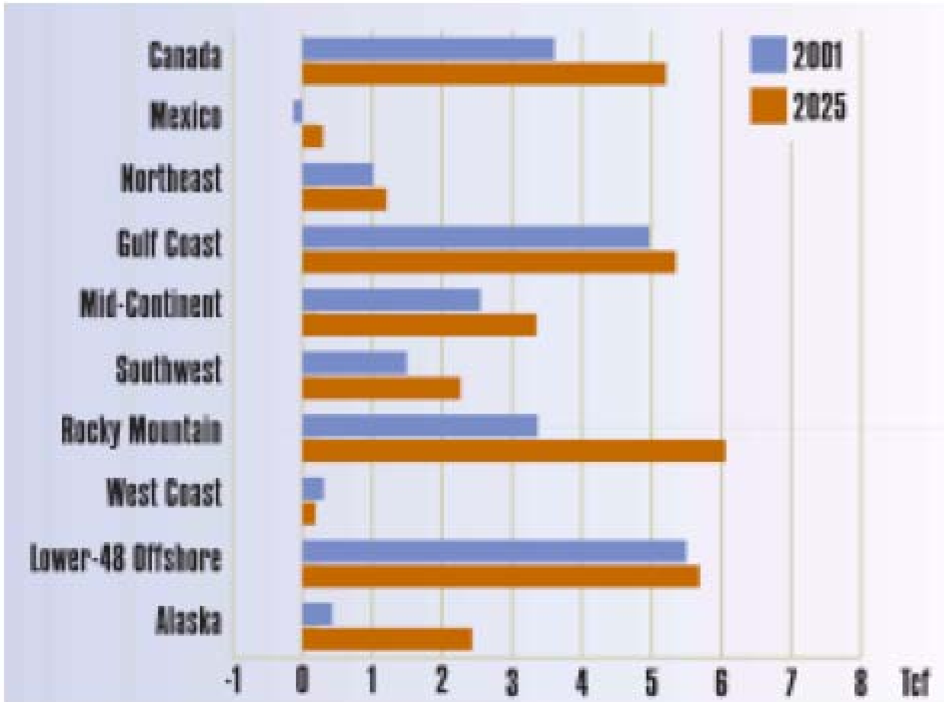


Figure 17: Potential Natural Gas Demand

Source: Natural Gas Fundamentals, From Resource to Market

The United States is a net exporter of natural gas to Mexico. Pipeline exports to Mexico totaled 110 billion cubic feet in 2000, representing an increase of almost 80 percent from the 1999 total. The United States also imported approximately 6 billion cubic feet of natural gas from Mexico in 2000, a decrease of 90 percent from the 1999 level. Both the decline in imports and the increase in exports probably are attributable to increased domestic demand and relatively flat production levels for natural gas in Mexico. The majority of new cross-border pipeline projects have been designed to supply natural gas to Mexico's power producers[53].

The ability to store natural gas is essential to the operation of the natural gas market. Withdrawals from storage provide additional gas-supply during seasonal and

[53] Natural Gas Fundamentals, From Resource to Market

short-term gas demand peaks, help keep pipelines and distribution systems in physical balance, and play an important role in management. In general storage is filled during low utilization periods and withdrawn during high utilization periods; however, increased demand for natural gas in the electricity generation sector during the traditional off-peak period in recent years has increased competition for gas to refill storage and put upward pressure on natural gas prices. In order for the storage of gas to be economical in competitive markets, the cost of storing generally should be less than the differential between the cost of natural gas in the withdrawal period and in the refill period. As of the end of October 2000, stocks stood at 2,699 billion cubic feet a new low for the beginning of the heating season in the modern era[54].

Anything that disrupts the normal cycle of supply and demand can exaggerate the price of natural gas. Such short-term disruptions can include supply disruptions such as pipeline ruptures or closings, line freeze-ups, and storage operation failures, as well as demand surges due to cold weather or fuel switching by customers. Influences on regional price patterns differ, depending on whether the markets are upstream (close to major producing areas) or downstream (close to major consuming markets). Generally when there is a wide spread change in supply and demand the prices rise in upstream markets. Changes in the upstream market in turn can affect prices in the downstream market[55].

The U.S. has a complex and extensive pipeline infrastructure for transporting natural gas from production areas to ultimate consumers. More than 165 U.S. intrastate and interstate natural gas pipeline companies operate about 278,000 miles of transmission

[54] Natural Gas Fundamentals, From Resource to Market
[55] Natural Gas Fundamentals, From Resource to Market

lines, hundreds of compressor stations and numerous storage facilities, allowing gas delivery throughout the lower 48 States. In 2000, these lines transported an estimated 22.8 trillion cubic feet of natural gas from supply sources to end-use markets. As sources of new supply have developed, new pipelines have been built and a large number of existing pipelines have been expanded to increase the level of service to a growing customer base[56].

The natural gas pipeline network has grown substantially since 1990, with more than 20 billion cubic feet per day of interregional capacity added through the end of 2000. The restructuring of the industry has changed the way in which network resources are used and has caused some shift in transportation routes and trading and shipping arrangements, but system reliability has continued to improve. Except during periods of extreme weather conditions or disruptions caused by isolated pipeline outages, there has been no sustained disruption of the network since the mid-1970s. The increasing growth in natural gas demand over the past several years has led to an increase in the utilization of pipelines and has resulted in some pressure for expansion in several areas of the country. From 1999-2000, more than 60 natural gas pipeline construction projects (35 in 1999 and 28 in 2000) were completed and placed in service in the United States. Since 1996, natural gas pipeline capacity has grown by more than 5 billion cubic feet per day annually in most years, totaling almost 30 billion cubic feet per day. Annual expenditures on pipeline development have exceeded $1.4 billion in most years[57].

[56] Gas Research Institute, GRI 2001Baseline Projection, February 2001.
[57] Gas Research Institute, GRI 2001Baseline Projection, February 2001.

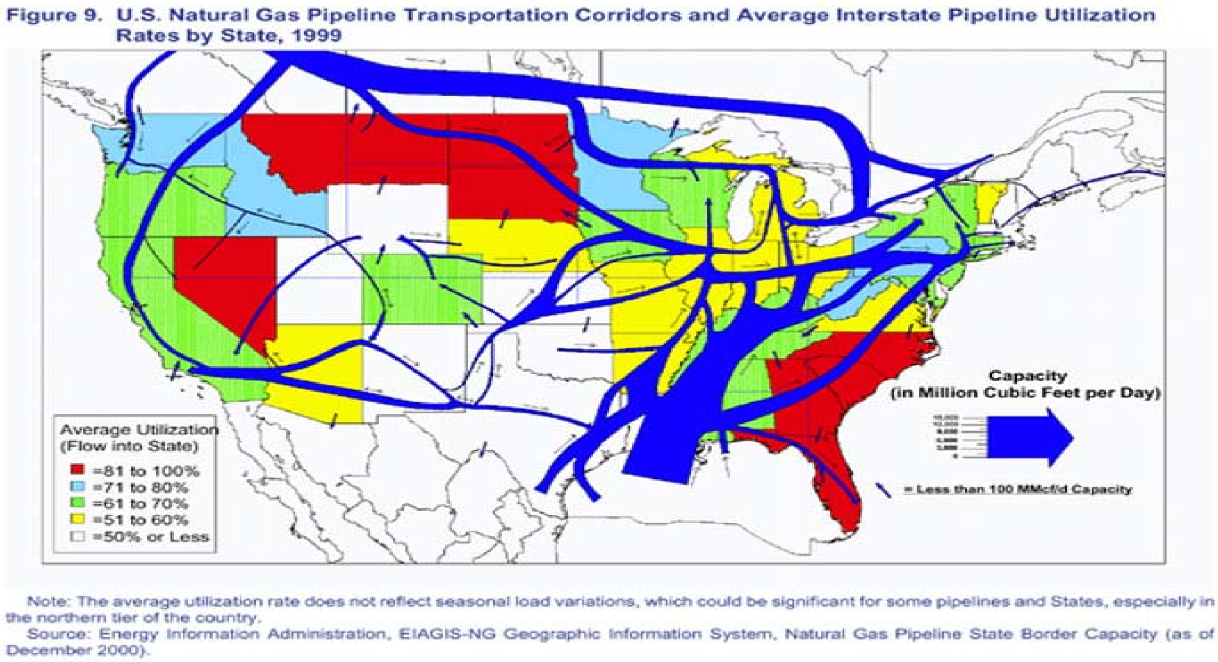


Figure 18: Natural Gas Pipelines

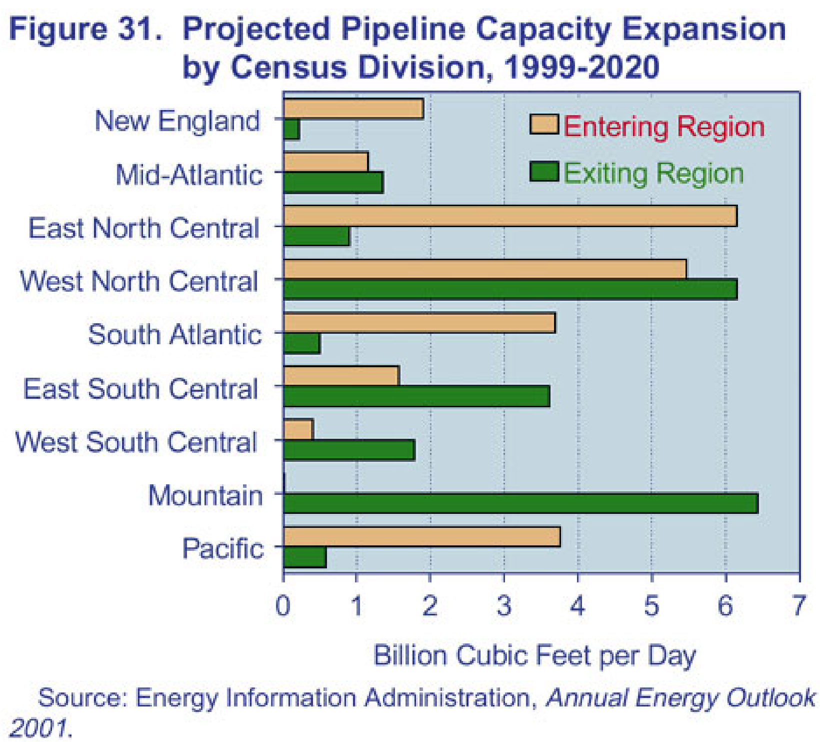


Figure 19: Project Pipeline Capacity

In March 2001, the gas rig count stood at about 900 units. EIA estimates that the number of new gas well completions in 2000 was 15,200, 45 percent above the 1999 total.

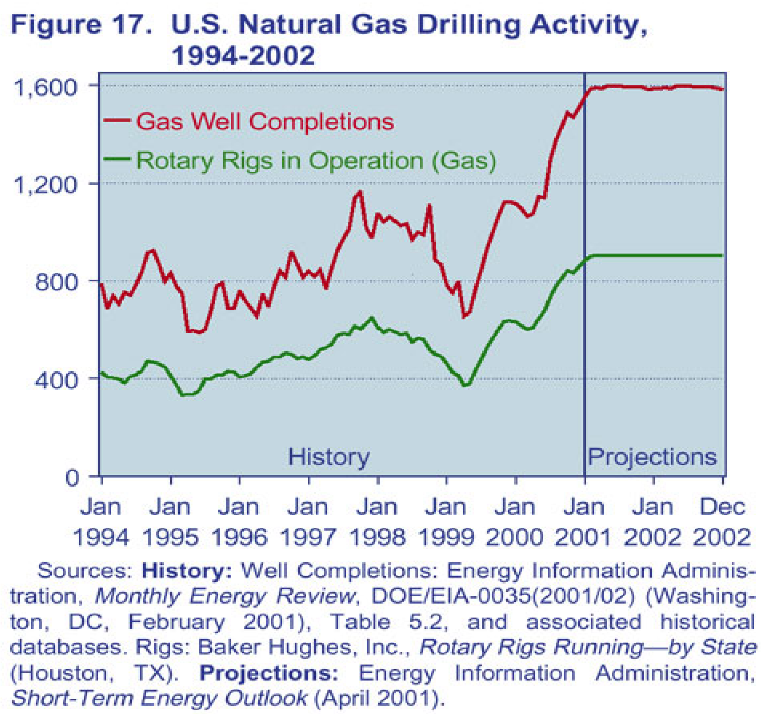


Figure 20: Natural Gas Drilling Activity

Moderating the recurrence and severity of "boom and bust" cycles while meeting-increasing demand at reasonable prices is one of the major challenges facing the U.S. natural gas industry today. The most serious short-term challenge will be to increase production rapidly enough to satisfy natural gas demand at reasonable prices. Sustained high short-term natural gas prices can prompt significant new drilling investments and bring on new supply, but they can also prompt consumers to make potentially irreversible equipment investments and switch to lower cost fuel options. Both factors tend to put downward pressure on natural gas prices[58].

Total expenditures for natural gas in the United States (calculated as the estimated sum paid for natural gas delivered to residences, commercial establishments, industrial plants, and electric power plants) rose from $105 billion in 1999 to $134 billion in 2000, an increase of 28 percent. The increase amounted to 25 percent. Total natural gas expenditures as a percent of GDP, which averaged 1.33 percent between 1995 and 1999 but moved up to 1.44 percent in 2000. Because gas resources are expected to be adequate to meet future natural gas demand through 2020, and technological progress for exploration and development is expected to be sustained, natural gas prices in the AEO forecast are expected to return to a lower price path after 2005 and gradually increase to $3.05 per million Btu in 2020. Advances in drilling technologies are expected to offset some of the cost increases associated with harder-to-find natural gas pockets and smaller pools. In the *AEO* forecast, natural gas consumption is projected to reach 31.6 trillion cubic feet in 2015 and continue to rise to 34.7 trillion cubic feet in 2020. As demand increases, pressure on natural gas supply and the transportation infrastructure are expected to grow[59].

Domestic natural gas production is expected to increase more slowly than consumption over the forecast, from 19.3 trillion cubic feet in 2000 to 29.0 trillion cubic feet in 2020. To satisfy demand of 31.6 trillion cubic feet in 2015, annual domestic natural gas production will need to increase by 7 trillion cubic feet. Thus, over the next 15 years, production increases must average over 460 billion cubic feet per year. To

[58] Annual Energy Outlook 2001, Washington, DC, December 2000, www.eia.doe.gov/oiaf/aeo/.
[59] Annual Energy Outlook 2001, Washington, DC, December 2000, www.eia.doe.gov/oiaf/aeo/.

produce 29.0 trillion cubic feet of gas in 2020, lower 48 natural gas wells drilled will have to increase from about 10,500 in 1999 to about 24,000 in 2020[60].

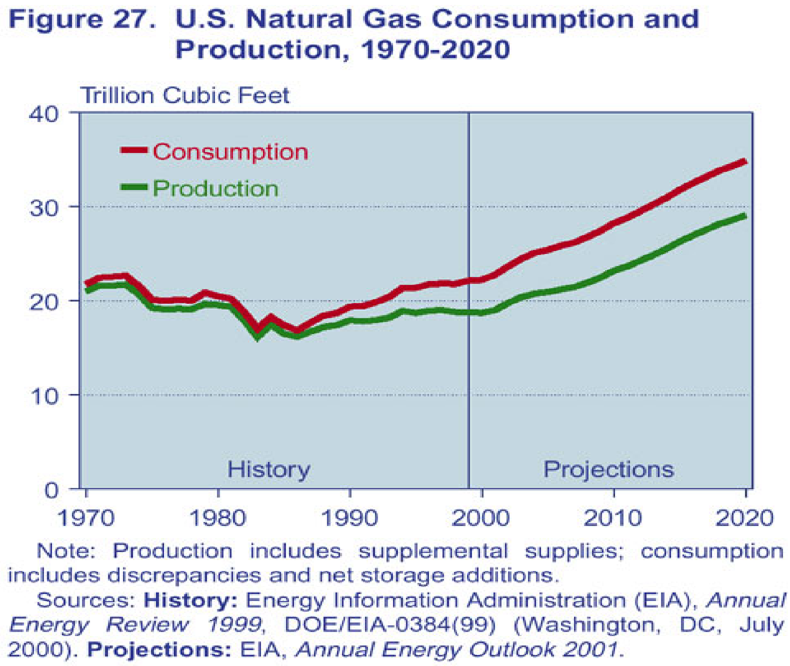


Figure 21: Natural Gas Consumption and Production

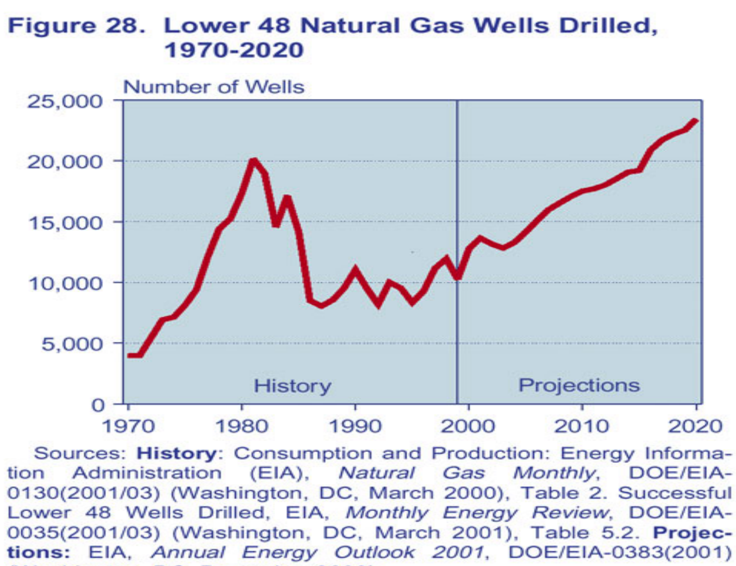


Figure 22: Natural Gas Wells Drilled

[60] Natural Gas Annual 1999, Washington, DC, October 2000.

There are several factors that can affect the supply of natural gas. One short-term factor is the availability of skilled workers. When there is increased demand for natural gas, there is a need for more workers. Since it takes awhile to properly train workers. Workers also desire higher wages.

The number of drilling rigs can also affect the supply of natural gas. Rigs take time to construct and also cost a significant amount of money. If there is a period of low demand, and then it suddenly increases, it would take too long to immediately satisfy the demand.

"The U.S. government owns more than 29 percent of all the land in the country and an estimated 40 percent of undiscovered natural gas exists on this land.[61]" The government has restricted access in federal land also. "About 9 percent of resource-bearing land in the Rockies is also off limits, and access to another 32 percent is significantly restricted."

Searching for natural gas is very costly. This creates a burden for companies that are trying to expand, or even keep up with the demand. "In fact, the National Petroleum Council estimated in 1999 that production companies will have to invest $658 billion in capital between 1999 and 2015 in order to keep pace with demand growth[62]."

---

[61] http://www.naturalgas.org/business/anaylsis.asp#liquifiedng.
[62] http://www.naturalgas.org/business/anaylsis.asp#liquifiedng.

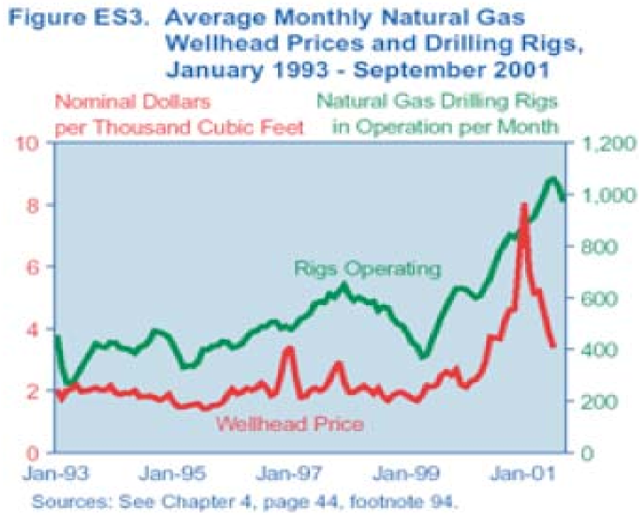


Figure 23: Average Natural Gas Wellhead Prices

Along with the increase in cost of drilling rigs, there will naturally be an increase in price. The first table shows the gradual, and then sudden increase in residential natural gas prices. The second demonstrates the same trend in the commercial market. In the past few years the industrial market price has decreased. However, the decrease isn't as significant as the increase in both residential and commercial prices for natural gas.

US Natural Gas Residential Price ($/Mcf)										
Decade	Year-0	Year-1	Year-2	Year-3	Year-4	Year-5	Year-6	Year-7	Year-8	Year-9
1960's								1.04	1.04	1.05
1970's	1.09	1.15	1.21	1.29	1.43	1.71	1.98	2.35	2.56	2.98
1980's	3.68	4.29	5.17	6.06	6.12	6.12	5.83	5.54	5.47	5.64
1990's	5.80	5.82	5.89	6.16	6.41	6.06	6.34	6.94	6.82	6.69
2000's	7.76	9.64	7.88							

Price of Natural Gas Sold to Commercial Consumers in the United States ($/Mcf)										
Decade	Year-0	Year-1	Year-2	Year-3	Year-4	Year-5	Year-6	Year-7	Year-8	Year-9
1960's								0.74	0.73	0.74
1970's	0.77	0.82	0.88	0.94	1.07	1.35	1.64	2.04	2.23	2.73
1980's	3.39	4.00	4.82	5.59	5.55	5.50	5.08	4.77	4.63	4.74
1990's	4.83	4.81	4.88	5.22	5.43	5.05	5.40	5.80	5.48	5.33
2000's	6.59	8.43	6.57							

Table 4: Natural Gas Prices

2.2.1 Natural Gas Predictions

Most studies have been done on oil consumption and oil production, but recently natural gas has been studied more because there are more problems associated with it. There are a couple main problems in securing an adequate future supply of natural gas; the first problem is the bulk of gas is located in remote areas difficult to access, which makes transport costly oppose to the relative easiness of attaining oil. Another problem facing natural gas is the amount of competition due to its preferred status as a fuel for power generators. Due to these hurtles facing natural gas meeting future needs are greater than they are for oil, any shortfalls associated with natural gas will have a greater impact on the market than oil supplies will; and the chances the U.S. will face shortfalls in gas supply is high and there is little the U.S. government can do. Since U.S. gas prices have doubled in last year it is thought the theory of gas peak may be seen soon followed by a steep decline in production, which could be catastrophic to the United States industry[63].

There has been many predictions on when the peak for the worlds natural gas will occur, but a theory followed by many was done by a man named M. King Hubbert. Hubbert used the bell curve method to say 1970 was the peak for U.S. natural gas production. Along with finding this and taking into account the average annual production rate Hubbert predicted the inflection point of the world natural gas production would occur in 2010. Since he knew the inflection point of the world oil production occurred in 1979, and the world's oil production has not peaked; hence the delay between the inflection point and the peak point of world oil production must be at least 23 years.

---

[63] http://ogj.pennnet.com/home.cfm.

Using this assumption the delay between peak point and inflection point is 23 years; this means the peak for the world's natural gas production will occur in 2033. Below is the curve that Hubbert used to describe his theory and how he came up with his dates for when energy resources would be depleted[64].

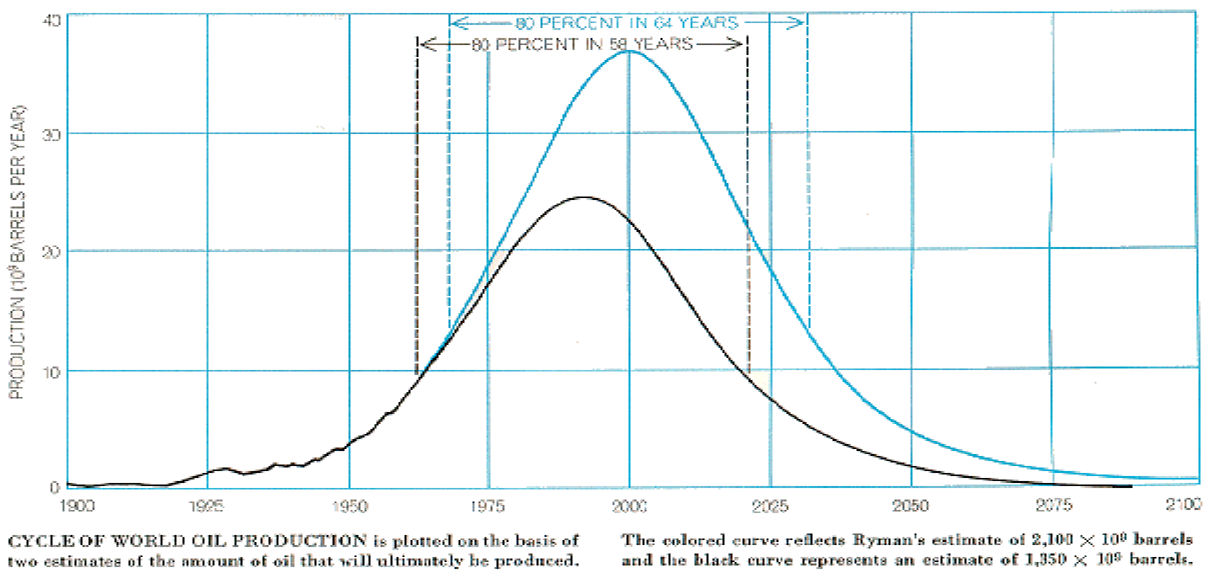


Figure 24: Natural Gas Prediction Curve

Source: www.hubbertpeak.com/hubbert/

Many believed Hubbert's model until people such as William Fisher started pointing out flaws in his analysis. Fisher said Hubbert made too many assumptions such as: he assumes amount of oil and gas is known, which it isn't. He assumes peak comes midway through production of resource, which would keep the symmetry of the curve, which isn't true. And he assumes the resources are inelastic and they don't respond to the growing technology and economy. He also says the Hubbert curve doesn't work for domestic gas because domestic gas is being explored and development continues.

64 http://ogj.pennnet.com/home.cfm.

Another critic of Hubbert's model is Michael Lynch who has criticized a couple things with his model. Lynch says with this model the global gas is very underestimated due to lack of studies on gas resources, with this underestimate of resources the peak calculation for natural gas is not correct. Another complaint he had with the curve is global gas production is based on demand; so creating a curve for production doesn't provide information about resources[65].

Assessments of gas resources have changed over time, and there is no way of knowing exactly how much gas is left due to many factors. The following graph shows how the assessments of the US's natural gas resources have grown over time.

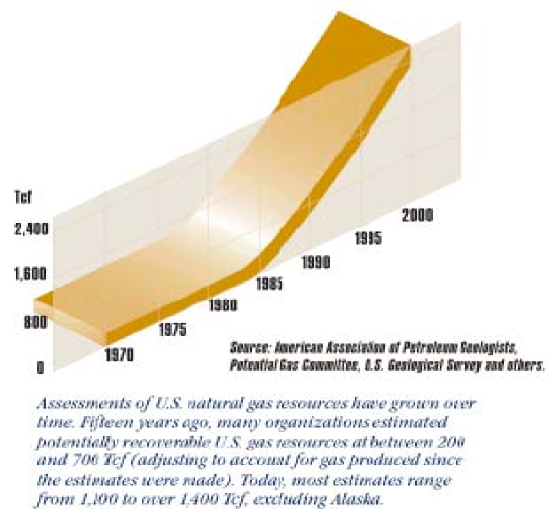


Figure 25: Growth of Natural Gas Resources

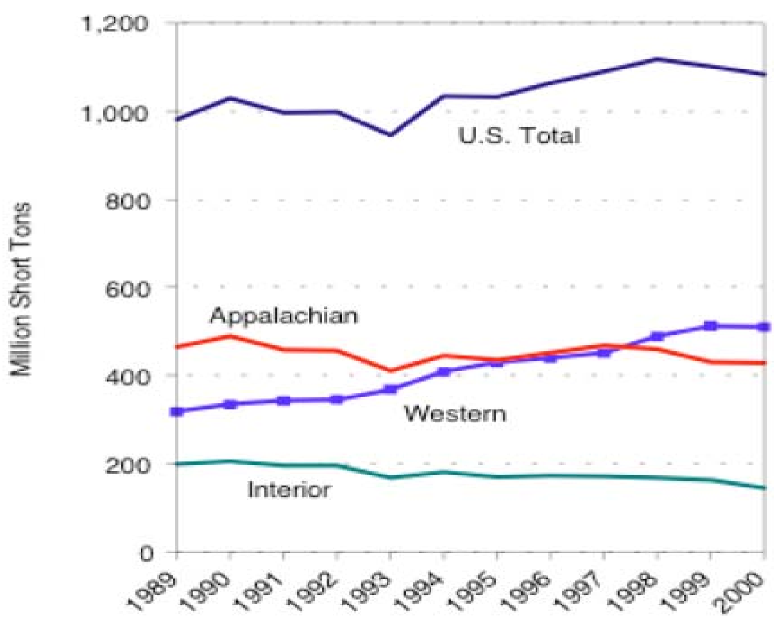
2.3 Coal

For the first time in 40 years the U.S. coal production decreased for two consecutive years, in 2000. However, production increased after that. This shows that coal has been and still is widely used in the U.S. and world today. In the U.S. 51.4% of

[65] http://www.hubbertpeak.com/hubbert/.

electricity is generated from coal power plants. Currently, coal used for electricity in the US constitutes 84% of total usage and coal used for steel purposes constitutes 16% of total usage. Also, coal reserves account for more than 85% of US known fossil fuel resources.[66]

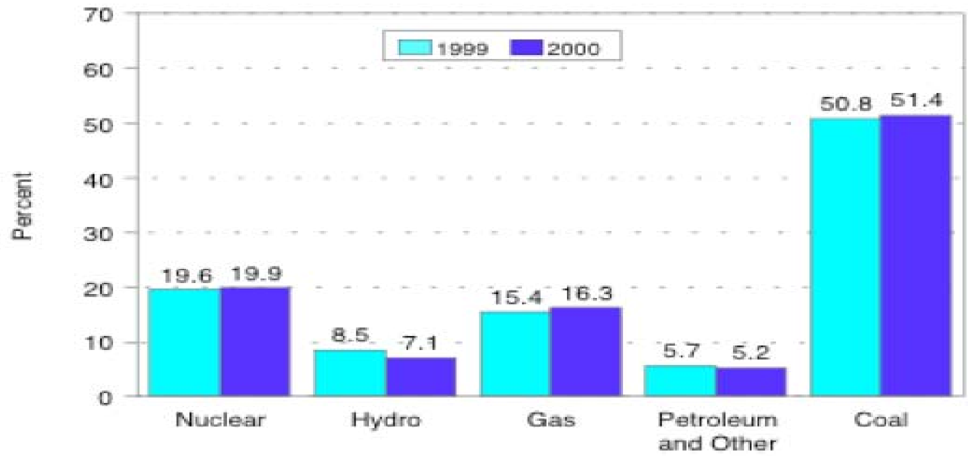
In 2000, coal production was 1,075.5 million short tons. The following graph shows the amount of coal production over the last decade.



Sources: Energy Information Administration, *Quarterly Coal Report, October-December 2000*, DOE/EIA-0121(00/4Q) (Washington, DC, April 2001); *Coal Production*, DOE/EIA-0118, various issues; and *Coal Industry Annual 1998*, DOE/EIA-0584(98) (Washington, DC, June 2000).

Figure 26: Coal Production

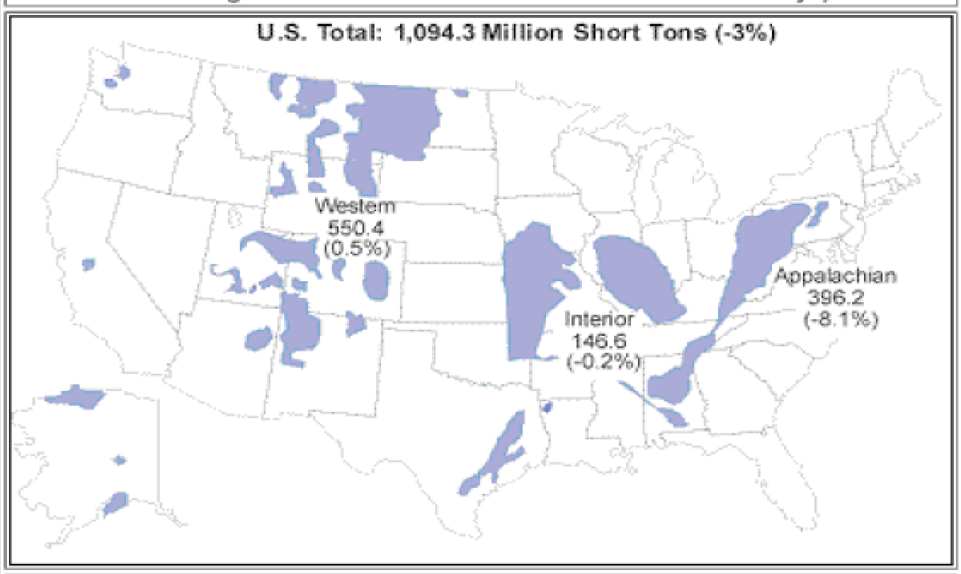
[66] Energy Information Administration, *Quarterly Coal Report,* DOE/EIA (Washington, DC, January 2002).



Sources: Energy Information Administration, *Electric Power Monthly, March 2001*, DOE/EIA-0226(01/02) (Washington, DC, March 2001); Form EIA-860B, "Annual Electric Generator Report – Nonutility," EIA-900, "Monthly Nonutility Power Report".

Figure 27: Electricity Output

Figure ES1. Coal Production by Coal-Producing Region, 2002
(Million Short Tons and Percent Change from 2001; Regional totals do not include refuse recovery.)



Source: Energy Information Administration, Annual Coal Report 2002, Table 1; DOE/EIA-0584(2002) (Washington, DC, November 2003).

Figure 29: Coal Production by Region

In the US in 2001, coal accounted for about 37% of the total installed electricity capacity. Coal plants were responsible for 52% of the electricity generated with over 965 million tons of coal being consumed for the generation of electricity.

Worldwide coal consumption is predicted to increase by 2.2 billions tons per year over the next 35 years. This translates to a 1.5% average annual rate of growth. US domestic coal is projected to grow at an average annual rate of 1.1% -1.5% through 2025. The EIA predicts that by 2025, the US electricity consumption will be at least 52% higher than today. The EIA suggests that in order to meet this increase in demand, we would require an additional 428 gigawatts of capacity.[67]

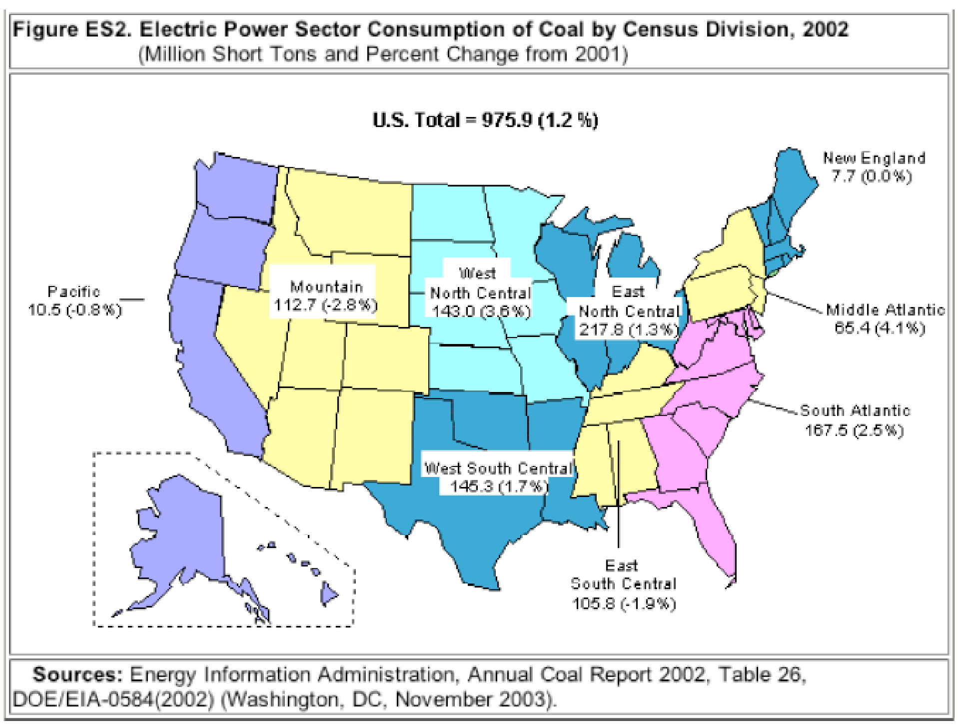


Figure 30: Electric Power Sector Consumption of Coal

[67] Energy Information Administration, *Annual Coal Report 2002,* DOE/EIA (Washington, DC, November 2003).

The main problem concerning coal consumption is pollution. Coal combustion produces two major unwanted products: excessive carbon dioxide emissions and particulate matter. Coal consumption is responsible for about 40% of total global emissions of carbon dioxide resulting from the use of fossil fuels.

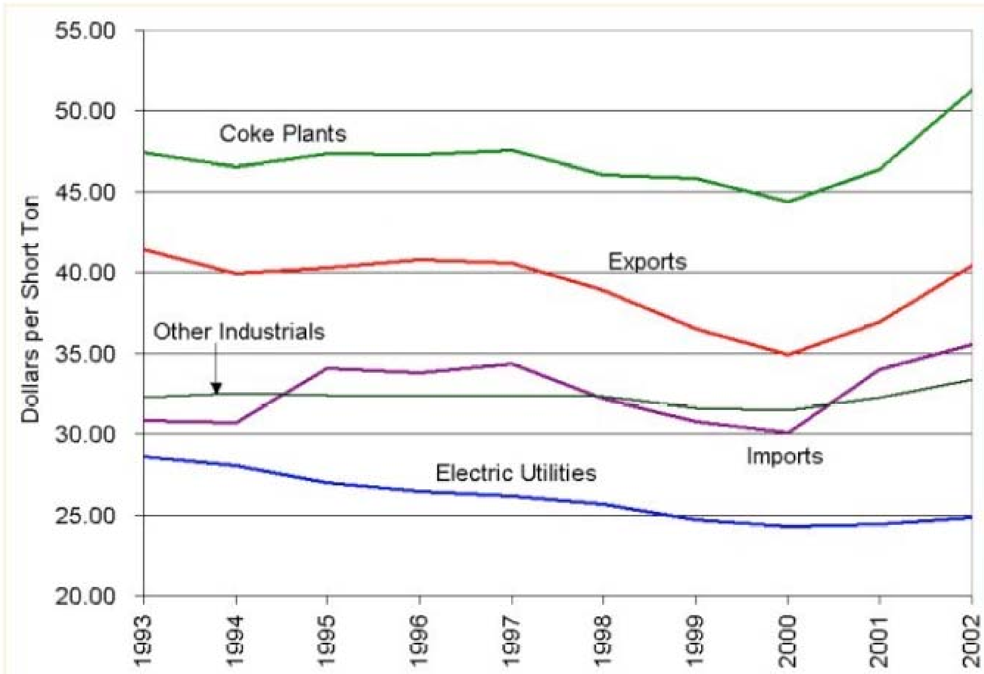
The one hundred coal plants that produce 57% of US electricity are also responsible for 93% of sulfur dioxide emissions from the entire utility industry and 80% of nitrogen dioxide emissions. In addition, coal plants are also heavy emitters of mercury, which, when consumed or absorbed, can have very serious health effects.

Currently, industry is researching methods to reduce emission to meet clean coal standards. However, these techniques are much more expensive and thus cannot be effectively implemented without massive price increases.

As more coal is used, the prices increase. On an annual basis, coal prices increased in. all sectors in 2002. The delivered price of coal rose for the second consecutive year in all sectors. The average delivered price of coal to electric utilities (a subset of the electric power sector) was $24.84 per short ton, an increase of 0.6 percent from the 2001 level of $24.68 per short ton. Even though there was a shrinking domestic coking coal market, the average delivered price of coal to coke plants increased in 2002 by 10.4 percent to reach $51.27 per short ton. The average price of coal delivered to the other industrial sector increased in 2002 by 3.5 percent, to $33.39 per short ton.[68]

The following graph shows the trends in the prices of coal over a nine year period. The cost for Electric Utilities has been on a steady downward slope, however it looks as this will change in the next several years.

[68] Energy Information Administration, *Quarterly Coal Report,* DOE/EIA (Washington, DC, January 2002).



Delivered Coal Prices, 1993-2002. This line graph shows the average delivered price per ton of coal in nominal dollars for the years 1993 through 2002 to the consuming sectors. The average delivered price per ton of coal at electric utilities in 1993 was $28.58 and was $24.84 in 2002. The average delivered price per ton of coal at other industrial plants in 1993 was $32.23 and $33.39 in 2002. The average delivered price per ton of coal at coke plants in 1993 was $47.44 and $51.27 in 2002.

Figure 31: Average Delivered Price

2.3.1 Coal Predictions

Let us consider the statement concerning the possibility of coal being able to meet domestic demand for more than 250 years. When analyzing this statement, it is important to understand the following. The capability of meeting domestic demand does not imply that doing so in this fashion is either practical or economically feasible. This prediction only considers domestic demand and not other sources mainly because domestic demand encompasses an overwhelming portion of the total demand for coal. But the most distinctive requirement is that the rate of consumption remains relatively the same. This assumption is highly improbable when considering the increasing energy usage by developing countries and the growth in world population. As quality of living increases around the world, energy use per person will skyrocket and this will require a vast increase in the production of energy.

The alarming observation concerning future coal technologies is that many people are convinced of its extreme potential to solve our energy problems because of the "vast amount of reserves". This is troublesome because we have established the fact that coal is a limited resource. No matter how long we predict these resources will last, using a non-renewable source of energy is not a long-term solution to our energy problems. Thus, even though coal has the potential to address our short-term needs assuming that pollution outputs can be reduced, it is not a source that will sustain our civilization's energy demand in the absolute future.

2.4 Environment

Among other things, the usage of fossil fuels is one of the main factors that contribute to greenhouse gases and global warming. Currently the usage of fossil fuels is on the rise. Due to that, there is an increase in air pollution and greenhouse gases.

"The greenhouse effect is a naturally occurring process that aids in heating the Earth's surface and atmosphere. It results from the fact that certain atmospheric gases, such as carbon dioxide, water vapor, and methane, are able to change the energy balance of the planet by being able to absorb long wave radiation from the Earth's surface."[69]

Often, people mistake the green house effect for global warming. Global warming happens because of the greenhouse effect, but without the greenhouse effect earth would be inhabitable. If there were no greenhouse gases the planet's average

[69] http://royal.okanagan.bc.ca/mpidwirn/atmosphereandclimate/greenhouse.html

temperature would be 253° K (-4.3° F). Thanks to the greenhouse effect, earth's average temperature is 288° K (58.7° F).[70]

The problem with pollution is that it adds more gases and chemicals to the atmosphere. These extra gases and chemicals intensify the greenhouse effect. Scientists say that is the cause of global warming. Some of those gases are carbon dioxide, methane, and nitrous oxide. Of those, Carbon dioxide account for more than half. "Different industries and the burning of fossil fuels release carbon dioxide into the air. Carbon dioxide is a greenhouse gas and collects in the atmosphere. This addition of more and more carbon dioxide is making the layer of gases thicker and thicker."[71] Since this amount of carbon dioxide is higher than what is natural, trees and plants are not able to convert it into oxygen as quickly. This is why there may be thicker layers of gases that could potentially cause problems in the future.

Most experts agree that global warming will increase temperatures worldwide. However, it is uncertain how much of an increase in temperature will happen. It has been estimated that up to a 3° K (5° F) increase could occur by the end of this century.[72] This potential temperature increase could cause changes in climate, since it upsets the delicate balance of nature. Without preventative measures, this project temperature increase can only get worse.

While many agree that there will be global warming, there is still a lot of uncertainty. Some parts of the earth could become dryer. Others believe there could be more precipitation. Another common prediction is that the polar ice caps could eventually melt. Many people think that water levels may rise due to the melting of polar

---

[70] http://www.science.gmu.edu/~zli/ghe.html
[71] http://mysite.freeserve.com/pollution/page3.html
[72] http://www.science.gmu.edu/~zli/ghe.html

ice caps. This could alter several things. Mainly it would cut down on coastal areas. It can also affect industries such as fishing or whaling.

The following graph[73] shows the exponential increase in carbon dioxide, recorded at Mauna Loa.

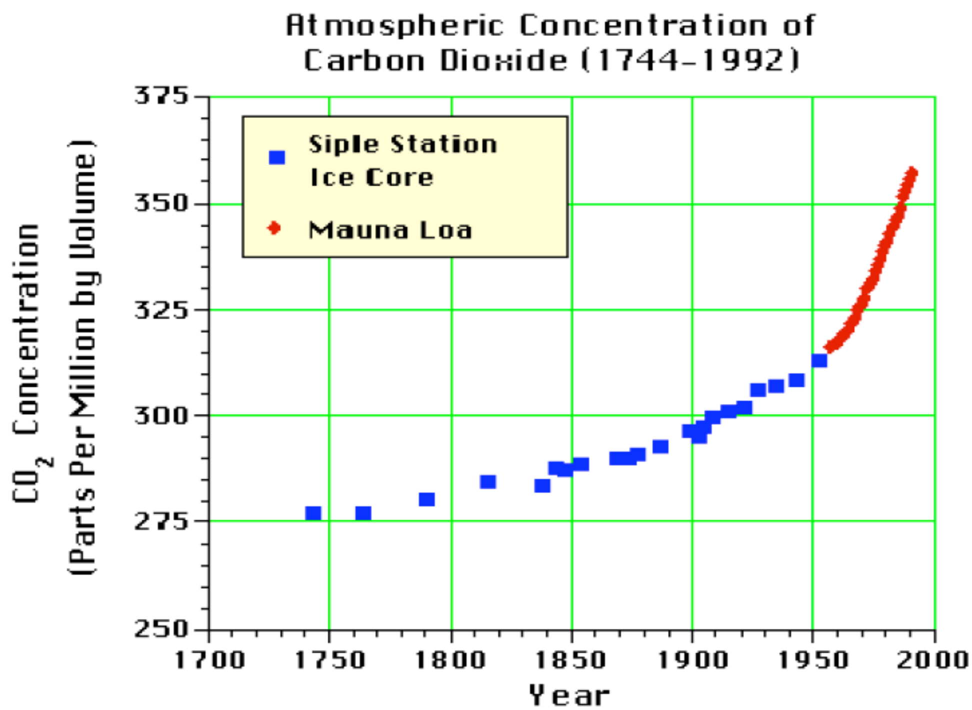


Figure 32:Atmosperic Concentration of Carbon Dioxide

Source : http://www.epa.gov/air/aqtrnd00/globwarm.html

The need for energy is always increasing. Currently most of the world's power plants are fossil fuel based. There are also an increasing number of cars on the road. All vehicles run from fossil fuels. This includes electric cars, in a way, since they need to be charged, usually from an outlet that is powered by a fossil fuel power plant.

[73] http://royal.oakangan.bc.ca/mpidwirn/atmosphereandclimate/CO2gas.html

Energy and transportation are the two predominant uses of fossil fuels. As more fossil fuel is being burned each year, there are more greenhouse gases released into the atmosphere. Of those gases, carbon dioxide takes up the highest percentage. The following chart[74] shows the amount of carbon dioxide compared with the other greenhouse gases in 1998.

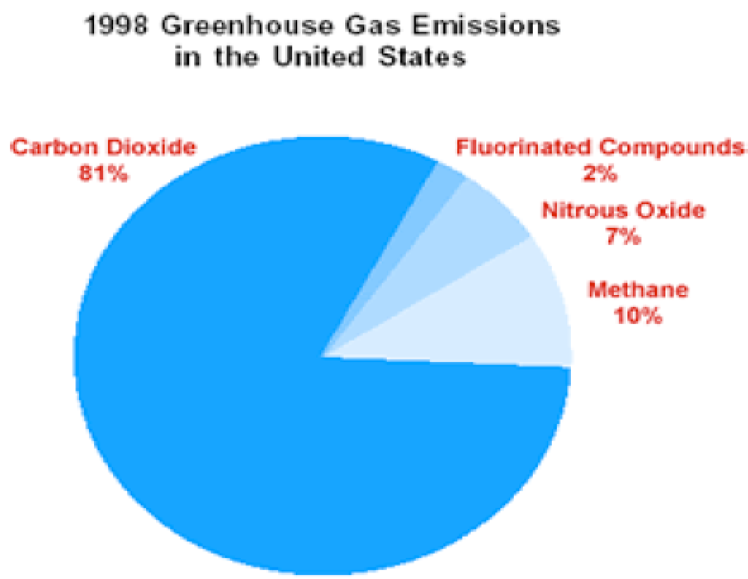


Figure 33: Greenhouse Gas Emissions

Source: http://www.hc-sc.gc.ca/hes-sesc/air_quality/respiratory.htm

The high amount of greenhouse gases leads to poor air quality. Bad air quality is not beneficial to the environment, but the main concern is how if affects humans. Poor air quality can contribute to circulatory and respiratory problems for people.

The respiratory system is most affected by air pollution. It is obvious since we are directly breathing in the air. "Airway tissues which are rich in bioactivation enzymes

[74] http://www.epa.gov/air/aqtrnd00/globwarm.html

can transform organic pollutants into reactive metabolites and cause secondary lung injury. Lung cells also release a variety of potent chemical mediators that may critically affect the function of other organs such as those of the cardiovascular system"[75]

Some diseases that air pollution can contribute to range from the common cold, to much more serious conditions such as lung cancer. Bronchitis and pneumonia are fairly common infections. They can't be blamed completely on air pollution, but air quality is a factor. One very common disease is asthma. This can be triggered by allergies, or simply by poor quality air. Asthma is becoming increasingly more common. A 10 year study of children funded by the California Environmental Protection Agency's Air Resources Board (ARB) and conducted by the University of Southern California (USC) has produced the strongest evidence to date that ozone can cause asthma in children.[76]

Increasing the quality of air is not only important for the environment, but also for human to live healthy lives. One way to improve the quality of the air is to cut down the amount of fossil fuels we burn.

Fortunately, there is a widespread effort to clean up the air and reduce emissions. In August 2001, New England governors and eastern Canadian premiers adopted the Regional Climate Change Action Plan. This plan hopes to reduce greenhouse gas emissions the levels they were at in 1990 by the year 2010. The ultimate goal is to reduce them to at least 10% below the 1990 levels by the year 2020.

Some states are even more ambitious. New Hampshire has declared carbon dioxide a pollutant. This allows them to regulate the CO_2 emissions from power plants, which they want to start doing. Massachusetts has already capped the carbon dioxide

---

[75] http://www.hc-sc.gc.ca/hes-sesc/air_quality/respiratory.htm
[76] http://www.sinusnews.com/Articles2/air-pollution-ozone-asthma.html

emissions of six major plants. California has begun regulating the CO_2 emissions from vehicles. Others states are planning to take similar measures also.

Cities are also taking an initiative and are reducing pollution. 138 cities in the United States, which make up 16% of the population and account for 16% of the pollution in the US, participate in the International Council for Local Environmental Initiative's Cities for Climate Protection Campaign. They have already reduced emissions by an estimated 10.4 million tons. Thirty-eight cities have set emissions targets for 2010 to be 20% below their 1990 emissions levels.[77]

Many technologies have the potential to reduce both generating costs and carbon emission avoidance by 2020. One study showed that by 2020, the global electricity industry "has the potential to reduce its carbon emissions by over 15%…together with cost saving benefits compared with existing generation." (Sims, Rogner, Gregory)

Every year, global electricity accounts for the release of over 7700 million tons of carbon dioxide to the atmosphere (2100 Mt C/yr). This is about 37.5 % of the total annual amount of CO_2 emitted by the world. If business continues to grow as it has in the past, the annual carbon emissions associated with electricity generation, including combined heat and power cogeneration, is projected to surpass the 4000 Mt C level by 2020 (IEA, 1998):

[77] Kates, Robert & Wilbanks, Thomas, "Making the Global Local", Environment, April 2003, Volume 45, Number 3.

Table 1
Past and projected global production from the electricity generating sector (TWh/yr) and average C emissions per kWh due to fuel switching and efficiency gains

	1971	1995	2000	2010	2020
Coal	2100	4949	5758	7795	10,296
Natural gas	691	1932	2664	5063	8243
Oil	1100	1315	1422	1663	1941
Nuclear	111	2332	2408	2568	2317
Hydro	1209	2498	2781	3445	4096
Other renewables	36	177	215	319	433
Total	5247	13,203	15,248	20,853	27,326
Average GHG emissions (g C/kWh)	200	158	157	151	147

Source: Adapted from IEA (1998).

Table 5: Global Production of Electricity

It is quite difficult to both monitor and control GHG emissions when they are being produced by a multitude of vehicles and personal appliances. Production can be controlled much more effectively and efficiently when dealing with a limited number of centralized power stations. With this in mind, if we intend to find methods to reduce GHG emissions, the electricity industry is one major area where changes must be made.

There are many general methods to reduce CO_2 emissions. With technological improvements, there is the possibility that the present typical power station efficiency can improve from 30% to more than 60%. If coal were replaced with gas, it would allow the opportunity to use advanced combined cycle gas turbine (CCGT) technologies to lower carbon emissions per kWh of electricity. Also, decarbonization of reactants used during combustion for electricity generation or decarbonization of products emitted after combustion for electricity generation has the possibility to reduce GHG emissions.

In relation to world electricity production, coal has the largest share at 38% followed by renewable (principally hydro power) at 20%, nuclear at 17%, natural gas at

16%, and oil at 9%. Currently, new technologies are being produced that improve the conversion efficiencies of carbon based fuels. With these technologies coming into use, average carbon emissions per unit generated are projected to decline over time.

Some of the electric utilities and power companies have decided to introduce new opportunities that provide renewable energy or energy efficiency assistance to energy consumers. One of the apparent goals of this decision by companies is to distinguish themselves from other providers to give their products more favorability.

One set of findings suggests that greater information about energy resource options will increase the public's willingness to pay additional money for both renewable energy and greater energy efficiency.

The study's surveys indicated that many residential energy consumers in the US are "willing to pay a premium for electricity from generation sources that have a minimal adverse impact on air quality" (Zarnikau). The amount of information that was provided about the energy opportunities significantly changed the distribution of reported willingness to pay for these resources. In general, many people were willing to pay a small amount for the alternative energies, but few were willing to pay larger amounts.

It is important to note that even if this information constitutes a plausible method to reduce emissions, industry may not adopt them for personal or financial reasons. In business, the driving force is profit maximization and this fundamental fact is what prevents the adoption of renewable technologies into society at this point in time. If there exists something cheaper that has the same function, the trend is that people will buy the cheaper item.

The irony lies in the fact that since our society is highly driven on competition and money, which prevents many of these technologies from gaining drive in markets, even if consumers know that renewable energy technologies benefit the environment and are the inevitable market of the future, why buy it now if there's something cheaper? Until prices decrease, or our values change, the problems will not disappear.

Conclusion

It is easy to see that there are many arguments for the development and usage of renewable energy. The main and most important reason is that fossil fuels will run out. If the world continues to be dependant on these energy sources, it will inevitably face a major crisis in the not-so-far future. The rate of consumption and demand are increasing. So, unless there is a major fossil fuel discovery, which is very unlikely, fossil fuels will be used up shortly.

As the demand increases and supply diminishes, prices will only increase. During the last several years of fossil fuel's existence, energy will be too expensive for many people to afford. Renewable energy plants may be expensive to build, but looking at the long run, seem to be the best solution. Once renewable energy is implemented more and more, the cost of building the plants will decrease and the actual cost of the electricity will have no need to rise.

Another reason to switch to renewable energy is the environment. Burning fossil fuels create many pollutants. These contribute to poor air quality, smog, green house effect, and it can even get into out water supply. These pollutant can be greatly reduced or eliminated with the use of renewable energy.

Simply put, fossil fuels are over 100 year old technology. There are many technological advancements being made today. Fossil fuels need to be a thing of the past, not a crutch for the world. The sooner renewable energy can replace fossil fuels, the better the world will be.

3- Alternative Energy Sources

Alternative energy sources are the key to meeting the future energy demands. The continuing decline in fossil fuels available along with an increasing demand for energy; makes finding alternate energy sources that are viable more prominent. The benefits to these alternative energy sources are that they are renewable. The success of society and the hopes for its' continuing development hinges on the advances made in the implementation of alternative energy sources. Solar and Wind are the two major forms of renewable energy that are being researched to solve this problem. Other ideas are biomass, solar mirrors, geothermal, improved efficiency, and hydroelectric.

Using windmills to produce energy is an idea that has been around for centuries. There have been numerous advances made in their design in order to generate more power. Countries are beginning to build wind farms in which the wind will be harnessed and translated into usable energy. Governments are passing laws that require an increase in the amount of energy produced by wind. The United States potential for producing wind energy is huge; it shows that wind power could be used to meet more then half the nation's energy demand. Wind energy is a becoming more and more popular in today's society because it is environmentally friends, a viable alternative to fossil fuels, and could hold a key to solving the energy crisis.

Solar energy is the one of the fasted growing alternative energy sources. Solar power can be produced in three different ways; they are by using power towers, dish engine systems, and parabolic troughs. The price for producing solar power is starting to fall making solar energy a more realistic option for the future. With the right technology and proper location solar power could be used to provide and ample amount of the countries energy.

Solar and wind energy are not the only two alternative energy sources that provide energy to our country, hydroelectric, biomass and geothermal energy are currently being used. Hydroelectric power is not a prominent as it once was. It would be impossible to use water as the sole source energy. Biomass makes up only a small portion of the energy and it would require too much material and money to implement a plan in which biomass was the major source of energy. Geothermal energy is the energy that is obtained from the naturally occurring heat below the earth's surface. Currently this is the third most used renewable energy. However, this has a lot of potential, especially in the western part of the United States.

There is one option for the future that could significantly help solve the world's energy crisis. This option is called space mirrors. The space mirrors are still in the early state of development. With advances in technology and space exploration the thought of implementing this is not as outrageous as it sounds. The space mirrors could provide the world with enough solar power to meet its growing energy demand.

The energy generated by the specific renewable energy system uses transmission lines to transport the power. The efficiency of the transmission lines can help improve the amount of energy transfer. Currently, one of the main issues with alternative energy sources is that too much power is lost along the line. The change to super conducting lines shows little to no benefit in improving the efficiency of the line. An improvement in the efficiency of the transmission lines would have a major impact on alternative energy sources. Improved transmission lines will make it easier to transmit the amount of energy produced without having significant losses along the line.

3.1 Wind Energy

Wind energy is one of the most important developing sources of energy in the world today. Between 1991 and 2002, global wind energy production capacity was substantially improved from 2 GW to over 31 GW. The average annual rate of growth during this time was roughly 26%. During this time both prices of wind turbines and cost of wind-generated electricity have been reduced. According to one source, "the wind energy potential on Earth is huge and enough, in principle, to meet all the world's electricity needs[78]."

This graph shows the increase in the world's ability to control wind power to produce electricity.

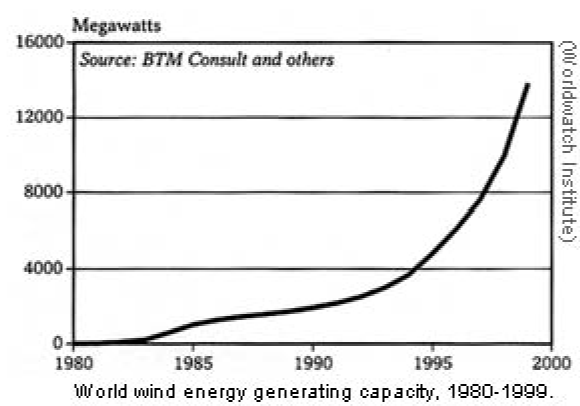


Figure 34: World Wind Energy Generating Capacity

Source: http://www.riverdeep.net/current/2000/11/112200_worldwatch.jhtml

[78] Sesto, Ezio; Casale, Claudio, 1998. "Exploitation of wind as an energy source to meet the world's electricity demand".

Windmills have come a long way from when they were first developed in 200 B.C., and extensive time and technology has been put into the modern day windmills. The first use for the mills in the early days was for grinding grain and pumping water, but since then we have harnessed the use of wind for a more important job, to produce electricity. Along with the different uses of wind, the blades and mills themselves have changed tremendously; the first turbines, which are not used today, were vertical axis turbines. There were two different types of vertical turbines, a Savonius Turbine first developed in Finland and the Darrieus Turbine developed in France in the 1920's. The Savonius Turbine was used for grinding grain and pumping water but due to its slow speed of rotation it is not efficient for producing electricity. The Darrieus Turbine is described as looking like an eggbeater and it rotates in and out of the wind, also due to its slow speed it cannot be used for producing energy. As of today we use horizontal axis, seen on the next page, which are turbines that look like a big fan, these big fans sit atop a tall tower and usually have 2 to 3 blades on them. These turbines can spin at a very fast rate, which means they can produce energy and electricity.[79]


[80]

Figure 35: Windmills

[79] http://www.sciam.com/search/search_result.cfm
[80] http://www.sciam.com/search/search_result.cfm

3.1.1 Wind Turbines

Wind electric turbines generate electricity for homes and businesses and for sale to utilities. There are two basic designs of wind electric turbines: vertical-axis, or "egg-beater" style, and horizontal-axis machines. Horizontal-axis wind turbines are most common today. Most manufacturers of utility-scale turbines offer machines in the 700-kW to 1.8-MW range. In the future, machines of larger size will be available, although they will probably be installed offshore, where larger transportation and construction equipment can be used. The following chart depicts a variety of turbine sizes and the amount of electricity they are each capable of generating.

	1981	1985	1990	1996	1999	2000
Rotor (meters)	10	17	27	40	50	71
KW	25	100	225	550	750	1,650
MWh	45	220	550	1,480	2,200	5,600

The output of a wind turbine depends on the turbine's size and the wind's speed through the rotor. Wind turbines being manufactured now have power ratings ranging from 250 watts to 1.8 megawatts (MW). A 10-kW wind turbine can generate about 16,000 kWh annually, more than enough to power a typical household. A 1.8-MW turbine can produce more than 5.2 million kWh in a year, which is enough to power more than 500 households. The average U.S. household uses about 10,000 kilowatt-hours of electricity each year. An example of this is, a 250-kW turbine installed at the elementary school in Spirit Lake, Iowa, provides an average of 350,000 kWh of electricity per year, and more than is necessary for the 53,000-square-foot school. The school uses electricity from the utility at times when the wind does not blow. This project has been so successful that the Spirit Lake school district has since installed a second turbine with a capacity of 750 kW.

The capacity factor is one element in measuring the productivity of a wind turbine or any other power production facility. A capacity factor of 40% to 80% is typical for conventional plants. A wind plant is "fueled" by the wind, which blows steadily at times and not at all at other times as a result of this most modern utility-scale wind have turbines operated with a capacity factor of 25% to 40%. It is possible to achieve much higher capacity factors by combining wind with a storage technology, such as pumped hydro or compressed air energy storage (CAES). While the capacity factor is almost entirely a matter of reliability for a fueled power plant, it is not for a wind plant; for a wind plant, it is a matter of economical turbine design. The most electricity per dollar of investment is gained by using a larger generator and accepting the fact that the capacity factor will be lower as a result. Wind turbines are fundamentally different from fueled power plants in this respect.

There have been considerable studies done on wind turbines and the aerodynamics of the blades that are associated with it. With the use of certain physics formulas and the study of wind tests, wind blade efficiency is better than ever. With these tests and derivation of equations engineers have been able to come up with certain formulas and theories such as the wind blade theory, to explain what is going on when a turbine is in use.

3.1.2 Wind Blade Theory

If you take a look at the wind blade theory you can see how much wind energy is actually useful. If you start by looking at Euler's Theorem you can see the formula of the force on the wind blade, which is:

1) $F = rA_T V_T(V_1 - V_2)$,

V_1 is the inlet wind velocity, V2 is the outlet wind velocity, A_T is the swept wind area around the blade, V_T is the average wind velocity which rotates the blades, and r which is the density of the air.

Now if you take a look at the formula below you can see the power on the wind blade axle, which affects the overall efficiency.

2) $P = FV_T = rA_T V_T^2(V_1 - V_2)$.

The power comes from the wind energy and is proportional to the wind velocity. If you double the wind velocity the power will increase eight times; which is because the power is proportional in the third order of the wind velocity.[81]

The kinetic power of the wind before it enters or leaves the blade is:

3) $D_{EK} = ½ m_A(V_1^2 – V_2^2)$

where m_A is the mass flow of the wind.

Assuming there are no losses, the power that drives the wind blade is equal to the kinetic power exchange, hence:

4) $P = D_{EK}$.

By combining your first four equations you derive:

---

81 http://www.ingenta.com/isis/searching/Search/ingenta;jsessionid=2m77ctg5nnc8s.crescent?form_name=home&title=aerodynamics+of+wind+turbines&database=1

5) $rA_TV_T^2(V_1 – V_2) = ½ rA_TV_T(V_1^2 – V_2^2)$.

And now from this equation you can get:

6) $V_T = (V_1+V_2)/2$.

With this equation you can combine it with equation 2 to get the power equation to look like:

7) $P = ¼ rA_T(V_1^2 – V_2^2)(V_1 + V_2)$

By using this previous equation you can get the wind velocity V2 for the maximum power that is obtained, which is:

8) $dP/dV_2 = ¼ rA_T(V_0 + V_2)(V_0 – 3V_2)$

And now the maximum wind velocity is:

9) $V_2=V_0/3$.

Now if you combine equation 9 and equation 7 you are given the maximum power:

10) $P_{max} = {}^8/_{27}\, rA_TV_0^3$

Finally if you combine equation 10 with equation 2 you are given the percentage of existing wind energy that can be converted into useful wind energy.

11) $P_{max}/D_{EK}=0.59$

This shows the result is 59% useful wind energy.

Through many derivations you can see how engineers have explained what is going on when it comes to the aerodynamics of wind blades, and with this they use their results to improve the efficiency of the overall turbines. This Wind blade theory is just one of many ways engineers have used to improve the wind turbines to what we see today. [82]

3.1.3 Economics of Wind Power

The cost of wind energy is declining steadily. Over the last 20 years, the cost of electricity from utility-scale wind systems has dropped by more than 80%. This technology has been focused on a lot in the past 20 years and it is the fastest growing technology in the world today. Although it is the fastest growing technology windmill companies are having problems finding investors to produce wind farms, these investors aren't sure this is an efficient source of energy and they want to see how it turns out in other countries before they invest huge amounts of money into them. This skepticism has put the U.S. behind other countries that are much farther along with their development of windmill farms. U.S. only has .5% of their energy from windmills oppose to Denmark who has 12% of their energy from windmills and Europe who has predicted they will have 50% of their energy from wind by 2030; due to increased concentration of windmill development and future projects in construction. If the U.S. gets enough investment and more interest in windmill design it is said they could quickly go from .5% to 12% wind energy; based on the rate of development in countries with advanced windmill development. The U.S. has not put as much research into windmills as other countries but they have not totally ignored wind energy[83].

In the early 1980s, when the first utility-scale turbines were installed, wind-generated electricity cost as much as 30 cents per kilowatt-hour. Based on its knowledge

---

82
http://www.ingenta.com/isis/searching/Search/ingenta;jsessionid=2m77ctg5nnc8s.crescent?form_name=home&title=aerodynamics+of+wind+turbines&database=1
83 www.sciencedirect.com

of current market conditions, the American Wind Energy Association (AWEA) estimates the levelized cost of wind energy at many of the larger sites as less than 5 cents per kilowatt-hour, not including the federal production tax credit (PTC). The credit applies to the first 10 years that a new wind plant operates, and can reduce the levelized cost of wind by about 0.7 cents/kWh over the plant's 30-year lifetime. It is clear that wind's costs are now in a competitive range with those of mainstream power technologies. The National Renewable Energy Laboratory (NREL) is working with the wind industry to develop a next generation of wind turbine technology. The products from this program are expected to generate electricity at prices competitive with natural gas turbines, the least expensive conventional power source.

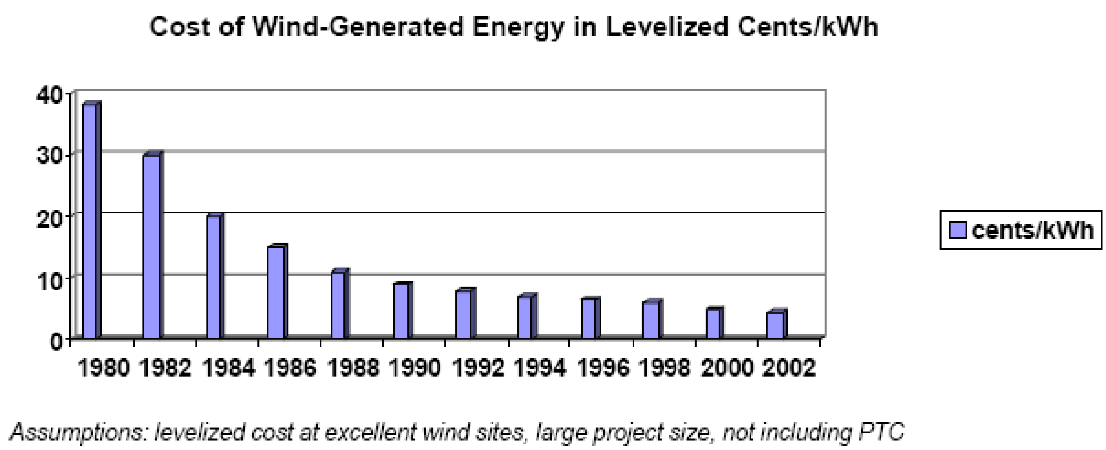


Figure 36: Cost of Wind Generated Energy

Source: National Renewable Energy Laboratory

In 2001, over 6,500 MW of wind energy generating capacity was added to the world supply, which raised total wind energy generating capacity to 24,000 MW. This addition created roughly 7 billion dollars in sales. This increase is the largest ever in terms of global wind energy additions. In comparison the capacity added in 2000 was 3,800 MW and in 1999 was 3,900 MW.

Over 70% of the world's wind power is produced by European countries. In 2001, they constituted two-thirds of the total additions. As a comparison of countries, of the total added wind energy generating capacity in 2001, over 2600 MW was due to Germany and only 1700 MW of this was due to the United States.

The following table compares the costs of major energy sources with wind energy. The figures are from the California Energy Commission's 1996 *Energy Technology Status Report,* which examined the costs and market readiness of various energy options. The CEC calculations do not include subsidies or environmental costs.

Fuel	Levelized costs (cents/kWh) (1996)
Coal	4.8-5.5
Gas	3.9-4.4
Hydro	5.1-11.3
Biomass	5.8-11.6
Nuclear	11.1-14.5
Wind (without PTC)	4.0-6.0
Wind (with PTC)	3.3-5.3

Table 6: Levelized Cost of Energy

Source: Energy Technology Status Report

The cost of natural gas has increased since 1996, so that the levelized cost of gas–fired power plants would now be considerably higher. In January 2001, the cost of natural gas generated power was running as high as 15 cents to 20 cents per kWh in certain markets. The cost of wind power, meanwhile, has declined slightly. Three additional points about the economics of wind energy should be considered when estimating its relative cost. First, the cost of wind energy is strongly affected by average wind speed and the size of a wind farm. Since the energy that the wind contains is a function of the cube of its speed, small differences in average winds from site to site mean large differences in production and, therefore, in cost. The same wind plant will, all other factors being equal, generate electricity at a cost of 4.8 cents/kWh in 16 mph winds, 3.6 cents/kWh at 18 mph winds, and 2.6 cents/kWh in 20.8 mph winds. Larger wind farms provide economies of scale. A 3-MW wind plant generating electricity at 5.9 cents per kWh would, all other factors being equal, generate electricity at 3.6 cents/kWh if it were 51 MW in size. Second, the cost of wind energy is dropping faster than the cost of conventional generation. While the cost of a new gas plant has fallen by about one-third over the past decade, the cost of wind has dropped by 15% with each doubling of installed capacity worldwide, and capacity has doubled three times during the 1990s. The cost of wind power is expected to decline by another 35-40% by 2006. Third, if environmental costs were included in the calculation of the costs of electricity generation, wind energy's competitiveness would increase further because of its low environmental impacts.

3.1.4 Wind Farms Environmental Impact

Wind energy system operations do not generate air or water emissions and do not produce hazardous waste. They also don’t deplete natural resources such as coal, oil, or gas, or cause environmental damage through resource extraction and transportation. Wind's pollution free electricity can help reduce the environmental damage caused by power generation in the U.S. and worldwide.

In 1997, U.S. power plants emitted 70% of the sulfur dioxide, 34% of carbon dioxide, 33% of nitrogen oxides, 28% of particulate matter and 23% of toxic heavy metals released into our nation's environment, mostly the air. These figures are currently increasing in spite of efforts to roll back air pollution through the federal Clean Air Act.

Sulfur dioxide and nitrogen oxides cause acid rain. Acid rain harms forests and the wildlife they support. Many lakes in the U.S. Northeast have become biologically dead because of this form of pollution. Acid rain also corrodes buildings and economic infrastructure such as bridges. Nitrogen oxides are also a primary component of smog. Carbon dioxide (CO2) is a greenhouse gas that buildup in the atmosphere contributes to global warming by trapping the sun's rays on the earth as in a greenhouse. The U.S., with 5% of the world's population, emits 23% of the world's CO2. The build-up of greenhouse gases is not only causing a gradual rise in average temperatures, but also seems to be increasing fluctuations in weather patterns and causing more severe droughts. Particulate matter is of growing concern because of its impacts on health. Its presence in the air along with other pollutants has contributed to make asthma one of the fastest growing childhood ailments in industrial and developing countries alike, and it has also recently been linked to lung cancer. Similarly, urban smog has been linked to low birth weight, premature births, stillbirths and infant deaths. In the United States, the research has documented ill effects on infants even in cities with modern pollution controls. Toxic heavy metals accumulate in the environment and up the biological food chain.

Development of just 10% of the wind potential in the 10 windiest U.S. states would provide more than enough energy to displace emissions from the nation's coal-fired power plants and eliminate the nation's major source of acid rain; reduce total U.S.

emissions of CO_2 by almost a third and world emissions of CO_2 by 4%; and help contain the spread of asthma and other respiratory diseases aggravated or caused by air pollution in this country. If wind energy were to provide 20% of the nation's electricity it could displace more than a third of the emissions from coal-fired power plants, or all of the radioactive waste and water pollution from nuclear power plants. The 10 billion kilowatt-hours currently generated by wind plants in the U.S. each year displace some 13.5 billion pounds of carbon dioxide, 35,000 tons of sulfur dioxide, and 21,000 tons of nitrogen oxides.

Wind power plants, like all other energy technologies, have some environmental impacts. However, the impacts of wind energy systems are local. This makes them easier for local communities to monitor and, if necessary, mitigate. The local environmental impacts that can result from wind power development include: Erosion which can be prevented through proper installation and landscaping techniques. Erosion can be a concern in certain habitats such as the desert, where a hard-packed soil surface must be disturbed to install wind turbines. Birds occasionally collide with wind turbines, as they do with other tall structures such as buildings. Visual impacts, which can be minimized through careful design of a wind power plant. Using turbines of the same size and type and spacing them uniformly generally results in a wind plant that satisfies most aesthetic concerns. Computer simulation is helpful in evaluating visual impacts before construction begins. Public opinion polls show that the vast majority of people favor wind energy, and support for wind plants often increases after they are actually installed and operating. Noise was an issue with some early wind turbine designs, but it has been largely eliminated as a problem through improved engineering and through appropriate use of setbacks from nearby residences. Aerodynamic noise has been reduced by adjusting the thickness of the blades' trailing edges and by orienting blades upwind of the turbine tower. A small amount of noise is generated by the mechanical components of the turbine. To put this into perspective, a wind turbine 250 meters from a residence is no noisier than a kitchen refrigerator.

3.1.5 Wind Energy Potential

Wind energy has enormous potential in the United States, could supply about 20% of the nation's electricity, according to Battelle Pacific Northwest Laboratory, a federal research lab. Wind energy resources useful for generating electricity can be found in nearly every state. North Dakota alone is theoretically capable of producing enough wind-generated power to meet more than one-third of U.S. electricity demand. The theoretical potentials of the windiest states are shown in the following table.

1	North Dakota	1,210	11	Colorado	481
2	Texas	1,190	12	New Mexico	435
3	Kansas	1,070	13	Idaho	73
4	South Dakota	1,030	14	Michigan	65
5	Montana	1,020	15	New York	62
6	Nebraska	868	16	Illinois	61
7	Wyoming	747	17	California	59
8	Oklahoma	725	18	Wisconsin	58
9	Minnesota	657	19	Maine	56
10	Iowa	551	20	Missouri	52

THE TOP TWENTY STATES for wind energy potential, as measured by annual energy potential in the billions of kWhs, factoring in environmental and land use exclusions for wind class of 3 and higher.

Source: An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States, Pacific Northwest Laboratory, 1991.

Table 7: Wind Energy Potential

In order to reach the projected potential of wind energy in the U.S. a transmission system must be set up. The entire transmission system of the Missouri River Basin, which covers the central one-third of the U.S., needs to be extensively redesigned and redeveloped. At present, this system consists mostly of small distribution lines instead; a series of new high-voltage transmission lines is needed to transmit electricity from wind plants to population centers. Second there would have to be nondiscriminatory access to the transmission lines. Transmission line operators typically charge generators large penalty fees if they fail to deliver electricity when scheduled to be transmitted. The purpose of these penalty fees is to punish generators and deter them from using transmission scheduling as a "gaming" technique gain advantage against competitors, and the fees are therefore not related to whether the system operator actually loses money as a result of the generator's action. But because the wind is variable, wind plant owners cannot guarantee delivery of electricity for transmission at a scheduled time. Wind energy needs a new penalty system that recognizes the different nature of wind plants and allows them to compete on an equitable basis. Transmission will be a key issue for the wind industry's future development over the next few decades.

If enough attention and development is put into windmills we can put them across the Great Plains, which would produce enough electricity for the whole country to run on, not to mention the development off offshore wind farms, which have high winds and a higher energy output. The benefits of offshore windmills compared to inland wind farms is people don’t have to live next to them, they don’t take up needed land and they help out fishermen because they are like a sunken ship which produces reefs. Although for the country to totally run off wind energy we need to find stronger lighter material that can resist fatigue better and for cheaper rice because as of now windmills are just too expensive to develop compared to the use of other energy sources such as fossil fuels. The section Specific Wind Farms contains the information and data complied from various major wind farms that exist or are planned for the future in the United States.

3.1.6 Specific Wind Farms

Algona, Iowa Wind Farm

In Algona, Iowa there is a 2.25 MW wind farm. The farm is made up or three 750 kW turbines. The turbines have 166-foot rotors on them. The tower height is also 164 ft. Average wind speed with 15.9 miles per hour, which is above the 9 mph required to generate electricity. They are capable of producing 1.8 million kilowatt-hours per year.[84]

The three turbines combined are capable of producing a total of 2,250 Kilowatts. Power from this project will be transported over existing regional electrical transmission lines to end users. The Zond Z-50 wind turbines weight 92 tons. They are built of reinforced fiberglass.

The three turbines offset over 13 million pounds of global warming emissions (carbon dioxide), 54,000 pounds of acid rain-causing emissions (sulfur dioxide), and 55,000 pounds of smog-causing emissions (nitrogen oxides), as well as trace metals like mercury and arsenic commonly released from coal-fired power plants.

In all, Iowa is home to 327 large-scale wind turbines, with a total generating capacity of 242 MW. The turbines provide enough power for about 80,000 homes. Iowa

[84] http://www.epri.com/corporate/discover_epri/news/releases/windfarm.html

has only begun to tap its wind resource. The wind turbines in Algona have performed well beyond expectations in their first year of operation. Thanks to a bumper crop of wind and outstanding equipment reliability, the turbines produced 13 % more than was predicted before construction. Electricity production from the Algona wind farm over the 12 months ending November 1999 was 6,527 megawatt-hours, enough to supply all the power needs of 673 typical Iowa households.

A kilo or megawatt is the measure of power. While a kilowatt or megawatt-hour is a unit of energy equivalent to one kilowatt of power expended for one hour of time.[85]

In all, Iowa is home to 327 large-scale wind turbines, with a total generating capacity of 242fMW. The turbines provide enough power for about 80,000 homes. Iowa has only begun to tap its wind resource. The state's wind energy potential is the 10th largest of the contiguous U.S. states, according to a federal study.

The three turbines offset over 13 million pounds of global warming emissions (carbon dioxide), 54,000 pounds of acid rain-causing emissions (sulfur dioxide), and 55,000 pounds of smog-causing emissions (nitrogen oxides), as well as trace metals like mercury and arsenic commonly released from coal-fired power plants.

California Wind Farms

Throughout the past 20 years or so, California has been the leading wind farm producer in America and they are pushing the competition for wind farm production. The largest farms which have the most turbines in one area are in California, there are many reasons this is true. California has ideal wind conditions for the farms to have maximum power output, and these ideal wind conditions happen to be near electrical

[85] http://whatis.techtarget.com/definition/0,,sid9_gci797759,00.html

power transmission line and are near large cities. Another coincidence that makes California an ideal place to have wind farms is the peak wind speeds are around the same time as the peak electricity demands. Even though California has been producing wind farms since the 1980's development has not slowed and a new farm has just been finished. This new farm can produce enough energy for 75,000 homes and produces 146 megawatts of electricity, and more are in production today.[86]

California gets more energy from wind than any other state in the country. In 2000 California got 3,604 million Kilowatt-hours of electricity which is about 1.27% of the states electricity, which is enough to light all of San Francisco. California is allowed to get this much energy from wind because according to the Electric Power Research Institute, the cost of wind energy has decreased four fold since 1980 due to improved aerodynamics of the blades and more efficient motors. This improvement can be seen by the decrease in cost of wind energy; from 1993 till today prices of wind energy has gone from 7.5 cents per kilowatt/hour to 3.5 cents per kilowatt/hour. Along with the benefit of a clean energy source that won't run out is wind farms create jobs. The American Wind Energy Association estimated through the early 1990's 1,200 direct jobs were created and 4,000 indirect jobs were created by the creation of wind farms in California alone. A major draw back is it is a big risk to invest in these farms because it is very expensive and if something goes wrong the investors are going to lose out on a lot of money; the total private investment in wind energy in California in 1991 alone was $3.2 billion, but if everything goes as expected the investors will see profit after the farms are up and

[86] www.energy.ca.gov/wind.html

running. Below is a graph of different turbines and it shows the price of each and the total annual production of energy from each specific one. [87]

Costs and payback of typical wind turbines

System Size	Capital or up-front cost	Annual energy production	Payback using all farm power needs
10 kW	$32,000	20,000–28,000 kWh	18–27 years
50 kW	$130,000	100,000–150,000 kWh	12–18 years
225 kW	$325,000	425,000–600,000 kWh	9–13 years
660-750 kW	$800,000–$900,000	1,500,000–2,300,000 kWh	6–8 years

Table 8: Cost and Paybacks of Wind Turbines

Source: www.eere.energy.gov

California has the three largest wind farms and they are located at Altamont Pass, California, Tehachapi Mountains in Kern County, and at San Gorgonio Pass; all having thousands of wind turbines. These turbines account for 13,000 of all of California's wind turbines or 95% of California's wind turbine capacity. At Altamont Pass, air from the Pacific Ocean funnels through the pass producing winds that reach 18-27 MPH during the summer. The Altamont Pass alone accounts for 1 to 1.2 TWh per year. The Tehachapi Wind Farm is 40 square miles and an ideal site for a wind farm because the Tehachapi Mountains direct the winds, which reach speeds of 15-20 MPH. The final farm in this area is at the San Gorgonio Pass where hot air rises over the valley forcing the cooler air through the pass, which creates average wind speeds of 15-20 MPH; there are over 4,000 wind turbines in this 70 square mile area alone. Below is a picture of the San Gorgonio Pass I described.

[87] www.eere.energy.gov/consumerinfo.html

Figure 37: Wind Farm

Source: www.awea.org/projects.com

Here is a graph of the different wind farms I discussed and the energy output of each:

Major CA Wind Energy Resource Areas

Existing Project or Area	MW Installed*	Annual Energy Output (Yr of Est)	Power Purchaser/ User	Turbines
1. Altamont Pass	548.32	637 M kWh (1998)	Pacific Gas & Electric	Variety
2. Pacheco Pass	16.0	22.3 M kWh (1998)	Pacific Gas & Electric	Variety
3. San Gorgonio Pass	588.0	805 M kWh (1998)	So. California Edison	Variety
4. Solano County	159.96	N.A.	S.M.U.D	Kenetech & Vestas
	60.0	97.1 M kWh (1998)	Pacific Gas & Electric	U.S. Wind- power 100
5. Tehachapi	605.72	1.2 B kWh (1998)	So. California Edison	Variety
Others	0.675	N.A.	U.S. Navy	NEG-Micon

Table 9: Major CA Wind Energy Resource Areas

Source: www.awea.org/projects.com

Due to the advances in technology wind turbines are becoming more common and cheaper to produce; between 1990 and 2000, the cost of wind energy went from ten cents to less than five cents per kWh. Twenty years ago, the capacity of turbines was 150 kilowatts compared to today's capacity of 750 KW. Turbines being developed today are as big as 6 MW, which will allow one turbine to do a lot more work than they have in the past thus decreasing the cost of the turbines and increasing the investment in developing wind farms.[88]

Stateline Project

A new generation of wind power is online--and profitable. FPL Energy leads this tiny industry with the biggest project in the country. FPL Energy, a subsidiary of FPL Group in Juno Beach, Fla., began harvesting the area's most bountiful resource, the strong gusts of wind that whip out of the bend in the Columbia Gorge at up to 60 miles an hour. The ridge catches winds, which average 16 to 18 mph; this is considered excellent for wind farm development. The area around the project is used mostly for private farming, and this will continue beneath the completed wind project. The site is also close to preexisting transmission lines, reducing the need for new cables and minimizes the amount of power lost during transmission. This is known as the Stateline Wind Energy Center completed at a cost of $260 million, the 50-square-mile expanse is now dotted with 400 new turbines.

Stateline Wind Energy Farm is the largest wind farm in the country; it produces 263 megawatts at peak, or an estimated $21 million of electricity a year (at 3 cents per

[88] www.planetark.org

kilowatt-hour). On average the project is expected to receive enough wind to deliver 30-35 percent of its peak capacity year round: enough power for more than 21,600 Northwest homes. Tax subsidies effectively add 1.8 cents to the 3-cent revenue for a kilowatt-hour. FPL's buyer, under a 25-year contract, is wholesaler PacifiCorp Power Marketing, a subsidiary of Scottish Power Plc. That subsidized 3-cent price is less than the 4 cents PacifiCorp pays for natural gas. Due to bigger, more efficient turbines, the cost of producing wind energy is down 80% from ten years ago. Stateline was its most ambitious farm yet. Just to begin construction, 368,000 tons of rock, were crushed to roll out 70 miles of road. The construction crew at times totaled 350.

Another developer, James Dehlsen, who built vast but marginally profitable wind farms in California in the early 1980s, is now back and raising funds to build a site even bigger than FPL's: Rolling Thunder, a 3,000-megawatt farm that will cover 390 square miles in South Dakota. That bodes well for local farmers, who will lease out breezy rural patches for an average $2,500 a year for each turbine. So far FPL is the most aggressive builder. Already the $8.4 billion energy company owns almost half of the 4,300 megawatts of wind power in the U.S. By 2003 FPL expects to double its capacity, a windy wager that could cost $1.5 billion.

In the race for efficiency, size matters. The turbines at Stateline, designed by Danish maker Vestas, can produce 660 kilowatts each from a triplet of blades 75 feet long. With the hub 164 feet off the ground, that means the tip of an upright blade is about 240 feet up in the air. At its optimal generation, each turbine will generate up to 667 kilowatts of electricity. The turbine's power is six times that of its decade-old predecessors. Vestas now sells an even bigger machine, a 1.8-megawatt turbine that stretches to a height of 328 feet. Wind turbines operate best when the average wind speed is at least 13 miles per hour. It is windier at higher elevations and, thanks to the laws of physics; the power in wind per square yard of area captured by the windmill blades is proportional to the cube of the wind's velocity. Vestas' turbines self-adjust to sudden gusts by changing the blades' pitch and increasing rotor speed up to. 10%. If gusts blow above 55 miles an hour, the turbine shuts itself down and waits until the wind slows for at least ten minutes before starting up again. This prevents damage to the gearbox. Motorized controls rotate the turbines so the hub faces into the wind.

Better technology means less manpower to run Stateline: 20 maintenance guys for all 400 turbines, an 80% reduction in labor from FPL's older farms. At Stateline, 140 miles of fiber-optic cable connect turbines to a computer in a trailer. Operators remotely monitor some 60 parameters, such as voltage spikes, gearbox temperature and oil viscosity in the generator. Wind still has one big limitation: Sometimes it just won't blow. With an intermittent source like wind, transmission lines go unused about two-thirds of the time, compared with conventional energy generators, which fill power lines 80% of the time. Gaps in transmission make wind energy twice as costly to transport for PacifiCorp Power Marketing, the wholesaler. Power-grid operators in most states, including Oregon and Washington, can fine wholesalers for failing to deliver a scheduled amount of power. PacifiCorp has negotiated with the Bonneville Power Administration to cap most of these delivery penalties.

The Stateline wind project was planned carefully and underwent extensive review to minimize its environmental impact. Early biological studies indicated that the site receives little use by birds or other vulnerable species. The project uses tubular towers and buried cables in order to avoid adding new perching places for birds. Slower-moving blades and an upwind design further minimize any potential for avian fatality. As a clean power source, the project also eliminates some of the need for fossil fuel electric plants in the region. If natural gas or coal were used to generate the same amount of power, they would emit at least 310,000 tons of carbon dioxide per year, as well as air pollutants and acid rain precursors. Wind power produces no air emissions.

Long Island, New York

Wind energy has been touted by many as one of the more promising ways of obtaining energy through renewable means. A large surge in demand for electricity on Long Island coupled with the highest cost of electricity in the country has generated a substantial interest in renewable energy. The Long Island Power Authority, a government created utility, is pushing two initiatives to make wind power a reality for Long Islanders, one of which is a proposal to site several wind turbines on Long Island farmland, the other: an offshore project. Wind power testing is already underway at South Hampton College in collaboration with AWS Scientific, Inc. The wind turbine installed at South Hampton College is a Bergey Wind power unit, is estimated to produce approximately 13,200 kWh.[89]

Farmwind Initiative

LIPA has narrowed down a list of a 40 interested farms into five that it plans to site wind turbines on. The first has already been installed on Zeh Farm off of route 25 in Calvertown, Long Island. The Zeh Farm unit is manufactured by the Atlantic Orient

[89] Wind Turbine at Southampton College http://www.lipower.org/projects/wind_sc.html

Corporation based in Norwich, Vermont. LIPA estimates that each one of these units will be capable of producing approximately 100,000 kWh or enough to power the average needs of 12 Long Island homes each year.[90] The turbines are designed to passively rotate in the direction of the wind in order to capture it most efficiently. The five sites selected are subject to the following criteria:

- Farm owner is LIFB member who has not transferred ownership of development rights on the potential site;
- The site must be part of a farm of at least 20 acres with adequate setbacks from neighbors;
- It must have unobstructed exposure to the prevailing wind;
- There must be a minimum of 11 miles per hour average wind speed;
- It must be near a three-phase electric distribution line to minimize the cost of connecting to LIPA's electric grid.

The farmers willing to site these units on their farms are estimated to receive an incentive of approximately $3000 (approximately 25% the value of the electricity produced by each windmill) off their annual energy bill. An entire installation takes less than six weeks to complete (far less than that of a fossil fuel fired turbine), and leaves a mere 25' x 35' footprint on the ground, which houses the tower, control box and transformer. The equipment is connected to the grid via underground transmission lines. The five initial turbines being installed on Long Island farmland will serve as a test bed for future units sited on farms.

---

[90] LIPA and the Long Island Farm Bureau-
"Keeping Long Island Green":Land-based Wind Turbine Demonstration
http://www.lipower.org/projects/zeh.html

Offshore Initiative

Wind energy is also being considered by LIPA for larger scale projects. Due to the dense development of Long Island, there is a lack of suitable space for wind turbines. Long Island does however possess an extensive shoreline all around it. With abundant wind offshore and copious open space available in the water, a two-phase study has been completed to study the feasibility of an offshore wind farm.

Figure 38: Long Island Wind Farm

Source: http://www.lioffshorewindenergy.org/photos.html

The entire south shore of the island is being considered for wind farm development, with a maximum potential of filling 314 square miles of off shore property with wind turbines. If this entire area were to be filled with wind turbines, and estimated 5200 MW of power could be generated. This particular scenario is highly unlikely to become reality, as additional restrictions will limit the area in which the equipment can be installed. A more limited, yet still relatively large off shore wind farm could come in the form of a 135 square mile area 3 to 6 knots offshore. LIPA is looking to site the turbines in water depths of less than 50 feet. Currently LIPA believes the area just south of Jones Beach would be the most promising site although further studies continue to proceed. The LIPA sponsored Long Island Offshore Wind Initiative as it is called has published the following findings:

- "The most feasible offshore area for wind generators is a 314 square-mile band that stretches along the entire south shore and to the east of Montauk Point;
- a 100 MW offshore project would cost about $150 to $180 million;
- interconnections costs would range from $40 to $70 million;
- developing wind generators within the entire south shore band (which runs three to six miles offshore) could produce about 5,200 MW of electricity;
- developing wind generators in a smaller, 135 square mile band running three miles offshore could produce as much as 2,250 MW of power;
- most offshore wind generation developed in Europe has been done in water 50 feet or less in depth;
- the rotor hub for an offshore wind turbine would be 262 feet above the surface of the water, and rotor blades 164 feet long would make the tip of the rotor reach a height of 426 feet above the surface of the water;
- an initial assessment suggests the avian impacts should not be ecologically significant; however a more detailed study would be needed at specific site locations; and
- the permitting process, due to multiple oversight entities, would take a minimum of three years. "[91]

[91] http://www.lioffshorewindenergy.org/press/2002/april22.html

Cape Cod Wind Farm

Wind Energy is an Alternative Energy Resource that is being explored by the United States. The people at Cape Wind would like to build America's first offshore wind farm. The wind farm would cost around 700 million dollars; this includes construction and research. This wind farm could set a precedent for 25 other wind farms to be built in the Untied States. Cape Wind's plan is to build a wind farm 5 miles off the coast of Massachusetts on Horseshoe Shoal; which is located between Nantucket Sound and Martha's Vineyard. The farm would consist of 130 windmills that stand 260 feet tall, each with a 150-foot long blade. The windmills would be laid out in a grid pattern over 25 square miles. Each of the park's 130 windmills will have a foundation that will be between five and six and a half meters across and will weigh between 250 and 350 tons. Depending on the specific seabed conditions, the foundations will be driven approximately 85 feet into the seabed. With the foundations securely in place, the support towers can be installed, followed by the turbines. Once all the turbines are in place, each one will be connected to the local cable grid and will then be ready to begin producing energy.[92]

The project developers claim that the windmills will produce 420 mega watts of electricity; which will be enough for the Cape during peak operation. They also claim the wind farm is capable of replacing 113 million gallons of oil used by the cape each year. It will also eliminate 4,642 tons of Sulfur Dioxide, 120 tons of Carbon Monoxide, and 1,566 tons of nitrous oxides that are released into the air each year will be gone.

---

[92] Scientific American, "Blowing Out to Sea", Williams, Wendy, March 2002.

According to the companies calculations the wind farm will save the Cape 800 million dollars over the next two decades. [93]

La Capra Associates (La Capra), a leading energy consulting firm with over 20 years of experience, estimated the financial impact that the Cape Wind project would have on the New England energy market along with computing the other specific calculations. La Capra used complex market process with a number of variables including the amount of electricity demanded, the cost and availability of power plants, fuel costs to generate the electricity, the amount of electric transmission capacity, etc. to calculate the cost of electricity. La Capra used PROSYM software, a well-established dispatch simulation software program, to develop a model of the wholesale electricity market in northeast North America. The La Capra model uses projections of future demands; fuel prices, existing unit retirements, new unit additions and power plant-specific information to generate hourly estimated clearing prices. It simulates how the electricity spot market in the Northeast works. To ensure greater accuracy of the results, La Capra compares its forecast to historical trends and includes methodologies that capture "price spikes" and the impact weather has on load.[94]

To establish how the Cape Wind project could affect prices, La Capra developed two simulations of the regional energy market for 2005-2009. The first was a base case based on recent long-term planning assumptions. The second simulation added the projected monthly energy output from the Cape Wind project, which was calculated based on typical meteorological data. Based on these results La Capra found that it would

[93] Cape Wind, "Protecting Our Environment, September 2003, www.capewind.org
[94] Cape Wind, "Calculating the Saving", September 2003, www.capewind.org

lead to a savings of approximately $25 million per year for the New England electricity market.[95]

PROSYM is a chronological electric power production costing simulation computer software package. It is designed for performing planning and operational studies, and as a result of its chronological nature, accommodates detailed hour-by-hour investigation of the operations of electric utilities. The model is a proprietary model that is licensed by The Henwood Energy Services, Inc. of Sacramento, California. Because of its ability to handle detailed information in a chronological fashion, planning studies performed with PROSYM will closely reflect actual electric utility operations. PROSYM considers a complex set of operating constraints to simulate the least-cost operation of the utility, or least-bid operation of the pool. This hour-by hour simulation, respecting chronological, operational, and other constraints in the case of cost based dispatch, and relevant pool or independent system operator (ISO) rules in the case of bid based dispatch, is the essence of the model.

PROSYM is a general-purpose simulation model capable of representing most electric load and resource situations. To perform simulations, the PROSYM system requires: at least one basic set of annual hourly loads; projections of peak loads and energies on an annual basis for the study of any future period; and data representing the physical and economic operating characteristics of the electric utility, and any relevant ISO rules. PROSYM simulations consist of a two-step process: projection of the load data over the study period and simulation of utility or regional operation. It is used to define power system operating costs to meet power loads; costs for each plant and input into the model are fuel costs, variable operation and maintenance costs, and startup costs.

[95] Cape Wind, "Calculating the Saving", September 2003, www.capewind.org

PROSYM recognizes operating constraints imposed on individual units, output production costs by resources to meet weekly loads, outputs available by regions, by plants, and it includes a pollution emission subroutine; which estimates emissions with each scenario.

Cape Wind plans call for the park to be constructed and fully operational by 2005, with construction beginning in 2004. The Cape Wind project will be subject to a comprehensive environmental review process. This process, led by ESS Group, Inc. will ensure that any environmental impact of the wind park's construction and operation is carefully studied. Cape Wind's permit application for a renewable wind energy project is undergoing more rigorous and comprehensive review from federal and state agencies than was required for any previous power plant. The agencies that must approve the permits for the wind farm are the US Army Corps of Engineers, US Environmental Protection Agency, National Marine Fisheries Service, US Coast Guard, Federal Aviation Administration, Massachusetts Executive Office on Environmental Affairs, Massachusetts DEP—Division of Wetlands and Waterways, Massachusetts Coastal Zone Management, and the Cape Cod Commission.[96]

The Cape Cod wind farm, despite providing environmentally safe electricity to the Cape, is not favored by everyone. Two state officials that are opposed to the idea are Governor Mitt Romney and Senator Kennedy. Romney maintains Nantucket Sound is not the proper place for a wind farm and could hurt tourism and the Cape's economy. Romney has written to officials at the Army Corps to express his opposition to the project. Eight Cape towns, Nantucket and four Martha's Vineyard towns have signed a resolution asking Romney and Reilly to do whatever they can to establish state

[96] Cape Wind, "Permits", September 2003, www.capewind.org

jurisdiction over Nantucket Sound, including the part where the wind farm is planned. There is fear that the wind farm will affect the fishing and kill numerous birds. Previous wind-power projects have resulted in numerous bird killings. At a massive 7,000-turbine power plant in California's Altamont Pass, 182 birds were killed over a two-year period ending in 1992. The fishing community fears the poles of the turbines, which would be sunk about 80 feet into the seabed, would disrupt the feeding and nursing grounds of valuable fish, including striped bass and summer flounder. The local people feel that the beautiful scenery will be ruined and their companies will lose business from the lack of tourism.[97]

The citizens' argument that the wind farm will ruin the beautiful scenery and affect tourism is not a sound argument. The pictures attached show what the turbines will look like from various points on the cape during different weather conditions. As the pictures show the turbines are barely visible during a clear day, they look like a bunch of sailboats off in the horizon. The pictures of the view during cloudy conditions or at night show that the windmills can't be seen at all.

The opposition to the wind farm off the cost of the Cape is weak. The economical and environmental advantages that the wind farm will create for the cape far out way the few disadvantages it creates. It is true that the installation of the turbine could disrupt the fishing for that area; however the revenue that could be generated by those fishermen is not significant enough to warrant stopping the production of the wind farm. In the long run that wind farm will create more opportunities and save the Cape more money then those fishermen could have made. The fact that the turbines could lead to some birds being killed by flying into the turbines is not insignificant, however these loses seem

[97] Cape Cod Times, "State urged to 'step up' wind farm opposition", Leaning, John, April 18,2003.

minor when compared to the long term environment advantages. The opposition needs to build a stronger case if they intend to stop the production of the wind farm. Cape Wind just recently won a court case that will allow them to continue production of the test tower. The fact that the court is willing to allow them to continue the production bodes well for Cape Wind in the future.

The Cape Cod Wind Farm is still in the early stages of development. They are building a 200-foot test tower in the sound to test the conditions and collect data. The strong opposition to the wind farm could create a legal battle, which will slow production. The entire project is now under a state and federal environmental review that could take up to five years to complete. The Cape Wind Company is in the process of applying for permits. They are optimistic that they will receive the permits by the early 2004 and be able to start construction.

Minnesota Wind Data

Minnesota started a Wind Resource Assessment Program (WRAP) in 1982 to quantify the relative impressions of “windy.” The first measurement towers had one anemometer located at 30 meters above ground. The program was significantly upgraded in 1994 to 14 sites with three levels of anemometers at 30, 50, and 70 meters. Currently there are approximately 30 monitoring sites operating at any one time, which includes five towers with peak measurement heights of 90 meters and seven portable tip-up towers ranging from 30 to 50 meters tall. WRAP has evolved as the wind monitoring technology, techniques, and data needs as the wind industry has developed. In order to stay current there needs to be an increase long-term peak monitoring heights to 90-120 meters. Modern wind turbine towers are increasing in height to 75 meters, with the rotor blades reaching up an additional 35 meters. The height of the measurement equipment needs to keep pace with industry developments to remain valuable[98].

The data collection and interpretation techniques are evolving and can be updated to include 2-minute peak wind measurements, whereas previous measurements only included a 24-hour peak measurement. The U.S. Department of Energy expects to develop a revised national map in two to three years based on the data collected here and the techniques used to collect it. Recent wind energy installations in Minnesota fall into two size categories, small (less than 40 kW) and large (more than 660 kW). Minnesota's Department of energy continued to contract for wind installations to meet their mandate of 425 MW by 2003. The final 130 MW were installed in 2002 using a 1.5 MW machine, the largest in Minnesota. Additionally, development increased due to the declining cost to install wind farms and also through green pricing programs offered by Minnesota electric cooperatives and municipal utilities.

The graphs in the appendix are a representation of our interpretation of the data that Minnesota collected. There are two types of graphs one is of the meters per second at that specific site and the other one is of the watts per square meter at that specific site. The data is a representation of the average per month for all of the sites with 70-meter towers. The same is true for the 90-meter sites, 50-meter sites, 70-meter sites with various sensors, and 40-meter sites. The data is useful because it provides the government of Minnesota the areas in which it could produce the most wind energy. This is a benefit because it allows them to be more efficient when they decide to build more wind farms. The wind speed per month and watts per month that are produced are helpful also

[98] "Wind Resource Analysis Program 2002", Minnesota, 2002.

because it allows the state to know which time of year is a problem area, so that they can address it before they build the wind farms. The results of the graphs are pretty constant; they all show the highest tower per site usually averages the highest wind speed and highest energy output per month. The 90-meter two has the largest average yearly output of watts per square meter. The graphs show that the summer month (June, July, and August) produces the lowest wind speeds on average and the smallest wattage output. This is useful because it identifies a problem that will have to be dealt with in order to implement wind energy. The data is a collection of numbers from various sites from 1996 to 2001. Minnesota spent a lot of time analyzing it and is now finding it useful in the construction of their wind farms[99].

The measurement of the wind speed at the sites was done by and anemometer. Wind speed is the fundamental measurement that allows for all wind power analysis. Each hour, a data logger averages the anemometer output providing an hourly average wind speed. The newer sites were set up such that the wind speed is averaged every 10 or 15 minutes. Wind speeds are averaged for each site on a monthly, yearly, or cumulative basis. These averages are the values used in wind power calculations for each site. The tendency for wind speed to increase with height above ground is called wind shear. Surface roughness and obstacles on the ground, which cause friction and slow the wind, result in wind shear. The result of wind shear is a wind speed distribution typical of Figure 2[100].

---

[99] "Wind Resource Analysis Program 2002", Minnesota, 2002.
[100] "Wind Resource Analysis Program 2002", Minnesota, 2002.

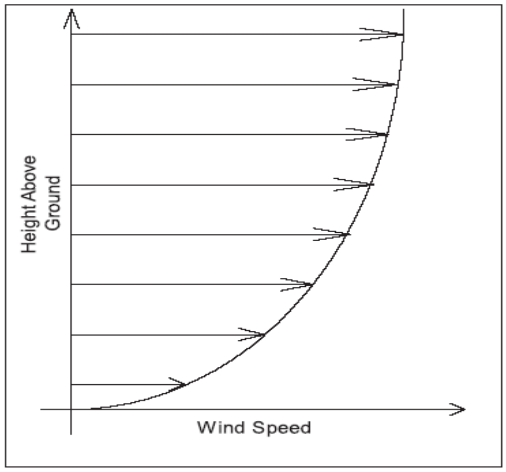


Figure 39: Wind Speed

Wind shear values are found between the 30-meter and 50-meter monitoring levels as well as the 50 meter and 70 meter levels. These values are averaged monthly for each set of heights at each site. The results can be found in the Summary Data and Site Descriptions Section.

Nearest City	Developer	Date	MW	Affiliated Electric Utility	#, Manufacturer, Size
Marshall	Navitas Energy	1992	0.6	Marshall Municipal Utility	5, WindWorld, 120 kW
Buffalo Ridge	Kenetech Windpower	1994	24.82	Xcel Energy	73, Kenetech, 340 kW
Chandler (I)	enXco, PRC	1998	1.98	Great River Energy[G]	3, Vestas, 660 kW
Lake Benton (I)	Enron Wind Corp.	1998	107.25	Xcel Energy	143, Zond, 750 kW
Woodstock	Edison Capital	1999	10.2	Xcel Energy	17, Vestas, 600 kW
Moorhead (I)	Moorhead Public Service	1999	0.75	Moorhead Public Service[G]	1, NEG Micon, 750 kW
Hendricks	Navitas Energy	1999	11.25	Xcel Energy	15, NEG Micon, 750 kW
Lake Benton (II)	FPL Energy	1999	103.5	Xcel Energy	138, Zond, 750 kW
Hendricks	Navitas Energy	1999	11.88	Xcel Energy	18, Vestas, 660 kW
Elk River	Navitas Energy	2001	0.66	Xcel Energy	1, Vestas, 660 kW
Ruthton	Navitas Energy	2001	15.84	Xcel Energy	24, Vestas, 660 kW
Hendricks	Navitas Energy	2001	11.88	Xcel Energy	18 Vestas, 660 kW
Averill	Navitas Energy	2001	1.98	Xcel Energy	3, Vestas, 660 kW
Chandler (II)	enXco, PRC	2001	3.96	Great River Energy[G]	6, Vestas, 660 kW
Wilmont	Navitas Energy	2001	1.5	Alliant EnergyG	1, NEG Micon, 1500 kW
Moorhead (II)	Moorhead Public Service	2001	0.75	Moorhead Public Service[G]	1, NEG Micon, 750 kW
Hendricks	Navitas Energy	2001	0.9	Ottertail Power [G]	1, NEG Micon, 900 kW
Wilmont	Navitas Energy	2001	0.9	SMMPA[G]	1, NEG Micon, 900 kW
Worthington	Missouri River	2002	1.8	Missouri River[G]	2, NEG Micon, 900 kW
Dodge Center	ReGen Technologies	2002	9.0	Xcel Energy	10, NEG Micon, 900 kW
Pipestone	DanMar Associates	2002	3.0	Xcel Energy	4, NEG Micon 750 kW
Total Installed			324.4		
Estimated homes/yr	124,326*				

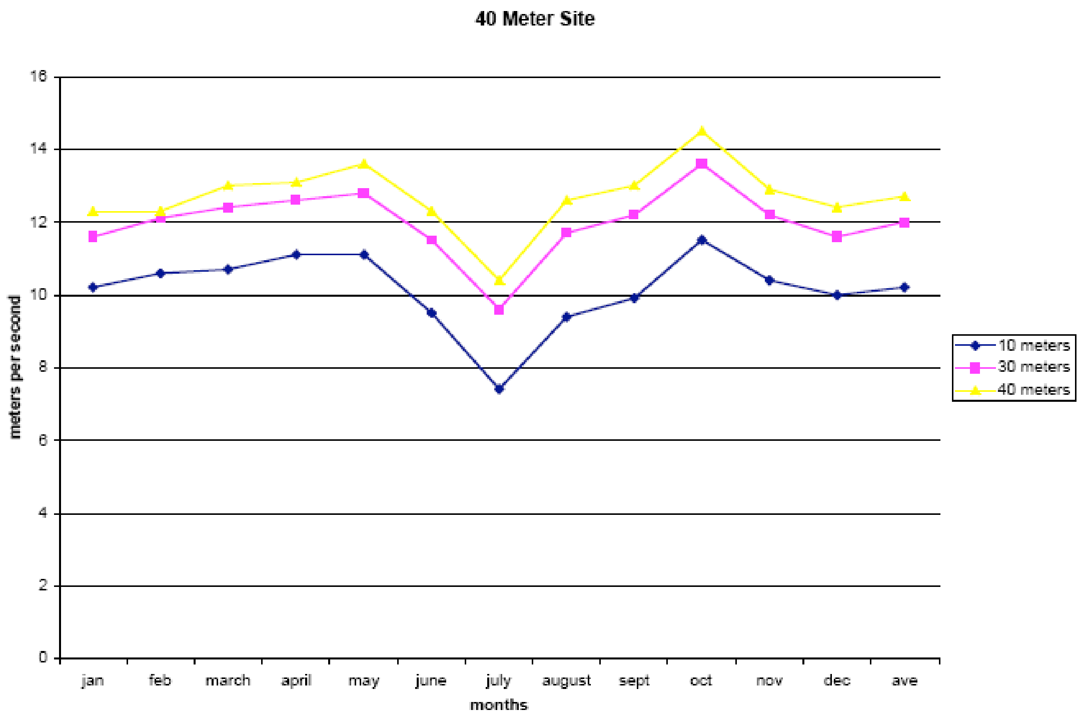
- Navitas Energy, formerly Northern Alternative Energy; PRC: Project Resources Incorporated
- Xcel Energy is mandated to acquire 425 MW of wind power by the end of 2002 and an additional 400 MW by 2012.
- [G] Green power program.
- * Based on average use of 8,000 kWh/household/yr and 35% capacity factor of electricity production.

Table 10: Minnesota Wind Farm Data

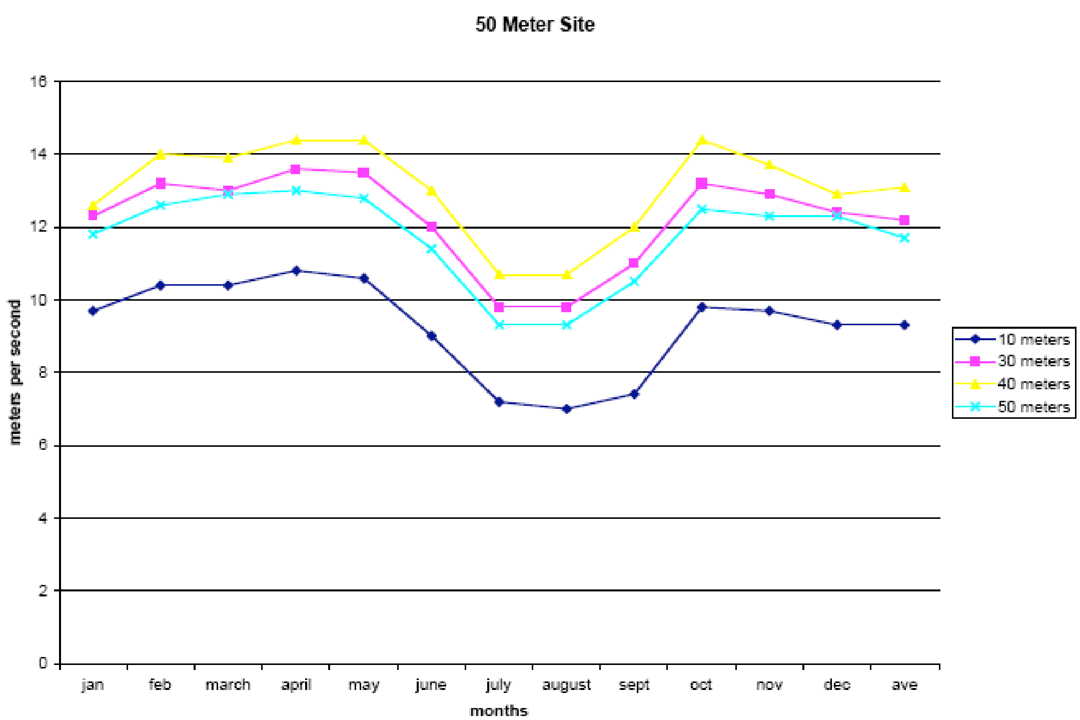
The chart above is of the current wind farms in Minnesota. It provides the size, the date it was built, and the electric utility affiliated with it. Wind Power however, only provides 1.5% of Minnesota's energy. This is a rather small percentage; it is expected to increase in the future considering Minnesota has one of the highest potentials for wind power. Now that they have collected data and done studies they are projecting to build more farms in the areas that are best suited as shown by the data. Of the 1.5% of wind energy that the state produces 90% of that comes from large-scale wind farms. The price of wind energy is becoming more respectable which is leading them to implement more of this technology and providing more energy from the wind[101].

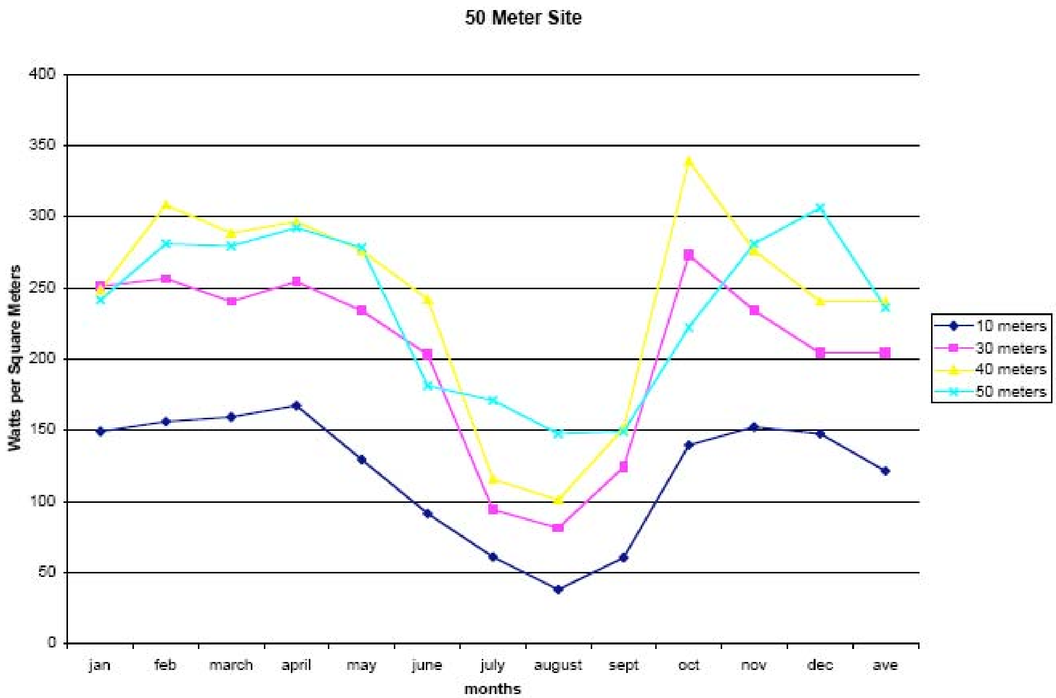
[101] "Wind Resource Analysis Program 2002", Minnesota, 2002.

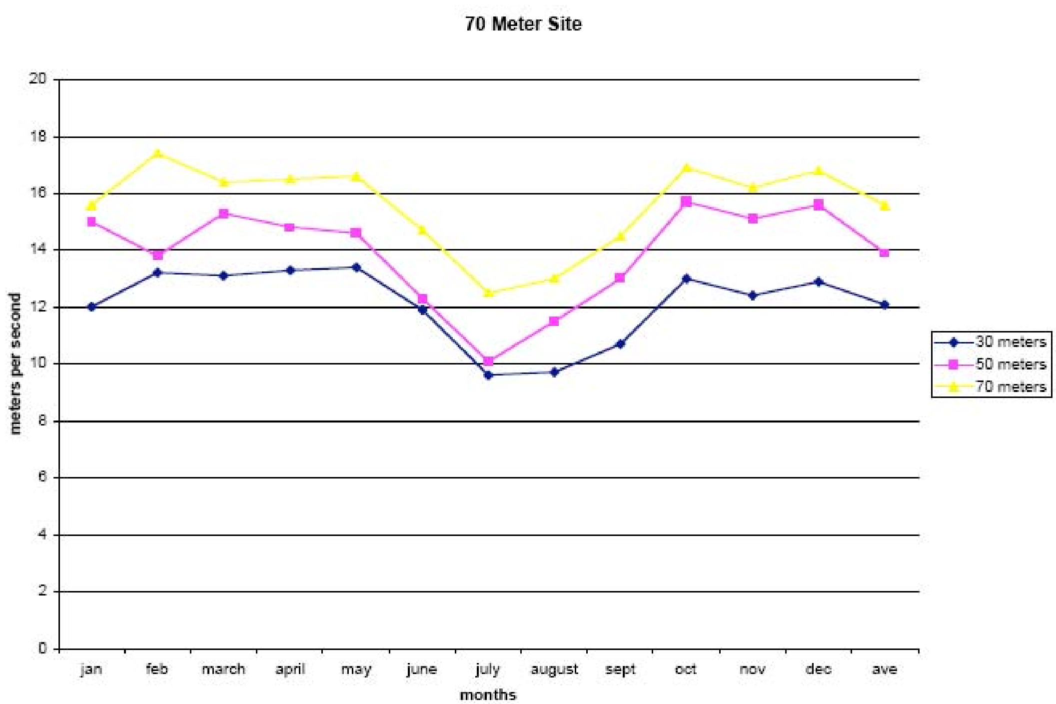
40 Meter Site

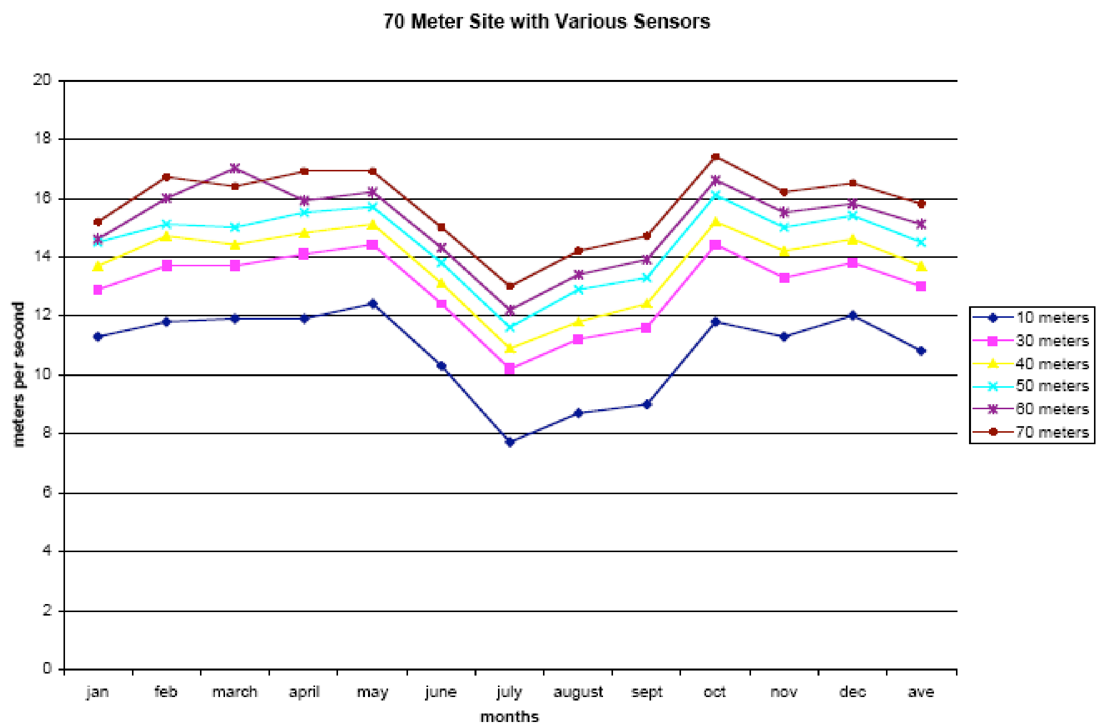


50 Meter Site



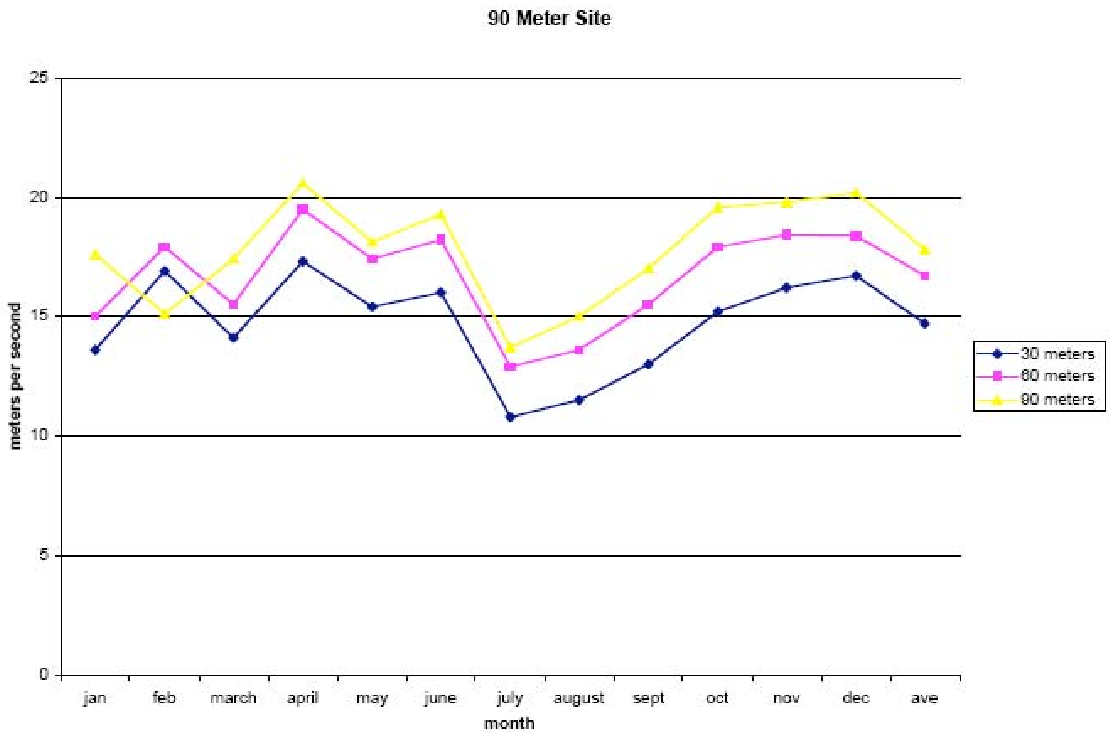

50 Meter Site
Watts per Square Meters
400
350
300
250
200
150
100
50
0
jan
feb
march
april
may
june
july
august
sept
oct
nov
dec
ave
months
10 meters
30 meters
40 meters
50 meters

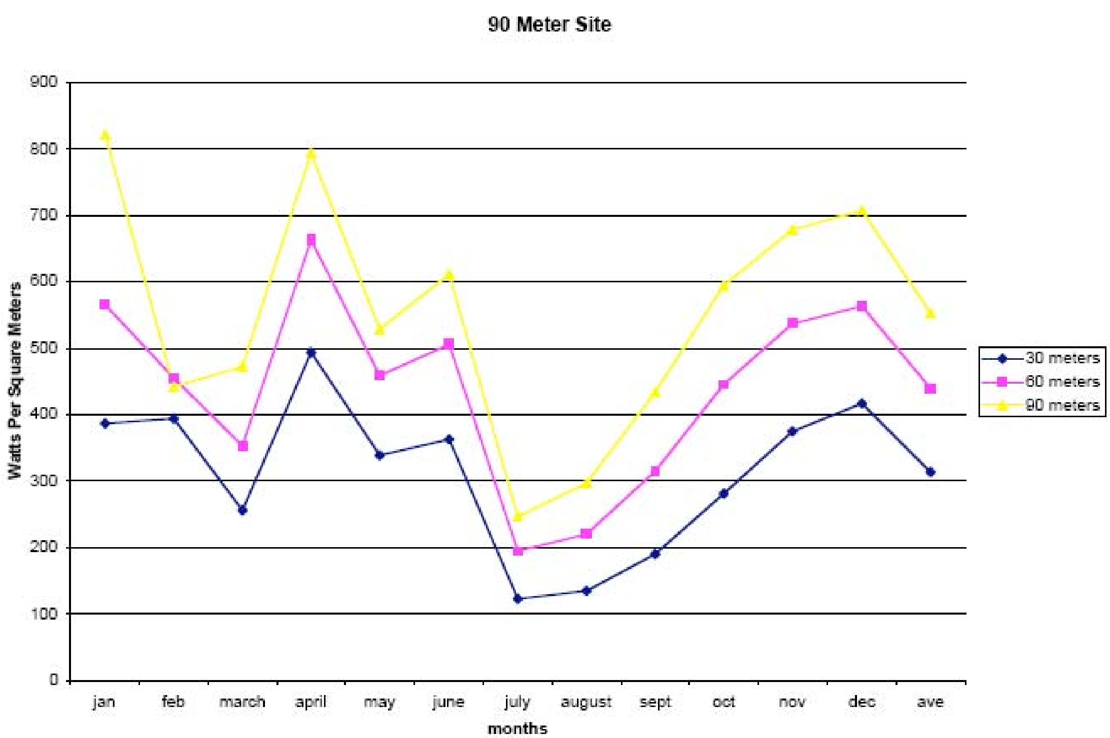

70 Meter Site
meters per second
20
18
16
14
12
10
8
6
4
2
0
jan
feb
march
april
may
june
july
august
sept
oct
nov
dec
ave
months
30 meters
50 meters
70 meters



70 Meter Site with Various Sensors
meters per second
months
jan
feb
march
april
may
june
july
august
sept
oct
nov
dec
ave
10 meters
30 meters
40 meters
50 meters
60 meters
70 meters

70 Meter Sites
Watts Per Square Meter
months
jan
feb
march
april
may
june
july
august
sept
oct
nov
dec
ave
30 meters
50 meters
70 meters


90 Meter Site
25
20
15
10
5
0
meters per second
jan
feb
march
april
may
june
july
august
sept
oct
nov
dec
ave
month
30 meters
60 meters
90 meters


90 Meter Site
900
800
700
600
500
400
300
200
100
0
Watts Per Square Meters
jan
feb
march
april
may
june
july
august
sept
oct
nov
dec
ave
months
30 meters
60 meters
90 meters

3.2 Solar Energy

According to the Texas Renewable Energy Industries Association (TREIA), renewable energy is any energy resource that is naturally regenerated over a short time scale and derived directly from the sun, indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy).[102] Obviously solar energy qualifies as a renewable energy source.

Many solar powered systems work in two stages. Generally, the first stage gathers solar energy and turns it into heat. The second stage transforms that heat into electricity. Solar panels are used for the first stage. A conventional generator is used to turn the heat into electricity.

Though it may not be the cheapest form of renewable energy, but it is very efficient. If an area of 100 miles by 100 miles were covered with a trough solar system, it would generate enough electricity to for the entire nation.[103]

Solar power plants produce electric power by converting the sun's energy into high temperature heat using various mirror configurations. The heat is channeled through a conventional generator. The plants consist of two parts the collector of the solar energy and the other converts it into heat. There are three solar thermal power systems currently being developed by U.S. industry: parabolic troughs, power towers, and dish/engine systems. Because these technologies involve a thermal intermediary, they can be readily hybridized with fossil fuel and in some cases adapted to utilize thermal storage. The

---

[102] http://www.treia.org/redefinition.htm
[103] http://www.energylan.sanda.gov/sunlab/overview.htm

primary advantage of hybridization and thermal storage is that the technologies can provide dispatch able power and operate during periods when solar energy is not available. Hybridization and thermal storage can enhance the economic value of the electricity produced and reduce its average cost[104].

3.2.1 Parabolic Troughs

Parabolic trough technology is currently the most proven solar thermal electric technology. This is primarily due to nine large commercial-scale solar power plants, the first of which has been operating in the California Mojave Desert since 1984. These plants range in size from 14 to 80 MW and represent a total of 354 MW of installed electric generating capacity. Large fields of parabolic trough collectors supply the thermal energy used to produce steam for a Rankine steam turbine/generator cycle[105].

The collector field consists of a large field of single-axis tracking parabolic trough solar collectors. The solar field is modular in nature and is composed of many parallel rows of solar collectors aligned on a north-south horizontal axis. Each solar collector has a linear parabolic-shaped reflector that focuses the sun's direct beam radiation on a linear receiver located at the focus of the parabola. The collectors track the sun from east to west during the day to ensure that the sun is continuously focused on the linear receiver. A heat transfer fluid (HTF) is heated as it circulates through the receiver and returns to a series of heat exchangers in the power block where the fluid is used to generate high-pressure superheated steam. The superheated steam is then fed to a conventional reheat

---

[104] Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996.
[105] Cohen, G., and S. Frier, "Ten Years of Solar Power Plant Operation in the Mojave Desert", Proceedings of Solar 97, the 1997 ASES Annual Conference, Washington, D.C. April, 1997.

steam turbine/generator to produce electricity. The spent steam from the turbine is condensed in a standard condenser and returned to the heat exchangers through condensate and feed water pumps to be transformed back into steam. Condenser cooling is provided by mechanical draft wet cooling towers. After passing through the HTF side of the solar heat exchangers, the cooled HTF is re-circulated through the solar field[106].

The Integrated Solar Combined Cycle System (ISCCS) is a new design concept that integrates a parabolic trough plant with a gas turbine combined-cycle plant. The ISCCS has generated much interest because it offers an innovative way to reduce cost and improve the overall solar-to-electric efficiency. The ISCCS uses solar heat to supplement the waste heat from the gas turbine in order to augment power generation in the steam Rankine bottoming cycle. In this design, solar energy is generally used to generate additional steam and the gas turbine waste heat is used for preheat and steam superheating[107].

---

[106] Meinecke, W., and M. Bohn, Solar Energy Concentrating Systems: Applications and Technologies, Heidelberg, Germany, 1995.

[107] Meinecke, W., and M. Bohn, Solar Energy Concentrating Systems: Applications and Technologies, Heidelberg, Germany, 1995.

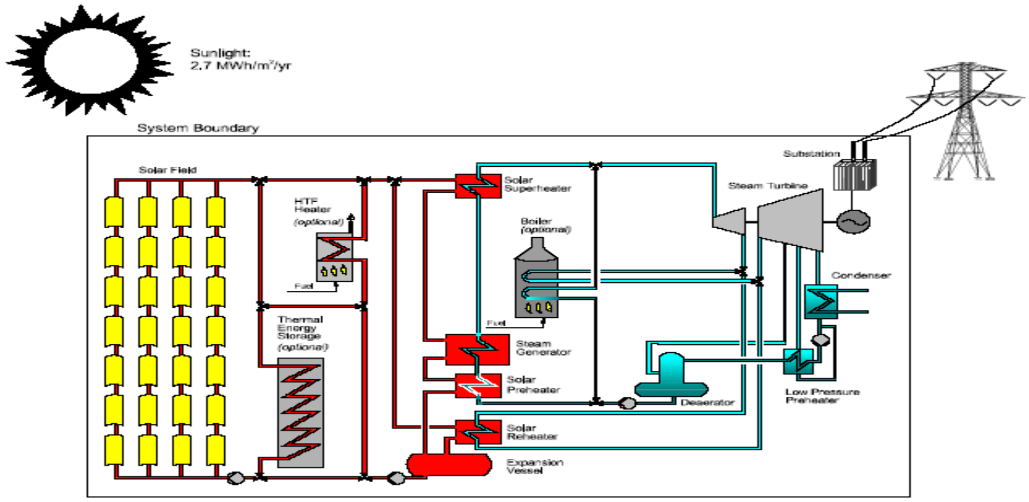


Figure 1. Solar/Rankine parabolic trough system schematic [1].

Figure 40: Parabolic Trough System

3.2.2 Power Towers

Power Tower systems use a circular field array of large individually tracking mirrors to focus sunlight onto a central receiver mounted on top of a tower. A heat transfer fluid heated in the receiver is then used to generate steam, which is used in a conventional turbine to produce electricity. Individual commercial plants can produce anywhere from 30 to 400 megawatts of electricity. They are unique because they have the ability to efficiently store solar energy and dispatch electricity to the grid when needed[108].

In a molten-salt solar power tower, liquid salt at 290ºC is pumped from a cold storage tank through the receiver where it is heated to 565ºC and then on to a hot tank for storage. When power is needed from the plant, hot salt is pumped to a steam generating system that produces steam. From the steam generator, the salt is returned to the cold tank where it is stored and eventually reheated in the receiver[109].

---

108 Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996.
109 Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996.

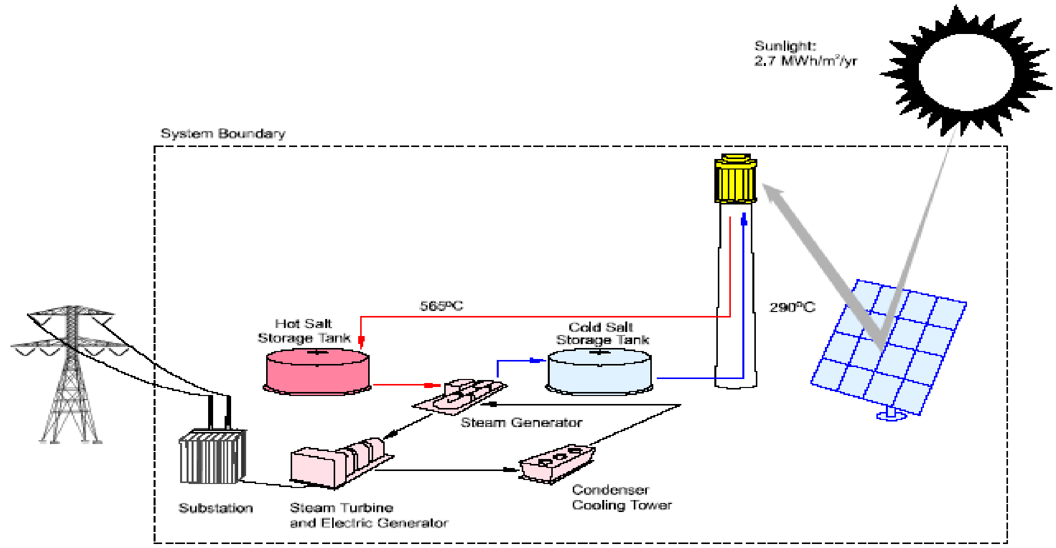


Figure 1. Molten-salt power tower system schematic (Solar Two, baseline configuration).

Figure 41: Power Towers

Solar One, which operated from 1982 to 1988, was the world's largest power tower plant. In that plant, water was converted to steam in the receiver and used directly to power a conventional Rankine-cycle steam turbine. The heliostat field consisted of 1818 heliostats of 39.3 m reflective area each. The project met most of its technical objectives by demonstrating the feasibility of generating power with a power tower, the ability to generate 10 MW for eight hours a day at summer solstice and four hours a day near winter solstice. During its final year of operation, Solar One's availability during hours of sunshine was 96% and its annual efficiency was about 7%. The efficiency was due to the small size. The Solar One thermal storage system stored heat from solar-produced steam in a tank filled with rocks and sand using oil as the heat-transfer fluid. The system extended the plant's power-generation capability into the night and provided heat for generating low-grade steam for keeping parts of the plant warm during off-hours and for morning startup[110].

Southern California Edison joined with the U.S. Department of Energy to redesign the Solar One plant to include a molten-salt heat-transfer system. The goals of the redesigned plant, called Solar Two, were to validate nitrate salt technology, to reduce the technical and economic risk of power towers, and to stimulate the commercialization of power tower technology. Solar Two has produced 10 MW of electricity with enough thermal storage to continue to operate the turbine at full capacity for three hours after the sun has set[111].

The inexpensive and efficient energy storage system that the power towers provide give it a competitive advantage. Table 2 shows a comparison of the predicted cost and length of storage for the three various types of solar energy. It shows how the power towers are the cheapest, most efficient, and longest lasting. The thermal energy storage in the power towers allow for electricity to be dispatched to the grid when the demand for power is the highest. This increases the monetary value of the electricity being provided[112].

---

[110] Winter, C.-J., R. Sizmann, and L. Vant-Hull, eds., Solar Power Plants - Fundamentals, Technology, Systems.
[111] Central Receiver Commercialization Plan, Bechtel National Inc., for the California Energy Commission: June 1995.
[112] Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.

Table 2. Comparison of solar-energy storage systems.

	Installed cost of energy storage for a 200 MW plant ($/kWhr$_e$)	Lifetime of storage system (years)	Round-trip storage efficiency (%)	Maximum operating temperature (°C/°F)
Molten-Salt Power Tower	30	30	99	567/1,053
Synthetic-Oil Parabolic Trough	200	30	95	390/734
Battery Storage Grid Connected	500 to 800	5 to 10	76	N/A

Table 11: Comparison of Solar Energy Storage Systems

Source: Cost Analysis of Energy Storage for Electric Utility Applications

3.2.3 Dish/Engine Systems

Dish/Engine systems use an array of parabolic dish-shaped mirrors (deflect 92%of the sunlight) to focus solar energy onto a receiver located at the focal point of the dish. Fluid in the receiver is heated to 750 C and used to generate electricity in a small engine attached to the receiver. Engines currently in use include Stirling and Brayton cycle engines. Several prototype dish/engine systems, ranging in size from 7 to 25 kW have been deployed in various locations in the U.S. and abroad. High optical efficiency and low startup losses make dish/engine systems the most efficient (29.4%) of all solar technologies[113].

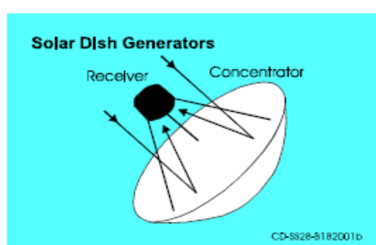


Figure 3. Solar dish/engine system.

Figure 42: Solar Dish Generators

[113] Washom, B., "Parabolic Dish Stirling Module Development and Test Results," Proceedings of the IECEC.

Dish/engine systems utilize concentrating solar collectors that track the sun in two axes. A reflective surface reflects incident solar radiation to a small region called the focus. The size of the engine determines the size of the solar concentrator for dish/engine systems. At maximum direct solar isolation of 1000 W/m^2 a 25-kW dish Stirling system's concentrator has a diameter of approximately 10 meters. The concentrator's optical design and accuracy determine the concentration ratio, which is usually over 95%. Tracking in two axes is accomplished in one of two ways, azimuth-elevation tracking and polar tracking. In azimuth-elevation tracking, the dish rotates in a plane parallel to the earth and in another plane perpendicular to it. This gives the collector left/right and up/down rotations. Rotational rates vary throughout the day but can be easily calculated. Most of the larger dish/engine systems use this method of tracking. In polar tracking the collector rotates about and axis parallel to the earth's axis rotation. The receiver absorbs the energy reflected by the concentrator and transfers it to the engine's working fluid. The surface that absorbs the energy is placed behind the focus of the concentrator to reduce the flux; an aperture is placed on the focus to reduce radiation and convection heat loss. The receivers are typically about 90% efficient in transferring energy delivered by the concentrator to the engine[114].

The engine in a dish/engine system converts heat to mechanical power in a matter similar to conventional engines. This is done by compressing working fluid when it is cold, heating the compressed working fluid, and then expanding it through a turbine to produce work. There are two types of engines, the Stirling engine and the Brayton engine, each of which has its own interface. The electrical output in the current

---

[114] Washom, B., "Parabolic Dish Stirling Module Development and Test Results," Proceedings of the IECEC.

dish/engine systems is about 25kW for the Stirling system and about 30kw for the Brayton system[115].

The dish/engine systems have the attributes of high efficiency, versatility, and hybrid operation. High efficiency contributes to high power densities and low cost. Depending on the system and the site, dish/engine systems require approximately 1.2 to 1.6 ha of land per MW. System installed costs are $12,000/kW for solar-only prototypes and approach $1,400/kW for hybrid systems in mass production. This relatively low-cost potential is a result of dish/engine system's inherent high efficiency[116].

The dish/engines versatility and hybrid capability make them capable of a wide range of potential applications. They are capable of providing power ranging from kilowatts to gig watts. However, it is expected that dish/engine systems will have their greatest impact in grid-connected applications in the 1 to 50 MW power range. The largest potential market for dish/engine systems is large-scale power plants connected to the utility grid. The ability to be quickly installed, inherent modularity, and have minimal environmental impact makes them an ideal candidate for new peaking power installations. The output from many modules can be ganged together to form a dish/engine farm and produce a collective output of virtually any desired amount. In addition, systems can be added as needed to respond to demand increases. Although dish/engine systems do not currently have a cost-effective energy storage system, their ability to operate with fossil fuels makes them dispatch able. This capability along with

---

115 Beninga, K, et. al., "Performance Results for the SAIC/STM Prototype Dish/Stirling System," Proceedings of the 1997 ASME International Solar Energy Conference, Washington, D.C., 1997.
116 Washom, B., "Parabolic Dish Stirling Module Development and Test Results," Proceedings of the IECEC.

their modularity and relatively minor environmental impacts suggests that grid support benefits could be a major advantage of these systems[117].

3.2.4 Solar Energy Conversion

The Stirling cycle engine used are high temperature, high pressure externally heated engines that use hydrogen or helium working gas. The working gas is alternately heated and cooled by constant temperature and constant volume processes. The figure below shows the four basic processes of a Stirling cycle engine. The best Stirling engine achieves thermal to electric conversion efficiencies of about 40%. The Stirling engine is the leading candidate for dish/engine systems because of their high efficiency and their external heating makes them adaptable to concentrated solar flux[118].

---

[117] Beninga, K, et. al., "Performance Results for the SAIC/STM Prototype Dish/Stirling System," Proceedings of the 1997 ASME International Solar Energy Conference, Washington, D.C., 1997.
[118] Walker, G., "Stirling Engines", Clarendon Press, Oxford, England, 1980.

SOLAR DISH ENGINE

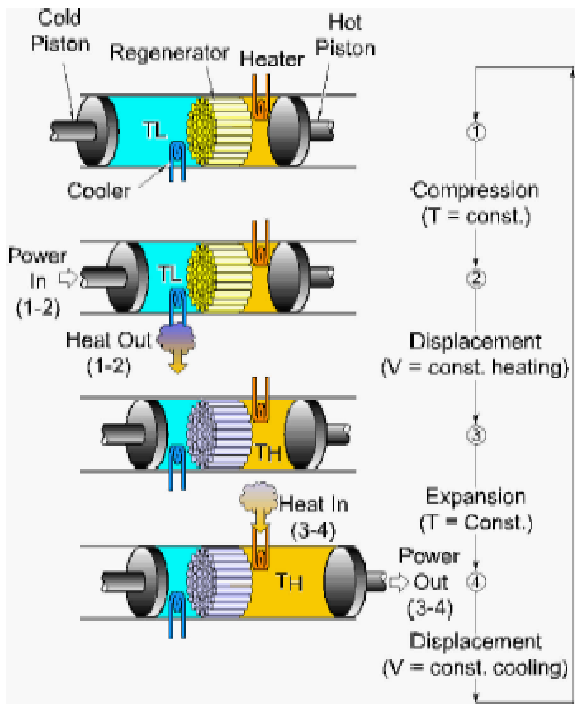


Figure 43: Solar Dish Engine

Source: West, C.D., "Principles and Applications of Stirling Engines," Van Nostrand Reinhold Company

The Brayton engine is an internal combustion engine, which produces power by the controlled burning of fuel. In the engine air is compressed, fuel is added and the mixture is burned. The solar heat is used to replace the fuel that is normally used in systems like this. In the gas turbine the burning is continuous and the expanding gas is used to turn a turbine and alternator. The efficiencies for this thermal to electric engine are just over 30%. The picture below is a model of a Brayton dish/engine system[119].

[119] West, C.D., "Principles and Applications of Stirling Engines," Van Nostrand Reinhold Company, New York, NY, 1986.

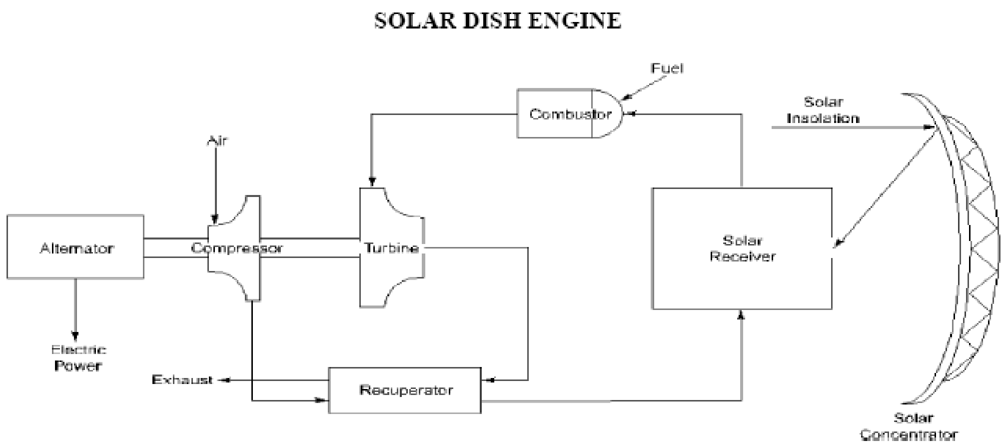


Figure 44: Solar Dish Engine

Source: West, C.D., "Principles and Applications of Stirling Engines," Van Nostrand Reinhold Company

.

Towers and troughs are best suited for large, grid-connected power projects in the 30-200 MW size, whereas, dish/engine systems are modular and can be used in single dish applications or grouped in dish farms to create larger multi-megawatt projects. Parabolic trough plants are the most mature solar power technology available today and the technology most likely to be used for near-term deployments. The modular nature of dishes will allow them to be used in smaller, high-value applications. Towers and dishes offer the opportunity to achieve higher solar-to-electric efficiencies and lower cost than parabolic trough plants[120].

[120] Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996.

Table 1. Characteristics of solar thermal electric power systems.

	Parabolic Trough	Power Tower	Dish/Engine
Size	30-320 MW*	10-200 MW*	5-25 kW*
Operating Temperature (°C/°F)	390/734	565/1,049	750/1,382
Annual Capacity Factor	23-50%*	20-77%*	25%
Peak Efficiency	20%(d)	23%(p)	29.4%(d)
Net Annual Efficiency	11(d')-16%*	7(d')-20%*	12-25%*(p)
Commercial Status	Commercially Available	Scale-up Demonstration	Prototype Demonstration
Technology Development Risk	Low	Medium	High
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes
Cost			
$/m^2	630-275*	475-200*	3,100-320*
$/W	4.0-2.7*	4.4-2.5*	12.6-1.3*
$/W$_p$†	4.0-1.3*	2.4-0.9*	12.6-1.1*

* Values indicate changes over the 1997-2030 time frame.

† $/W$_p$ removes the effect of thermal storage (or hybridization for dish/engine). See discussion of thermal storage in the power tower TC and footnotes in Table 4.

(p) = predicted; (d) = demonstrated; (d') = has been demonstrated, out years are predicted values

Table 12: Solar Thermal Electric Power Systems

Source: Cost Analysis of Energy Storage for Electric Utility Applications

3.2.5 The Future of the Three Solar Systems

The 1997 baseline technology was assumed to be the 30 MW SEGS VI plant. The SEGS VI plant is a hybrid solar/fossil plant that uses 25% fossil input to the plant on an annual basis in a natural gas-fired steam boiler. The plant uses the second generation Luz LS-2 parabolic trough collector technology. The solar field was composed of 800 LS-2 SCAs arranged in 50 parallel flow loops with 16 SCAs per loop. The year 2000 plant is assumed to be the next parabolic trough plant built which is assumed to be the 80 MW SEGS X design. The primary changes from the 1997 baseline technology is that this plant size increases to 80 MW, the LS-3 collector is used in place of the LS-2, the HCE uses an improved selective coating, and flex hoses have been replaced with ball joint assemblies.

The solar field is composed of 888 LS-3 SCAs arranged in 148 parallel flow loops with 6 SCAs per loop[121].

The plans for 2005 are to have the power plant scaled up to 160 MW. Six hours of thermal storage is added to the plant to allow the plant to operate at up to a 40% annual capacity factor from solar input alone. No backup fossil operating capability is included. The LS-3 parabolic trough collector continues to be used, but the solar field size is scaled up to allow the plant to achieve higher annual capacity factor using 2,736 SCAs arranged in 456 parallel flow loops with 6 SCAs per loop. The predicted power plant for 2010 is scaled up to 320 MW and operates to an annual capacity factor of 50% from solar input. Again no fossil backup operation is included. This design incorporated the next generation of trough collector, possibly something like the Luz LS-4 advanced trough collector. The solar field continues to use a heat transfer fluid but the collector is assumed to have a fixed tilt of 8^{o}[122].

Increasing the performance of the solar collectors and power plant are one of the primary opportunities for reducing the cost of trough technology. Collector performance improvements can come from developing new more efficient collector technologies and components but often also by improving the reliability and lifetime of existing components. Table 4 shows the annual performance and net solar-to-electric efficiency of each of the technology cases described above[123].

The 1997 baseline case performance represents the actual 1996 performance of the 30 MW SEGS VI plant. During 1996, the SEGS VI plant had an annual net solar-to-

[121] "Solar Electric Generating System IX Technical Description", LUZ International Limited: 1990.
[122] Winter, C.-J., R. Sizmann, and L. Vant-Hull, eds., Solar Power Plants - Fundamentals, Technology, Systems, Economics.
[123] O&M Cost Reduction in Solar Thermal Electric Plants - 2nd Interim Report on Project Status, KJC Operating Company, for Sandia National Laboratories: July 1, 1996.

electric efficiency of 10.7%. The year 2000 technology shows a 20% improvement in net solar to electric efficiency over the 1997 baseline system performance. This is achieved by using current technologies and designs; by reducing HCE heat losses and electric parasitic. New HCEs have an improved selective surface with a higher absorption and a 50% lower emittance. This helps reduce trough receiver heat losses by one third. The ball joint assemblies and the reduced number of SCAs per collector loop will reduce HTF pumping parasitic. A new 80 MW plant would be expected to have a net solar-to-electric efficiency of 12.9%[124].

The 2005 technology shows a 7% increase in efficiency primarily as a result of adding thermal storage. Thermal storage eliminates dumping of solar energy during power plant start-up and during peak solar conditions when solar field thermal delivery is greater than power plant capacity. Thermal storage also allows the power plant to operate independently of the solar field. This allows the power plant to operate near full load efficiency more often, improving the annual average power block efficiency. The thermal storage system is assumed to have an 85% round trip efficiency. Annual net solar-to-electric efficiency increases to 13.8%.

Table 4 shows the total plant capital cost for each technology case on a $/kW/m basis. The technology shows a 30% cost reduction on a $/kW basis and a 55% reduction on a $/m basis. These cost reductions are due to: larger plants being built increased collector production volumes, building projects in solar power park developments, and savings through competitive bidding. For trough plants, a 49% reduction in the power block equipment cost results by increasing the power plant size from 30 to 320 MW. The

---

[124] O&M Cost Reduction in Solar Thermal Electric Plants - 2nd Interim Report on Project Status, KJC Operating Company, for Sandia National Laboratories: July 1, 1996.

increased production volume of trough solar collectors reduces trough collector costs by 44%. A 10% cost reduction is assumed for competitive bidding in later projects. The annual operation and maintenance (O&M) costs for each technology are shown in Table 4. O&M costs show a reduction of almost 80%. This large cost reduction is achieved through increasing size of the power plant, increasing the annual solar capacity factor, operating plants in a solar power park environment, and continued improvements in O&M efficiencies. Larger plants reduce operator labor costs because approximately the same number of people is required to operate a 320 MW plant as are required for a 30 MW plant. In addition, about one third of the cost reduction is assumed to occur because of improved O&M efficiency resulting from improved plant design and O&M practices based on the results of the KJC O&M Cost Reduction Study[125].

Table 4. Performance and cost indicators.

INDICATOR NAME	UNITS	1997 SEGS VI* Base Case	+/-%	2000 SEGS LS-3 25% Fossil†	+/-%	2005 SEGS LS-3 w/Storage	+/-%	2010 SEGS LS-4 w/Storage	+/-%	2020 SEGS DSG w/Storage	+/-%	2030 SEGS DSG w/Storage	+/-%
Plant Design													
Plant Size	MW	30		80		161		320		320		320	
Collector Type		LS-2		LS-3		LS-3		LS-4		LS-4		LS-4	
Solar Field Area	m^2	188,000		510,120		1,491,120		3,531,600		3,374,640		3,204,600	
Thermal Storage	Hours	0		0		6		10		10		10	
	MWh_t	0		0		3,000		10,042		9,678		9,678	
Performance													
Capacity Factor	%	34		34		40		50		50		50	
Solar Fraction (Net Elec.)	%	66		75		100		100		100		100	
Direct Normal Insolation	kWh/m^2-yr	2,891		2,725		2,725		2,725		2,725		2,725	
Annual Solar to Elec. Eff.	%	10.7		12.9		13.8		14.6		15.3		16.1	
Natural Gas (HHV)	GJ	350,000		785,000		0		0		0		0	
Annual Energy Production	GWh/yr	89.4		238.3		564.1		1,401.6		1,401.6		1,401.6	
Development Assumptions													
Plants Built Per Year		2		2		2		3		3		3	
Plants at a Single Site		5		5		5		5		5		5	
Competitive Bidding Adj.		1.0		1.0		0.9		0.9		0.9		0.9	
O&M Cost Adjustment		1.0		0.9		0.85		0.7		0.6		0.6	
Operations and Maintenance Cost													
Labor	$/kW-yr			32	25	21	25	14	25	11	25	11	25
Materials				31	25	31	25	29	25	23	25	23	25
Total O&M Costs		107		63		52		43		34		34	

Notes:
1. The columns for "+/- %" refer to the uncertainty associated with a given estimate.
2. The construction period is assumed to be 1 year.
3. Totals may be slightly off due to rounding.

* SEGS VI Capital cost of $99.3M in 1989$ is adjusted to $119.2M in 1997$. Limited breakdown of costs by subsystem is available. Performance and O&M costs based on actual data.

† By comparison, an ISCCS plant built in 2000 with an 80 MW solar increment would have a solar capital cost of $2,400/kW, annual O&M cost of $48/kW, and an annual net solar-to-electric efficiency of 13.5%[1].

‡ To convert to peak values, the effect of thermal storage must be removed. A first-order estimate can be obtained by dividing installed costs by the solar multiple (i.e., SM={peak collected solar thermal power}÷{power block thermal power}).

[125] Winter, C.-J., R. Sizmann, and L. Vant-Hull, eds., Solar Power Plants - Fundamentals, Technology, Systems, Economics.

Table 4. Performance and cost indicators.(cont.)

INDICATOR NAME	UNITS	1997 SEGS VI * Base Case	+/-%	2000 SEGS LS-3 25% Fossil †	+/-%	2005 SEGS LS-3 w/Storage	+/-%	2010 SEGS LS-4 w/Storage	+/-%	2020 SEGS DSG w/Storage	+/-%	2030 SEGS DSG w/Storage	+/-%
Capital Cost													
Structures/Improvements	$/kW	54		79	15	66	15	62	15	60	15	58	15
Collector System		3,048		1,138	25	1,293	25	1,327	25	1,275	25	1,158	25
Thermal Storage System		0		0		392	+50/-25	528	+50/-25	508	+50/-25	508	+50/-25
Steam Gen or HX System				109	15	90	15	81	15	80	15	79	15
Aux Heater/Boiler		120		164	15	0	15	0	15	0	15	0	15
Electric Power Generation				476	15	347	15	282	15	282	15	282	15
Balance of Plant		750		202	15	147	15	120	15	120	15	120	15
Subtotal (A)		3,972		2,168		2,336		2,400		2,326		2,205	
Engr, Proj./Const. Manag.	A * 0.08			174		187		192		186		176	
Subtotal (B)		3,972		2,342		2,523		2,592		2,512		2,382	
Project/Process Conting	B * 0.15			351		378		389		377		357	
Total Plant Cost		3,972		2,693		2,901		2,981		2,889		2,739	
Land @ $4,942/ha				11		15		18		17		17	
Total Capital Requirements	$/kW	3,972		2,704		2,916		2,999		2,907		2,756	
	$/kW$_{peak}$ ‡	3,972		2,704		1,700		1,400		1,350		1,300	
	$/m^2	634		424		315		272		276		275	
Operations and Maintenance Cost													
Labor	$/kW-yr			32	25	21	25	14	25	11	25	11	25
Materials				31	25	31	25	29	25	23	25	23	25
Total O&M Costs		107		63		52		43		34		34	

Notes:

1. The columns for "+/- %" refer to the uncertainty associated with a given estimate.
2. The construction period is assumed to be 1 year.
3. Totals may be slightly off due to rounding.

* SEGS VI Capital cost of $99.3M in 1989$ is adjusted to $119.2M in 1997$. Limited breakdown of costs by subsystem is available. Performance and O&M costs based on actual data.

† By comparison, an ISCCS plant built in 2000 with an 80 MW solar increment would have a solar capital cost of $2,400/kW, annual O&M cost of $48/kW, and an annual net solar-to-electric efficiency of 13.5%[1].

‡ To convert to peak values, the effect of thermal storage must be removed. A first-order estimate can be obtained by dividing installed costs by the solar multiple (i.e., SM={peak collected solar thermal power}÷ {power block thermal power}).

Table 13: Performance and Cost Indicators

The 1997 baseline technology was the Solar Two project with a 43 MW molten nitrate salt central receiver with three hours of thermal storage and 81,000m of heliostats. The solar input was converted in the existing 10 MW net Rankine steam cycle power plant. The first commercial scale power tower project following the Solar Two project was assumed to be a 145 MW molten nitrate salt central receiver with seven hours of thermal storage and 275,000 m of heliostats. In 2010, solar-only nitrate-salt power tower plants are expected to become competitive. The receiver is scaled up to 1,400 MW with thirteen hours of thermal storage and 2,477,000 m of heliostats. The solar plant is attached to a 200 MW Rankine cycle steam turbine and would achieve an annual capacity factor of about 65%[126].

[126] Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996.

All annual energy estimates presented in Table 3 are based on simulations with the SOLERGY computer code. The inputs to the SOLERGY computer code (mirror reflectance, receiver efficiency, startup times, parasitic power, and plant availability) are based on measured data taken from the 10 MW Solar One and the small molten-salt receiver system test conducted in the late 1980's. The SOLERGY code itself has been validated with a full year of operation at Solar One. Collection of this data is one of the main goals of the Solar Two demonstration project. The costs presented in Table 3 for Solar Two are the actual incurred for the project as reported by Southern California Edison.

During 1997, the plant was completing its startup phase. Solar Two is a sub-commercial-scale plant that was designed to demonstrate the essential elements of the technology. To save capital costs, the plant was sized to have a 20% capacity factor and three hours of thermal storage. The solar-to-electric annual efficiency at Solar Two will be significantly lower than initial commercial-scale plants because: Unlike the commercial plant, Solar Two does not use a reheat turbine cycle. Gross Rankine-cycle efficiency will be revised from 42% to 33%. The Solar Two heliostat field is not state-of-the-art. The heliostats being used employ an old control strategy and the mirrors have experienced degradation due to corrosion. Also, the reflectance of these older mirrors is below today's standard (89% vs. 94%). Reflectance, corrosion, and controls are not problems with current heliostat technology. Combining the factors, the simple equation below shows how the 15% annual efficiency for the commercial plant is equivalent to about 8.5% at Solar Two[127].

$$8.5\% = 15\% * (0.33/0.42) * (0.88/0.91) * (0.9) * (0.75/0.9)$$

[127] Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996.

Following successful operation of Solar Two, the first commercial scale power tower is assumed to be built in the Southwestern U.S. At the present time, the Solar Two business consortium is comfortable with scaling up the Solar Two receiver to 145 MW. This larger receiver will be combined with a state-of-the-art glass heliostat field, a next-generation molten-salt steam generator design, a high-efficiency steam turbine cycle, and will employ modern balance of plant equipment that will improve plant availability. To reduce the financial risk associated with the deployment of this first commercial-scale plant and to lower the cost of delivering solar power, the plant will likely be hybridized with a base-loaded fossil-fired plant. Hybridization significantly reduces the cost of producing solar power relative to a solar-only design for the following reasons: Capital costs for the solar turbine are reduced because only an increment to the base-load fossil turbine must be purchased. O&M costs are reduced because only an increment beyond the base-load O&M staff and materials must be used to maintain the solar-specific part of the plant[128].

The receiver in the plants is scaled-up another factor of 3.3 to 470 MW. The receiver materials will likely be improved relative to the 316 stainless steel tubes currently used at Solar Two. Stainless is limited to a peak incident flux of about 800 suns. SunLab and Rocketdyne are currently testing advanced receiver materials that appear capable of with standing greater than 1100 suns. This higher-concentration receiver will be able to absorb a given amount of solar energy with a smaller surface area. Reducing surface area improves efficiency because thermal losses are lowered. In addition, advanced manufacturing techniques currently being developed in a Sandia/Boeing

[128] O&M Cost Reduction in Solar Thermal Electric Plants - 2nd Interim Report on Project Status, KJC Operating Company, for Sandia National Laboratories: July 1, 1996.

research project will be employed to reduce the cost of the receiver and improve reliability. The improved economy of scale will significantly reduce the cost of the heliostats on a \$/m basis. In addition, increases in annual production are expected to lower heliostat costs[129].

In 2010, the first commercial-scale solar-only plants are assumed to be built. Scoping calculations at Sandia National Laboratories suggest that it is feasible to scale-up the receiver another factor of three to a rating of about 1,400 MW. If this receiver is attached to a 200 MW steam generation/turbine system, 13 hours of thermal storage (6,760 MWh) would be necessary to avoid overfill of the storage and a significant discard of solar energy. The annual capacity factor of this plant would be approximately 65%, and it would run at full turbine output nearly 24 hours/day during the summer months when the daylight hours are longer. During the winter, when days are shorter, the plant would shut down during several hours per night. Alternatively, the turbine could run at part load to maintain the turbine on line[130].

---

[129] Buck, R., P. Heller, and H. Koch, "Receiver Development for a Dish-Brayton System," San Antonio, TX, 1996.
[130] Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.

Table 3. Performance and cost indicators.

INDICATOR NAME	UNITS	Solar Two Prototype 1997	+/-%	Small Hybrid Booster 2000	+/-%	Large Hybrid Booster 2005	+/-%	Solar Only 2010	+/-%	Advanced Solar Only 2020	+/-%	Advanced Solar Only 2030	+/-%
Plant Size	MW	10		30		100		200		200		200	
Receiver Thermal Rating	MW_t	43		145		470		1,400		1,400		1,400	
Heliostat Size	m^2	40		95		150		150		150		150	
Solar Field Area	m^2	81,000		275,000		883,000		2,477,000		2,477,000		2,477,000	
Thermal Storage	Hours	3		7		6		13		13		13	
	MWh_t	114		550		1,600		6,760		6,760		6,760	
Performance													
Capacity Factor	%	20		43		44		65		77		77	
Solar Fraction		1.00		0.22		0.22		1.00		1.00		1.00	
Direct Normal Insolation	$kWh/m^2/yr$	2,700		2,700		2,700		2,700		2,700		2,700	
Annual Solar to Elec. Eff.	%	8.5	+5/-20*	15.0	+5/-20	16.2	+5/-20	17.0	+5/-20	20.0	+5/-20	20.0	+5/-20
Annual Energy Production	GWh/yr	17.5		113.0		385.4		1,138.8		1,349.0		1,349.0	
Capital Cost													
Structures & Improvements	$\$/kW_{nameplate}$			116	15	60	15	50	15	50	15	50	15
Heliostat System		†		1,666	25	870	25	930	25	865	25	865	25
Tower/Receiver System		†		600	25	260	25	250	25	250	25	250	25
Thermal Storage System		370		420	15	240	15	300	15	300	15	300	15
Steam Gen System		276		177	15	110	15	85	15	85	15	85	15
EPGS/Balance of Plant		†		417	15	270	15	400	15	400	15	400	15
Master Control System		†		33	15	10	15	15	15	15	15	15	15
Directs SubTotal (A)				3,429		1,820		2,030		1,965		1,965	
Indirect Engineering/Other	A * 0.1			343		182		203		197		197	
SubTotal (B)				3,772		2,002		2,233		2,162		2,162	
Project/Process Contingency	B * 0.15			566		300		335		325		325	
Total Plant Cost‡				4,338		2,302		2,568		2,487		2,487	
Land (@ $4,942/hectare)				27		27		37		37		37	
Total Capital Requirements	$\$/kW_{nameplate}$			4,365		2,329		2,605		2,523		2,523	
	$\$/kW_{peak}$ *			2,425		1,294		965		934		934	
	$\$/m^2$			476		264		210		204		204	
Operation and Maintenance Cost													
Fixed Labor & Materials	$/kW-yr												
Total O&M Costs		300		67	25	23	25	30	25	25	25	25	25

Notes:

1. The columns for "+/-%" refer to the uncertainty associated with a given estimate.
2. The construction period is assumed to be 2 years.

* Design specification for Solar Two. This efficiency is predicted for a mature operating year.

† Cost of these items at Solar Two are not characteristic of a commercial plant and have, therefore, not been listed.

‡ Total plant cost for Solar Two are the actuals incurred to convert the plant from Solar One to Solar Two. The indirect factors listed do not apply to Solar Two.

* To convert to peak values, the effect of thermal storage must be removed. A first-order estimate can be obtained by dividing installed costs by the solar multiple (i.e., SM = {peak collected solar thermal power} ÷ {power block thermal power}). For example, as discussed in the text, in 2010 the peak receiver absorbed power is 1400 MW_t. If this is attached to a 220 MW_e turbine (gross) with a gross efficiency of 42%, thermal demand of the turbine is 520 MW_t. Thus, SM is 2.7 (i.e., 1400/520) and peak installed cost is 2605/2.7 = $965/$kW_{peak}$. Solar multiples for years 1997, 2000, and 2005 are 1.2, 1.8, and 1.8, respectively.

Table 14: Performance and Cost Indicators

The base-year technology (1997) is represented by the 25 kW dish-Stirling systems developed by McDonnell Douglas (MDA) in the mid 1980s. Similar cost estimates have been predicted for the Science Applications International Corporation (SAIC) system with the STM 4-120 Stirling engine. Southern California Edison Company operated a MDA system on a daily basis from 1986 through 1988. During its last year of operation, it achieved an annual efficiency of 12%. Near-term systems (2000) are expected to achieve significant availability improvements resulting in an annual efficiency of 23%. The MDA system consistently achieved daily solar efficiencies in excess of 23% when it was operational. The technologies should see a modest reduction in the cost of the dish concentrator simply as a result of the benefits of additional design iteration[131].

Performance for 2005 is largely based on one of the solarizable engines being commercialized for a non-solar application. Use of a production level engine will have a significant impact on engine cost as well as overall system cost. This milestone will help trigger a fledgling dish/engine industry. A production rate of 2,000 modules per year is assumed. Achieving a high production rate is the key to reducing component costs, especially for the solar concentrator. Predictions for years 2010 and beyond are based on the introduction of the heat-pipe solar receiver. SunLab is currently supporting heat-pipe solar receiver development in collaboration with industrial partners. The use of a heat-pipe receiver has already demonstrated performance improvements of well over 10% for the STM 4-120 compared to a direct-illumination receiver. By 2010 dish/engine technology is assumed to be approaching maturity. A typical plant may include several hundred to over a thousand systems. It is envisioned that a city located in the U.S. Southwest would have several 1 to 50 MW installations located primarily in its suburbs[132].

---

131 Washom, B., "Parabolic Dish Stirling Module Development and Test Results," Proceedings of the IECEC

132 Walker, G., "Stirling Engines"

Table 1. Performance and cost indicators.

INDICATOR NAME	UNITS	1980's Prototype 1997	+/-%	Hybrid System 2000	+/-%	Commercial Engine 2005	+/-%	Heat Pipe Receiver 2010	+/-%	Higher Production 2020	+/-%	Higher Production 2030	+/-%
Typical Plant Size, MW	MW	0.025		1	50	30	50	30	50	30	50	30	50
Performance													
Capacity Factor	%	12.4		50.0		50.0		50.0		50.0		50.0	
Solar Fraction	%	100		50		50		50		50		50	
Dish module rating	kW	25.0		25.0		25.0		27.5		27.5		27.5	
Per Dish Power Production	MWh/yr/dish	27.4		109.6		109.6		120.6		120.6		120.6	
Capital Cost													
Concentrator	$/kW	4,200	15	2,800	15	1,550	15	500	15	400	15	300	15
Receiver		200	15	120	15	80	15	90	15	80	15	70	15
Hybrid		---		500	30	400	30	325	30	270	30	250	30
Engine		5,500	15	800	20	260	25	100	25	90	25	90	25
Generator		60	15	50	15	45	15	40	15	40	15	40	15
Cooling System		70	15	65	15	40	15	30	15	30	15	30	15
Electrical		50	15	45	15	35	15	25	15	25	15	25	15
Balance of Plant		500	15	425	15	300	15	250	15	240	15	240	15
Subtotal (A)		10,580		4,805		2,710		1,360		1,175		1,045	
General Plant Facilities (B)		220	15	190	15	150	15	125	15	110	15	110	15
Engineering Fee, 0.1*(A+B)		1,080		500		286		149		128		115	
Project /Process Contingency		0		0		0		0		0		0	
Total Plant Cost		11,880		5,495		3,146		1,634		1,413		1,270	
Prepaid Royalties		0		0		0		0		0		0	
Init Cat & Chem. Inventory		120	15	60	15	12	15	6	15	6	15	6	15
Startup Costs		350	15	70	15	35	15	20	15	18	15	18	15
Other		0		0		0		0		0		0	
Inventory Capital		200	15	40	15	12	15	4	15	4	15	4	15
Land, @$16,250/ha		26		26		26		26		26		26	
Subtotal		696		196		85		56		54		54	
Total Capital Requirement		12,576		5,691		3,231		1,690		1,467		1,324	
Total Capital Req. w/o Hybrid		12,576		5,191		2,831		1,365		1,197		1,074	
Operation and Maintenance Cost													
Labor	¢/kWh	12.00	15	2.10	25	1.20	25	0.60	25	0.55	25	0.55	25
Material	¢/kWh	9.00	15	1.60	25	1.10	25	0.50	25	0.50	25	0.50	25
Total	¢/kWh	21.00		3.70		2.30		1.10		1.05		1.05	

Notes:

1. The columns for "+/-%" refer to the uncertainty associated with a given estimate.
2. The construction period is assumed to be <1year for a MW scale system.

Table 15: Performance and Cost Indicators

Source: O&M

The solar resources for generating power from concentrating solar power systems are plentiful. The amount of power that can be generated by a power plant depends on the amount of direct sunlight. The southwestern part of the United States potentially offers the best development opportunity for concentrating solar power. The solar electric generating system plants operate for nearly 100% of the on peak hours of Southern California Edison. The map of the United States below shows the amount of direct sunlight produced in various areas. It is said that with the perfect system, covering about 9% of Nevada could generate enough electric power for the entire country. The southwestern states are poised to reap large economic benefits from solar power.

California, Nevada, Arizona, and New Mexico are each implementing policies that will aid the development of their solar-based industries[133].

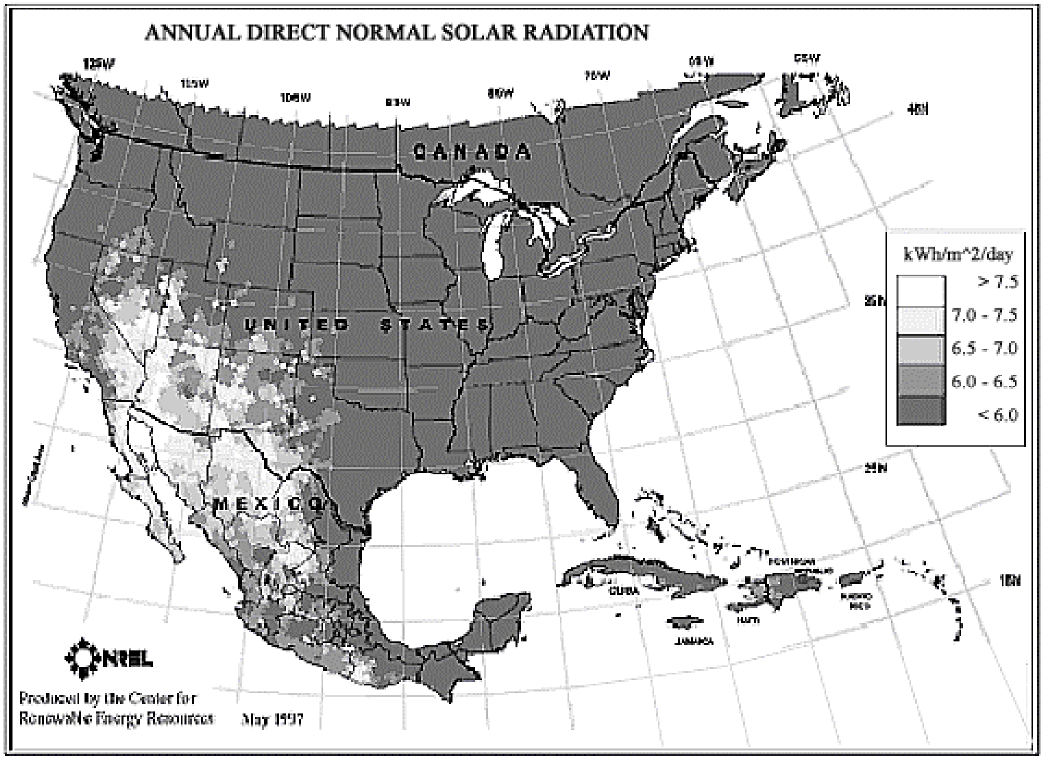


Figure 4. Direct normal insolation resource.

Figure 45: Annual Direct Normal Solar Radiation

In addition to the concentrating solar power projects under way in this country, a number of projects are being developed in India, Egypt, Morocco, and Mexico. In addition, independent power producers are in the early stages of design and development for potential parabolic trough power projects in Greece (Crete) and Spain. Given

[133] W. Fisher, “Energy and Environment into the Twenty First Century,” Environmental Geo Sciences, 1999..

successful deployment of one or more of these initial markets, additional project opportunities are expected in these and other regions.[134]

Analysts predict that the solar power industry will open several niche markets over the next 5 to 10 years. The U.S. Department of Energy estimates that by 2005 there will be as much as 500 megawatts of concentrating solar power capacity installed worldwide.[135]

3.2.6 Economics of Solar Power

There are four primary figures of merit: Net Present Value: Net Present Value (NPV) is the sum of all years' discounted after-tax cash flows. The NPV method is a valuable indicator because it recognizes the time value of money. Projects whose returns show positive NPVs are attractive. Internal Rate of Return: Internal rate of return (IRR) is defined as the discount rate at which the after-tax NPV is zero. The calculated IRR is examined to determine if it exceeds a minimally acceptable return, often called the hurdle rate. The advantage of IRR is that, unlike NPV, its percentage results allow projects of vastly different sizes to be easily compared[136].

To calculate a levelized cost of energy (COE), the revenue stream of an energy project is discounted using a standard rate to yield an NPV. This NPV is levelized to an annual payment and then divided by the project's annual energy output to yield a value in cents per kWh. Energy policy analysts and project evaluators to develop first-order assessments of a project's attractiveness and then decide if the project is worthwhile often

[134] http://www.energylan.sanda.gov/sunlab/overview.htm
[135] http://www.energylan.sanda.gov/sunlab/overview.htm
[136] Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.

use the COE. Traditional utility revenue requirement analyses are cost-based, allowed costs, expenses, and returns are added to find a stream of revenues that meet the return criteria. A payback calculation compares revenues with costs and determines the length of time required to recoup the initial investment. A Simple Payback Period is often calculated without regard to the time value of money[137].

Four distinct ownership perspectives were identified for this analysis. Each reflects a different financial structure, financing costs, taxes, and desired rates of return. The four ownership scenarios are: Generating Company (GenCo) The GenCo takes a market-based rate of return approach to building, owning, and operating a power plant. The company uses balance sheet or corporate finance, where debt and equity investors hold claim to a diversified pool of corporate assets. For this reason, GenCo debt and equity are less risky than for an IPP and therefore GenCos pay lower returns. A typical GenCo capital structure consists of 35% debt at a 7.5% annual return and 65% equity at 13% return. Although corporate finance might assume the debt to equity ratio remains constant over the project's life and principal is never repaid, it is often informative to explicitly show the effect of the project on a stand-alone financial basis. Therefore, to be conservative, the debt term is estimated as 28 years for a 30-year project, and all the debt is repaid assuming level mortgage-style payments. Flow-through accounting is used so that the corporate GenCo receives maximum benefit from accelerated depreciation and tax credits[138].

---

[137] Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.
[138] Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.

Independent Power Producer (IPP): An IPP's debt and equity investment is secured by only the one project, not by a pool of projects or other corporate assets, as is the case for a GenCo. In this project finance approach, a typical capital structure is 70% debt at 8.0% annual return and 30% equity at a minimum 17% return. A 6-month Debt Service Reserve is maintained to limit repayment risks. Debt term for an IPP project is generally 15 years, with a level mortgage-style debt repayment schedule. Flow-through accounting is used to allow equity investors to realize maximum benefit from accelerated depreciation and tax credits[139].

Regulated Investor-Owned Utility (IOU): The regulated IOU perspective analyzes a project with a cost-based revenue requirements approach. As described by the EPRI Technical Assessment Guide (TAG), returns on TM investment are not set by the market, but by the regulatory system. In this calculation, operating expenses, property taxes, insurance, depreciation, and returns are summed to determine the revenue stream necessary to provide the approved return to debt and equity investors. Use of a Fixed Charge Rate is a way to approximate the levelized COE from this perspective. IOU capital structure is estimated as 47% debt at a 7.5% annual return; 6% preferred stock at 7.2%; and 47% common stock at 12.0%. Debt term and project life are both 30 years. Accelerated depreciation is normalized using a deferred tax account to spread the result over the project's lifetime. Capital structure is, however, assumed to be 100% debt at 5.5% annual return, and the public utility pays neither income tax nor property tax[140].

---

[139] http://www.energylan.sanda.gov/sunlab/overview.htm
[140] Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.

Table 2. Cost of Energy For Various Ownership Cases for Biomass Gasification in Year 2000

Financial Structure	Levelized Cost of Energy (constant 1997 cents/kWh)
GenCo	6.65
IPP	7.33
IOU	6.39
Muni	5.09

Table 16: Cost of Biomass Energy

Source: http://www.energylan.sanda.gov/sunlab/overview.htm

The technique to be used for calculating levelized COE varies with ownership perspective. Two of the four ownership perspectives employ a cost-based revenue requirements approach, while the other two use a market-based rate of return approach. The revenue requirements approach assumes a utility has a franchised service territory and, its rate of return is set by the state regulatory agency. The plant's annual expenses and cash charges are added to the allowed rate of return on the capital investment to determine revenues[141].

The market-based approach either estimates a stream of project revenues from projections about electricity sales prices or proposes a stream as part of a competitive bid. Annual project expenses, including financing costs, are calculated and subtracted from revenues and an IRR is then calculated. The process of calculating the achieved IRR differs from the revenue requirements approach where the rate of return is pre-determined. COEs can be calculated for both revenue requirements and rate of return approaches. The NPV is then levelized to current dollars and/or constant dollars using

[141] http://www.energylan.sanda.gov/sunlab/overview.htm

appropriate discount rates for each. These are then levelized and normalized to one unit of energy production (kWh) to calculate current and constant dollar COEs. This document cites levelized constant dollar COEs in 1997 dollars. The table below shows levelized COE for the various renewable energy technologies assuming GenCo ownership and balance sheet finance[142].

Table 1. Levelized Cost of Energy for GenCo Ownership

		Levelized COE *(constant 1997 cents/kWh)*				
Technology	Configuration	1997	2000	2010	2020	2030
Dispatchable Technologies						
Biomass	Direct-Fired	8.7	7.5	7.0	5.8	5.8
	Gasification-Based	7.3	6.7	6.1	5.4	5.0
Geothermal	Hydrothermal Flash	3.3	3.0	2.4	2.1	2.0
	Hydrothermal Binary	3.9	3.6	2.9	2.7	2.5
	Hot Dry Rock	10.9	10.1	8.3	6.5	5.3
Solar Thermal	Power Tower	--	13.6*	5.2	4.2	4.2
	Parabolic Trough	17.3	11.8	7.6	7.2	6.8
	Dish Engine -- Hybrid	--	17.9	6.1	5.5	5.2
Intermittent Technologies						
Photovoltaics	Utility-Scale Flat-Plate Thin Film	51.7	29.0	8.1	6.2	5.0
	Concentrators	49.1	24.4	9.4	6.5	5.3
	Utility-Owned Residential (Neighborhood)	37.0	29.7	17.0	10.2	6.2
Solar Thermal	Dish Engine (solar-only configuration)	134.3	26.8	7.2	6.4	5.9
Wind	Advanced Horizontal Axis Turbines					
	- Class 4 wind regime	6.4	4.3	3.1	2.9	2.8
	- Class 6 wind regime	5.0	3.4	2.5	2.4	2.3

* COE is only for the solar portion of the year 2000 hybrid plant configuration.

Table 17: Cost of Energy for GenCo

142 Akhil, A.A., S.K. Swaminathan, and R.K. Sen, Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997.

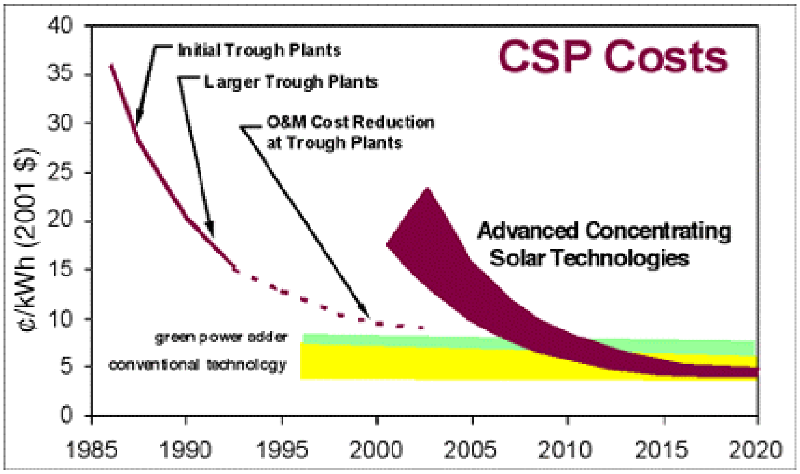


Figure 46: CSP Cost

This graph shows that the projects cost of solar power per kilowatt-hour will drop to around 4 to 5 cents. This will be down from the 9 to 12 cents per kilowatt-hour in 1997.

3.3 Other Renewable Resources

3.3.1 Hydro-electric

Hydro-electric power is the process where falling water is converted into electricity; and because the energy in flowing water comes from the sun, this process is continually being renewed. This is true because the sun evaporates the water from oceans and lakes and deposits it back on earth in the form of rain; once this precipitation is on earth it ultimately ends up in lower land elevations which creates the running water which is needed for Hydro-electric power. This power is the largest renewable source of electricity and accounts for 15% of the world's total electricity, but of late there has been opposition to this renewable resource from environmental groups and native people of the land.

Water power was first used in 250 BC to power a clock; since then water has been used to power many things such as grain and saw mills and paved the way for technological advances. The first time water was used to produce electricity was in 1882 in Wisconsin, where a waterwheel was produced. After this discovery of water being used to create electricity many others used this idea such as Thomas Edison when creating the incandescent light and the creation of many hydro-electric power plants at Niagara Falls. Some of these Hydro-electric power plants create a few kW, which is enough to supply a single family with electricity, and then there are some that create thousands of MW which can produce enough electricity for an entire city[143].

When hydro-electric power plants first started being used they were much more reliable than the fossil fueled fired plants that were being used, due to this where ever there was a water supply and a need for electricity small to medium power plants were being developed. The development of all these power plants became more of a problem [i]because the demand for electricity soared in the middle years of the century and fossil fueled power plants because more efficient so the small hydro plants were abandoned and the new hydro projects were huge "mega-projects". Most of these huge projects meant vast areas of land needed to be flooded so a constant water supply would be available. Recently this has been a big problem and developers are finding it to be more difficult to create these huge projects because the people on the land that would be flooded are making it more difficult for them along with the environmentalist who wants to preserve

[143] http://www.visionengineer.com/env/hydro.shtml

the land[144]. Below shows the amount of people that were forced out of their homes due to the creation of new dams:

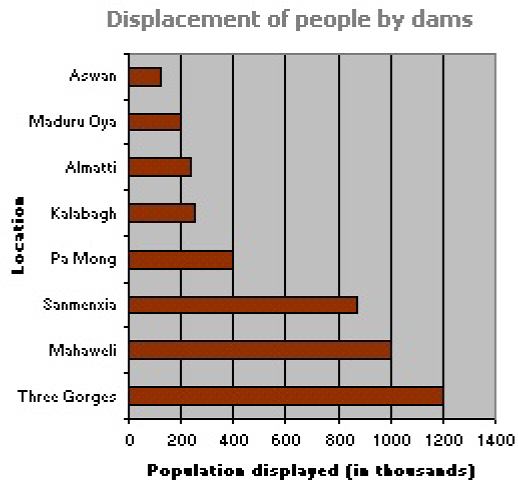


Figure 47: Displacement of People by Dams

Source: http://www.iclei.org/EFACTS/HYDROELE.HTM

Up until recent years hydro-electric power was thought to be a clean safe way of creating energy but recently many problems have arose. Hydro power has to be compared with other sources of energy before it can be said that it will impact the environment tremendously. Compared to fossil fuels hydro power doesn't give off toxins such as carbon dioxide or sulfur dioxide, knowing this it can be said hydro power is better than burning natural gas, oil or coal because it doesn't create acid rain or contribute to global warming; or so it was thought. Recent studies have shown large reservoirs promote the decay of vegetation due to the lands that were flooded, this decay is thought to give off greenhouse gases which are comparable to the gases given off by fossil fuels, which eventually creates global warming. Along with destroying our air quality these dams can have other impacts on the water system itself, such as altering the water quality

[144] http://www.iclei.org/EFACTS/HYDROELE.HTM

downstream and preventing fish from migrating upstream to spawn. Something else that is restricted from going upstream is silt which isn't able to fertilize the water bad past the dam and it builds up in the dam which eventually restricts the flow of water. Another problem is the decaying vegetation can change into mercury which contaminates the water and the fish in the water; this creates health problems to the people who eat the fish and drink the water[145].

Hydro-electric power plants get its energy from falling water that is channeled through a turbine that turns the water's energy into mechanical power, the rotation of the turbine is transferred to a generator which turns it into electricity. The amount of energy that is created at a specific plant is dependent on a couple factors the first being the flow rate which is measure as volume per unit time. The second factor is the distance the water falls which is called the head. Below is a formula which can be used to show how much power can be created by a hydro-electric power plant:

$$\text{POWER (kW)} = 5.9 \times \text{FLOW} \times \text{HEAD}$$

High head power plants are the most common plants used today, which store water at a high elevation. This type of dam provides the capability of flooding areas during drought and storing water during rainy periods, this provides consistent electricity. Another type of hydro-electric plant is the low head plant. This type of plant may use low dams to channel water, or no dam at all and just use the running water is a river. The problem with the use of rivers for electricity is that it isn't consistent and the power output depends on the seasonal flows of water. The final type of hydro-electric power is pumping storage. This type of energy is only used when peak energy supply is needed. This process involves pumping water from a lower reservoir to a higher reservoir when

---

[145] http://www.iclei.org/EFACTS/HYDROELE.HTM

energy demands are low, when the demand is increased the water is then ran back down to the lower reservoir thus creating energy. This type of energy is not used often because it takes more energy to pump the water up than you get out on the way down; it is only utilized in time of energy need[146].

Due to the environmental concerns the theoretical size of the worldwide hydro power output will never be met; this theoretical size is four times greater than that which we have now. The future of hydro power exists in developing countries such as Asia and Africa, but it isn't going to be easy because the construction costs of these plants are in the billions. Much money from the World Bank was put into the development of hydro dams but due to environmental assessments of the bank and opposition form environmentalist hydroelectric growth will slow tremendously. In North America most of the hydroelectric possibilities have been developed and due to opposition from many groups large scale projects are not going to be very abundant which will give room for the construction of small scale and low head hydro dams as research becomes better on low head turbines[147]. With the increase in computer technology existing systems can be improved which will create a higher energy output. Below are the hydroelectric power output potentials that each country has:

[146] http://www.visionengineer.com/env/hydro.shtml
[147] http://www.iclei.org/EFACTS/HYDROELE.HTM

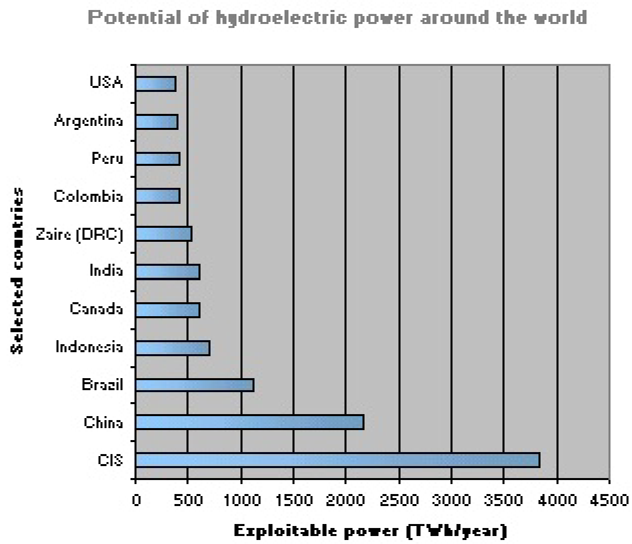


Figure 48: Potential of Hydroelectric Power

Source: http://www.iclei.org/EFACTS/HYDROELE.HTM

Hydroelectric power has been around for many years and has shaped the way we live by supplying a reliable cost effective source of energy. The effects of hydro electric facilities are not being fully understood and the future of hydro power is going to depend on the demand for electricity and how society see the negative effects of hydro power compared to other energy sources.

3.3.2 Biomass

Biomass is an important source of energy that is overlooked by many people. Biomass is organic matter that can be used to create various forms of energy, which include heat, electricity, and fuels. The most commonly used form of bioenergy is wood. However, many other kinds of biomass exist including plants, residue from agriculture or forestry, and the organic elements of many wastes.

In 2000, data from the IEA shows that renewable energy accounts for 13.33% of total world consumption:

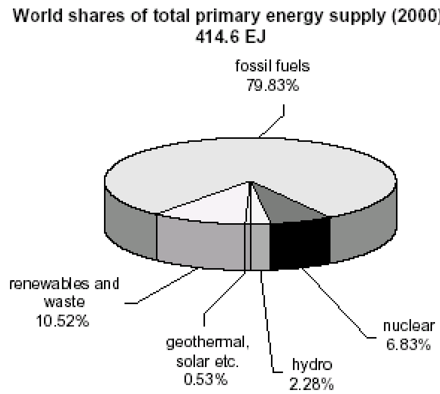


Figure 49: World Shares of Total Energy

Source: IEA, 2000

In developing countries, renewable energy, primarily biomass, accounts for the greatest portion of consumption. However, the use of biomass in these countries is causing increased deforestation due to domestic and industrial needs. Economic expansion can solve this problem, but will not contribute to the development of sustainable energies. Rather, with an expanding economy, there will most likely be an increase in fossil fuel usage since alternatives are too expensive for developing countries.

Since the beginning of the Industrial Revolution, the share of bioenergy has declined due to the increased usage of fossil fuels, specifically, oil, coal, and natural gas. However, in the last three decades, the interest in bioenergy has increased. The renewed interest stems from the major potential of biomass to reduce greenhouse gas (GHG) emissions, mainly CO_2.

The usage of biomass is a worthy consideration for the reduction of carbon dioxide emissions because the combined production and use of biomass has no net effect on carbon dioxide emissions. Recently, attention has been directed towards the potential for diminishing GHG emissions by storing carbon in soil and vegetation.

The most distinct feature of biomass as opposed to other renewable energies is that it can be converted directly into liquid fuels. The two most common biofuels that are produced are ethanol and biodiesel. Ethanol is used mostly as a fuel additive to reduce carbon monoxide emissions in vehicles. Biodiesel can be used as a diesel additive to reduce vehicle emissions or as stand-alone fuel.

There is also the possibility of using biomass to produce methanol and hydrogen. They have great potential for use in fuel cell vehicles which; will hopefully reach efficiency levels that are two to three times that of the current internal combustion engine. They are virtually silent and clean, and their use does not produce SO_x , NO_x , VOS or dust.

Methanol can be produced from biomass at a cost of about 14-17$/GJ with a total energy efficiency of about 55%. Hydrogen can be produced from biomass at a cost of about 10-14$ / GJ with a total energy efficiency of about 60%. However, current gasoline prices are much cheaper at around 4-6$/GJ making them much more desirable. Thus without competitive prices, these fuels will not gain market share.

The most obvious issue concerning the use of biomass is that despite the benefits of using this form of energy, it does not replace traditional energy systems that rely on fossil fuels. The interest in biomass is due to its potential as a solution to some of the problems surrounding fossil fuel consumption. Biomass is useful because it can be used in current energy systems while having a minimal effect on the environment.

The use of biomass would not seem to be the most practical form of renewable energy because it relies on products that must be created and maintained. Both solar and wind energy are more practical because they depend on directly absorbing energy without the maintenance of fuels. The only concern is the ability to control the rates at which these energies are absorbed and used. Thus the most practical considerations for sustainable renewable energy would be solar and wind energy.

3.3.3 Geothermal

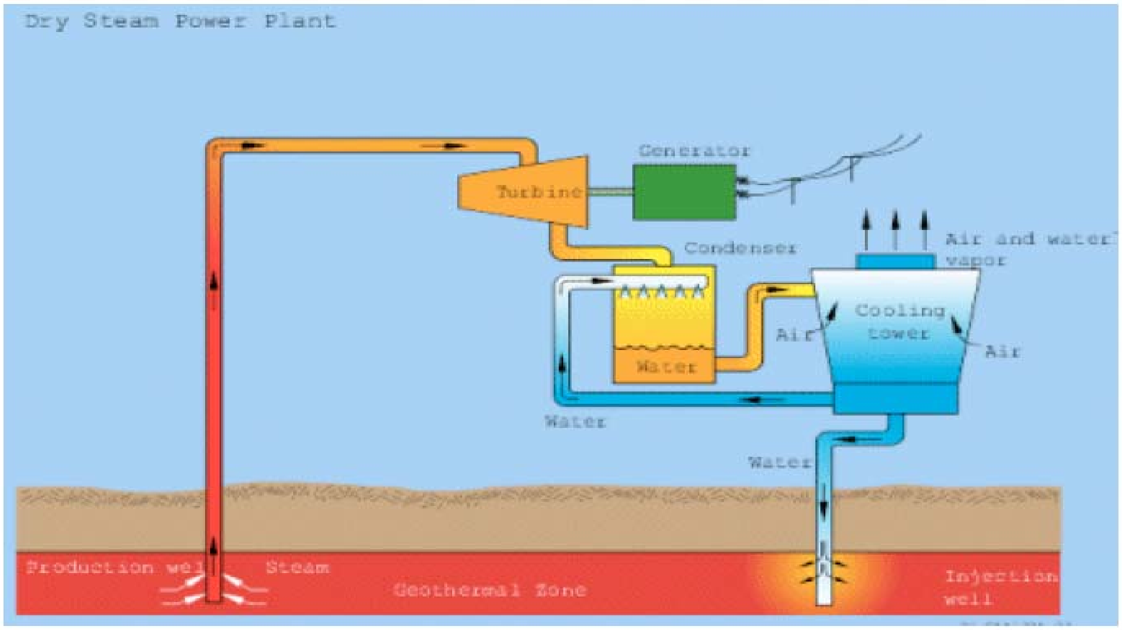
Geothermal energy is from the heat that naturally occurs from the heat below the surface of the earth. From shallow ground, to hot water, down to magma geothermal energy can be obtained. The upper 10 feet of the earth's surface maintains a temperature of 50 - 60°F.

Geothermal heat pumps can tap into this resource to heat and cool buildings. A geothermal heat pump system consists of a heat pump, an air delivery system, and a heat exchanger—a system of pipes buried in the shallow ground near the building. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water.[148]

The most popular geothermal plants are steam powered. There are three types: dry steam, flash steam, and the binary cycle. Dry steam is the simplest of the three. It

[148] "Geothermal Energy Basics", EERE: Geothermal Energy - Basics, http://www.eere.energy.gov/RE/geo_basics.html.

was the first type of geothermal energy used. The steam directly powers a turbine, which powers a generator. The following picture shows the basic set up for a dry steam system.

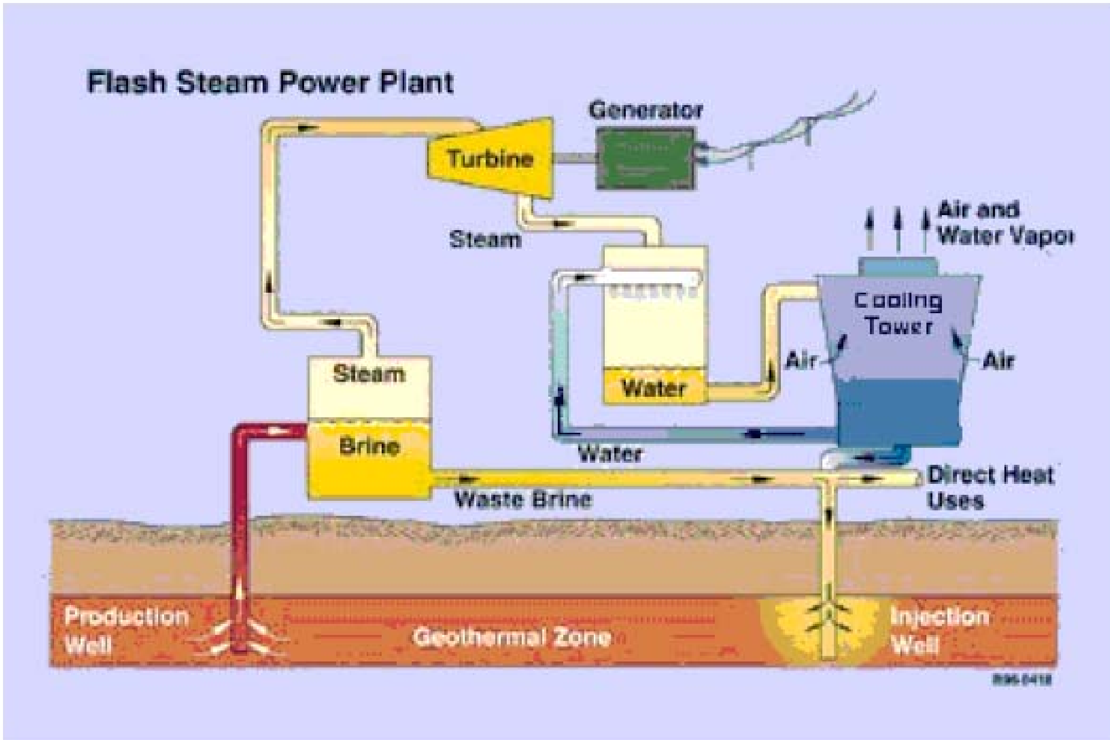


http://geothermal.id.doe.gov/what-is.shtml

Figure 50: Dry Steam Power Plant

Flash steam geothermal power plants are the most common systems now. They use water at temperatures greater than 360° F (182° C) that is pumped under high pressure to the generation equipment at the surface. Upon reaching the generation equipment the pressure is suddenly reduced, allowing some of the hot water to convert or "flash" into steam. This steam is then used to power the turbine/generator units to produce electricity. The remaining hot water not flashed into steam, and the water condensed from the steam is generally pumped back into the reservoir.[149]

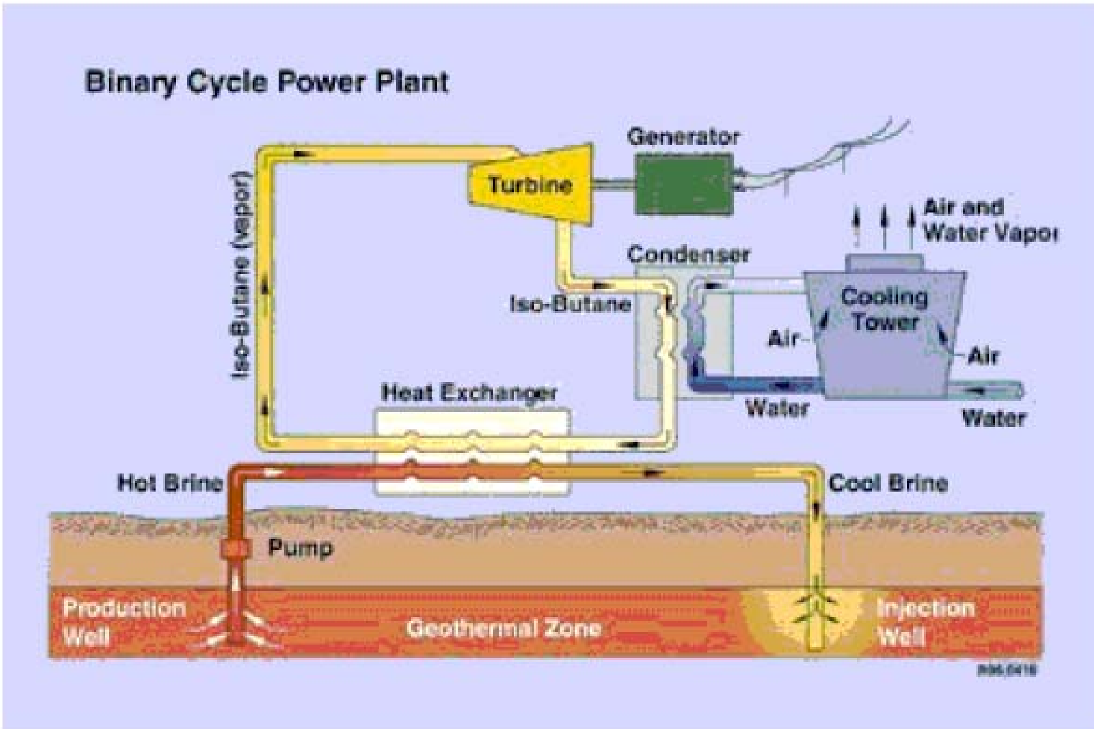
[149] "What is Geothermal Energy?" What is Geothermal Energy - INEEL, http://geothermal.id.doe.gov/what-is.shtml.



http://geothermal.id.doe.gov/what-is.shtml

Figure 51: Flash Steam Power Plant

Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units. In the Binary system, the water from the geothermal reservoir is used to heat another "working fluid" which is vaporized and used to turn the turbine/generator units. The geothermal water, and the "working fluid" are each confined in separate circulating systems or "closed loops" and never come in contact with each other. The advantage of the Binary Cycle plant is that they can operate with lower temperature waters (225° F - 360° F), by using working fluids that have an even lower boiling point than water. They also produce no air emissions.[150]



http://geothermal.id.doe.gov/what-is.shtml

Figure 52: Binary Cycle Power Plant

Aside from being renewable, geothermal energy has another great benefit over fossil fuels. It creates very little to no gas emissions. The following chart shows the amount of SO2 and CO2 emissions from geothermal plants compared to fossil fuel power plants.

[150] "What is Geothermal Energy?" What is Geothermal Energy - INEEL, http://geothermal.id.doe.gov/what-is.shtml.

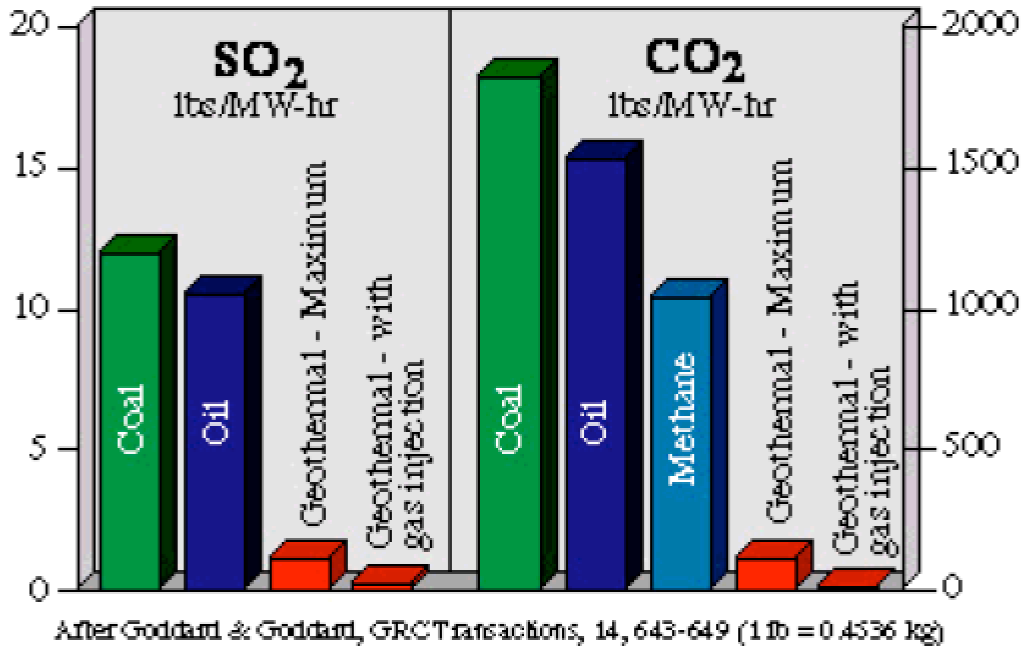


Figure 53: SO2 and CO2 Emissions

Source: http://www.eere.energy.gov/geothermal/geoimpacts.html

Electricity produced by geothermal power plants is becoming cost-competitive with other forms of energy. The cost of geothermal electricity currently ranges from about 4 to 8 cents per kilowatt-hour. The geothermal industry and the U.S. Department of Energy are working to achieve 3 cents per kilowatt-hour.[151]

3.3.4 Space Mirrors

One of the primary issues associated with obtaining solar energy on earth is the fact that much of the solar energy bound for Earth is filtered out in the ozone layer and atmosphere. This is good for the health of people on the planet, as it filters out dangerous

[151] "Environmental and Economic Impacts of Geothermal Energy", Geothermal Energy Program: Environmental and Economic Impacts, http://www.eere.energy.gov/geothermal/geoimpacts.html.

spectra, however it prevents a significant portion of solar energy from reaching terrestrial solar arrays. Solar power can be quite inefficient on earth, due not only to the filtering of spectra in the ozone, but because of cloud cover as well. Neither of these are issues in outer space, thus explaining the remarkable success solar power has had in providing power to satellites, space stations and robotic probes on the moon and mars. There has been great interest in capturing solar energy as the amount of solar energy produced by the sun is a constant 390,000,000,000,000 TWs (or 390 x $(1 \text{ trillion})^2$ Watts). Of this energy, 13,000 TWs are consistently received by the moon. To put that in perspective, the global amount of energy produced from fossil fuels is currently about 14 TWt. Estimates predict that for the world to prosper by 2050, taking into account a population of 10 billion that year; 60 TW of power would need to be produced a number no way achievable by terrestrial solar arrays. This enormous growth is a result of population growth as well as the idea of poor nations becoming industrialized and improving their quality of life.

Given this information a few concepts have been put on the drawing table to make better use of solar energy. Since most of the solar energy spectra is lost in the ozone, scientists and engineers believe the energy should be captured with solar cells in outer earth orbit or on the moon. At this point the energy would have to be converted to a wavelength that can easily pass through Earths atmosphere with high efficiency (minimal loss). Scientists believe this can be done in the form of microwaves beamed from an antenna array on the moon to large rectennas sited on Earth.

While the idea may sound far-fetched, there has already been a physical experiment yielding a proof of concept for microwave “power beaming”. A power beaming experiment was conducted in 1976 where the JPL-Goldstone 60 m diameter dish wirelessly beamed power across 1.6 km to an array of rectennas that output 30 kWe. This power beaming experiment was 82% efficient; this is not much less than in wired transmission lines. Another experiment which used as much as 10% of the energy proposed for a commercial power beaming system was successfully conducted using the Arecibo telescope. The telescope sent a beam of energy with a wavelength of 12.6 cm to the south pole of the moon with a power density of 20 W/m^2, the energy was successfully sent and reflected back accurately enough to reproduce an image of the lunar south pole.

3.4 Efficiency

It is highly relevant to explore distribution efficiency when considering renewable energy. First, since there are different losses associated with different transmission networks, the demand for energy production and thus renewable energy is affected. In addition with renewable energy, electricity must be produced where the renewable energy is available, where as fossil fuels can be transported to wherever a combustion site is desired. For instance, wind turbines must be located were it is windy and adequate land or seabed are available for siting. In the case of large scale solar installations, these are most effective in areas with long and frequent direct sunlight. An excellent example in the case of wind energy is the potential of the Dakotas where enough wind turbines can be sited to power not only the Dakotas but a significant number of other states. This scenario would require a distribution network capable of transporting a large amount of electricity over a great distance.

Planned for 2004-2005, the Long Island Power Authority (LIPA) will be performing the largest installation of super conducting co-axial cable to date. The cable that will be used in the project is referred to as High Temperature Superconducting cable or HTS. American Superconductor headquartered in Westborough, Massachusetts will be manufacturing and supplying the superconducting cable for the planned project.[152] American superconductor already has a demonstration project underway in Detroit. The Detroit project consists of three, single-core, warm dielectric cables. The cables each run a distance of 400 feet in a Detroit substation. The principle behind superconducting materials is that when proper conditions are met, power efficiency is 100%. Regardless of transmission line length the power applied to one end equals the power coming out on the other end. It may appear as though no more energy would need to be produced than the exact amount consumed. This only holds true to some degree, which is dependent on the specific material in use. Superconductivity can only be achieved at extremely low temperatures, thus superconductive transmission lines must be chilled. This process can be costly and requires energy consumption in itself. In summary the basic conditions required for superconductivity are listed below:

- The material must be cooled below a characteristic temperature, known as its superconducting transition or critical temperature (Tc).
- The current passing through a given cross-section of the material must be below a characteristic level known as the critical current density (Jc).
- The magnetic field to which the material is exposed must be below a characteristic value known as the critical magnetic field (Hc).[153]

[152] LIPA Slates New T&D System Improvements
http://www.lipower.org/newscenter/pr/2003/aug28.improvements.html 8/23/2003
[153] American Superconductor: About Superconductivity
http://www.amsuper.com/html/aboutUs/about_super.html

According to the US Department of Energy, power losses in the national power grid exceed 10% and this number continues to increase as more demand is imposed on a dated infrastructure. In other words the total efficiency of the power grid is about 90% and falling. These losses occur among two primary grid elements transmission & distribution lines, and transformers. Modern high voltage transformers typically exhibit efficiencies greater than 95%, so most "loss" can be attributed to resistive characteristics of the transmission and distribution lines. When considering the power grid it should be noted that the term transmission line refers to the large high voltage lines that connect major generation facilities to the grid while the term distribution line refers to more local lines; typically at significantly lower voltages connecting towns, streets and neighborhoods. For one transmission line, hundreds or even thousands of distribution lines can branch off of it. In brief, superconductive technologies allow for creating wires that have no resistance or are essentially "lossless". There is one difficulty with this technology in that superconductive materials must be chilled to extremely low temperatures. Fortunately, there have been several developments in the 1980's that have increased the temperature to which HTS or High Temperature Superconductive materials can operate with zero resistance (refer to table 18 below).

Development	Year Discovered	Temperature Req. for Superconductive Behavior
High-temperature superconductivity (HTS) discovered: ianthanum-barium- copper-oxide by Bednorz and Müller	1986	
Yttrium-barium- copper-oxide HTS	1987	T_c = 93 K
Bismuth-strontium- calcium-copper- oxide HTS	1988	T_c = 110 K
Thallium-barium- calcium-copper- oxide HTS	1989	T_c = 125 K

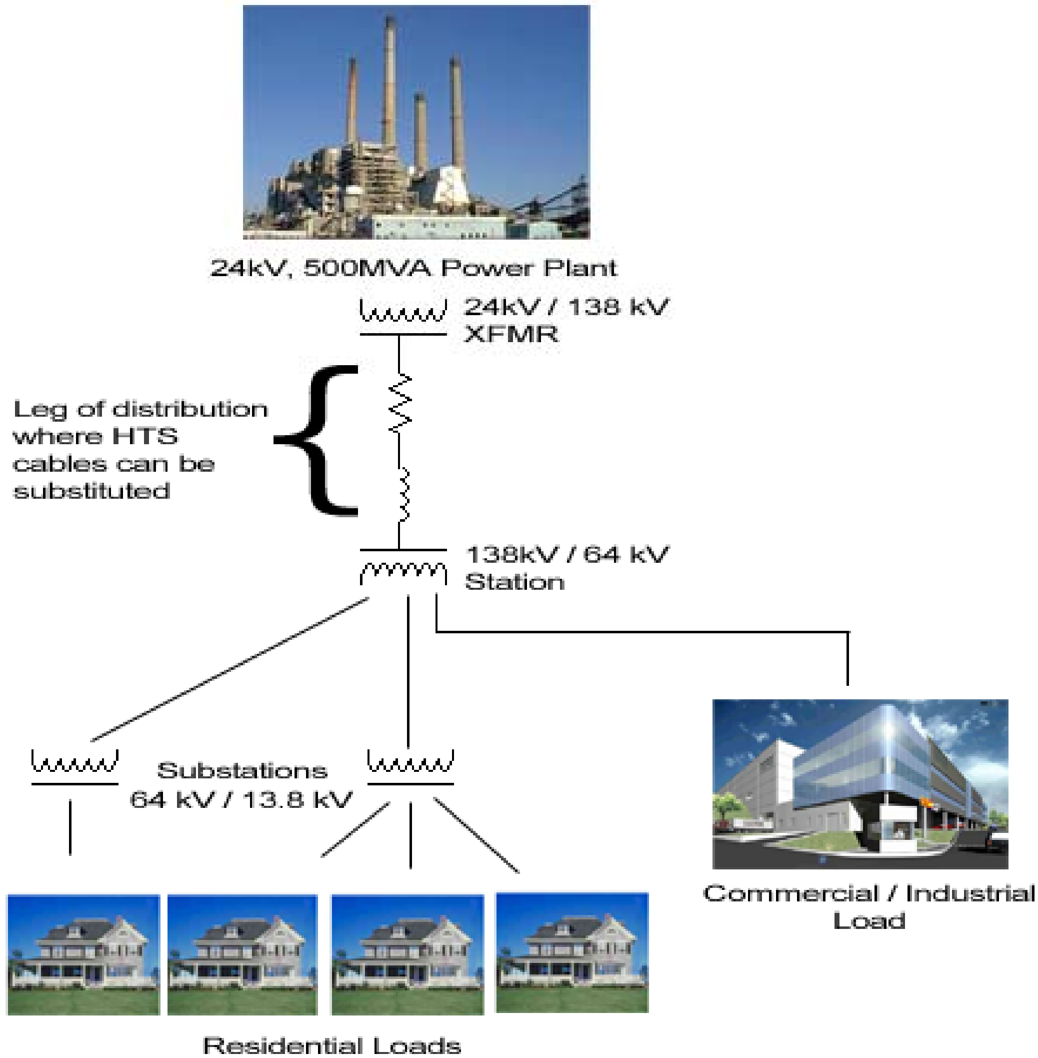
Table 18: Superconductors

Discoveries Leading to Superconductivity at Higher Temperatures[154]

Before attempting to make an arguable comparison between the efficiency of superconductive transmission systems and existing transmission technologies, the actual infrastructural differences must be defined. Several factors affecting efficiency must be considered when determining losses between the generation and the consumption (load) of power. This analysis is broken down into two situations; these being commercial/industrial and residential loads. Between the two there are several significant differences that affect the total efficiency (η_{TOTAL}) in the distribution network. For both residential and commercial load, there are essentially two primary areas where loss occurs in a distribution network; transformers and transmission lines. In the case of residential loads there are typically three or more transformers at which the voltage is altered. For industrial / commercial type loads, there are typically less transformers through which energy must pass. For the purposes of this analysis, the last leg of

[154] http://www.eere.energy.gov/superconductivity/about_hts_milestones.html

distribution will be neglected as it will be constant (equivalent) for both the case of an HTS infrastructure as well as with conventional transmission lines. With this provision, the distribution network will be considered from the point after generation at which the voltage is stepped up for transmission to the first station at which it is stepped back down; factors beyond that point will be omitted. For the purposes of this analysis transformer losses will not be explored in depth as this is a consideration of losses across transmission lines. However, it should be noted that wherever power passes through a transformer, losses will occur. With industrial loads there are typically fewer phases between the generation facility and the load. With this said it is safe to conclude there are fewer losses between the point of generation and the point of consumption due to transformer losses.



Model of Power Distribution Network

How Loss is Calculated

In general, the efficiency of a power line (η) is computed by dividing the power output from one end of line by the power input at the opposite end of the line (equation 1).

(1) $$\eta = \frac{Pout}{Pin} = \frac{Pout}{Pout + \Delta P} = 1 - \frac{\Delta P}{Pin}$$

Given this relationship between efficiency and *loss* has been considered, the next step is to calculate how great the loss (ΔP) actually is. Loss is dependent on several factors that are significantly different in HTS lines than in conventional transmission lines. Conventional AC power lines all posses some kind of characteristic resistance and reactance. When considered together, these characteristics exhibit a combined impedance that will ultimately result in losses across the transmission line. Given this impedance along with the conductivity constant of the conductor, ΔP can be determined using the following relationship:

(2) $$\Delta P = RI^2 + \Delta P_{Cu}$$

Ultimately the power loss can be calculated given data for a specific line length and substituted into equation 3. Equation 3 is limited to a study of resistance, as reactance data is unavailable or un-applicable to superconductors.

(3) $$\Delta P = A_{SURF}{}^2 \times \frac{R}{A_{CS}} \times 10^{-3}\, kW$$

Note: to gain these figures in terms of energy loss, multiply the result by time.

This formula can be demonstrated for conventional power lines using data of a particular conductor. An example of the loss factor for a copper conductor is illustrated in the table and computation below. This data has been calculated with an arbitrary length of 1km and a current density of 100 A_{CS}/cm^2.

Cross-sectional area (cm^2) A_{CS}	Resistance (Ω) **R**	Current (A) **I**	Copper loss (kW) ΔP_{Cu}	Surface area (m^2) A_{SURF}	Cooling rate (W/m^2)
7	0.02429	700	11.9	93.8	127
6	0.02833	600	10.2	86.8	118
5	0.03400	500	8.5	79.3	107
4	0.04250	400	6.8	70.9	96
3	0.05667	300	5.1	61.4	83
2	0.08500	200	3.4	50.1	68
1	0.17000	100	1.7	35.5	48

Table 19: Data for Example Copper Cable [155]

Taking a line of that data yields the following loss for a conventional copper conductor:

$$\Delta P = 70.9^2 \times \frac{0.04250}{4} \times 10^{-3} kW = 0.0534 kW \text{ per km}$$

For comparison, the theoretical loss of an HTS cable is zero because of a resistance of zero. This theoretical loss however fails to take into account energy consumed by the cooling system. An inference can be made that if the cooling system used to cool one km of HTS cable requires less than 0.0534kW or 53Watts, than the superconducting cable will exhibit a higher efficiency than the conventional cable used for comparison here. This scenario seems unlikely as 53Watts is less than enough power to light the average household light bulb. This data suggests the likelihood that superconductive cables are in fact less efficient than conventional transmission lines.

[155] P. 204-205 Freeman Electric Power Transmission & Distribution

Since very little data pertaining to the efficiency of superconductivity versus conventional distribution lines could be readily obtained, a telephone inquiry was made to the director of corporate communications at American Semiconductor (American Semiconductor is the Company responsible for the technology to be used in the LIPA installation). The director, Adam Banker was able to look into the inquiry regarding the efficiency of the HTS cables in which American Superconductor is developing. A follow up phone conversation was made on December 18 (2003), in which Mr. Banker was able to provide current information on behalf of American Superconductor.

The first point made by Mr. Banker is that high temperature superconductors are not being marketed as a solution to efficiency problems. While superconductive lines do not exhibit a loss in themselves, the total infrastructure required, specifically the necessary cooling system involved can be as inefficient, if not more inefficient than conventional transmission lines. Mr. Banker stressed that HTS lines are being considered for their current density properties. Current density is a term used in the field to describe how much power can flow through a fixed diameter of a conductor. Better conductors exhibit higher current densities in that a greater current can be supplied through thinner gauge wires without overheating. While the exact current density of HTS cables developed by American Superconductor has not yet been determined, American has estimated that if one took an HTS cable with the same diameter of a conventional cable, the HTS cable would be capable of carrying 3-5 times the current at the same voltages. Using the equation $P = IV$ (power equals current times voltage), this can be translated into three times the power using the same size cable. In short these benefits enable the addition of extra capacity to be installed in existing rights of way, due to the increase in power / current density. Additionally, when HTS lines are connected redundantly to the grid in parallel with conventional lines, they can take excess stress off of the conventional lines. This is due to the resistance free characteristics of HTS cable. Basic electrical principles dictate that current will take the path of least resistance. The idea of installing additional capacity in existing rights of way means the costs associated with establishing new rights of way in urban areas can be avoided all together. While this may in turn reduce the overall cost of electricity, the effects relating to a change in overall energy demand or a change in demand for renewable energy can essentially be neglected.

In conclusion, high temperature superconductive cables used in the application of energy distribution hold little if not any benefit to the implementation of renewable energy. At this point it is anticipated that there will be little or even negative gains in efficiency with the pilot HTS installations that are planned within the next couple of years. An additional study should be conducted no earlier than 2005 when the Long Island Power Authority completes its test installation of a half mile stretch of HTS cabling. Additional studies relating to superconductivity may prove more relevant to the implementation of renewable energy. These may include a close look at generators utilizing HTS wiring, as these may prove to be capable of improving efficiency in wind turbines or in non-renewable energy production.

Conclusion

The increasing demand for energy by society along with the diminishing fossil fuel reserves means that alternative energy sources are the future of energy. Hydroelectric power is the alternative energy resource that is used most. However due to its limited potential it can't provide much relief from fossil fuels. Wind and solar energy are currently the two most prominent forms of renewable energy. These two sources can help provide temporary relief. Advances are being made in wind energy, technology has been improved, data has been taken, and more wind farms are being proposed and built. Strides are also being made with solar energy, advances have been made in the engines used and new solar power plants are being built. The power that is produced by the systems must be transported to the grid; improvements in the transmission lines are being research in order for more efficiency. The idea that contains the most potential but is still in early stages of development are space mirrors. If they are able to be implemented that could single handedly solve the energy crisis. Alternative energy sources, despite being more inefficient than fossil fuels, more expensive, and still being developed must start playing a prominent role in providing energy because when fossil fuels become extinct the world will have to rely entirely on the alternative energy sources.

4- System Dynamics Model

Thus far, this project has researched into the current conditions surrounding energy consumption and production in the world, specifically in the areas of space-heating and electricity generation. The research has shown that the majority of society's energy demand is met by the consumption of fossil fuels. In addition, the dependence on this energy source continues to increase every year.

The work has identified and expanded upon the major energy concerns associated with the use of fossil fuels. It has been determined that the research and implementation of wind and solar energy constitutes the best possible option to solve this problem. The next step is to formulate an effective policy that will promote such goals.

The most appropriate course of action would be the reduction of energy produced from fossil fuels combined with the increase of energy produced from renewable sources. However, the exact implementation of this is complicated and is the main purpose of this study.

This portion of the IQP attempts to develop an accurate, although relatively simple, model of the current situation in order to help better understand how important factors relating to energy production and consumption interact and depend on one another.

This model will consider five sources of energy: oil, coal, natural gas, wind, and solar. The first three sources produce the majority of the energy we use today and thus they constitute the largest portion of our energy demand. The latter two produce very little of the worlds energy, but it has been argued that the development and integration of these two sources of energy into society is essential for providing a sustainable energy supply in the future.

By creating an accurate model of the current energy situation, individual parameters can be modified and the resulting simulations can be analyzed and compared. This technique will provide useful information and predictions that will help develop a more complete plan for creating a sustainable source of energy in the future.

4.1.1 Discussion of World Energy Dynamics

It is essential to understand that we are the source of our problems. The decisions we make as individuals and as groups determine our future. The continued dependence on fossil fuels to meet our energy demands is a problem that we have created and is a problem that we must solve. In order to solve this problem, we must understand the present situation and the decisions made in the past which inevitably brought us to where we are today. Thus, the purpose of this discussion is to provide a general framework that describes the basics of world energy dynamics. Specifically, this discussion will focus on energy demand and energy production.

First, consider the concept of world energy demand.

World energy demand is determined entirely by the needs of the population of this planet. Every person requires a certain amount of energy to live and every year this value continues to increase as explained by the continued advances in technology and the continued development of our culture. Thus as the population of the world increases, the total energy demand associated with our civilization will strictly increase.

World energy demand includes all types of energy uses in all areas of society. Uses include heat, electricity, transportation fuels, and industrial purposes. Areas of usage include residential, commercial, and industrial sectors.

Each combination of an energy type and an area of usage is a model in itself. Each pairing has its own set of energy sources and related parameters. However, if we consider only the four types of energy usages and the three areas of usage, we need to create twelve individual submodels to describe the whole system. This is too complicated for our purposes. Creating such a system is possible but would require too much time and effort to perfect and analyze.

Instead of having a set of submodels that represent every possible use of an energy source, they will be combined into one submodel with a single set of parameters. However, this will limit the accuracy of the model because by doing this we are assuming that each energy source can be used for any purpose. However, this is not the case as evidenced by the use of oil for industrial purposes. For such purposes, wind and solar energy are incompatible.

This is extremely important to understand because as wind and solar energy production increases, a portion of the additional energy being produced is being used for purposes that it currently cannot be used for.

This model will assume that energy demand encompasses every type of energy use and will represent energy demand as the sum of the most important sources of energy today and for the future. These are: oil, coal, natural gas, wind, solar, nuclear, and hydropower energy.

Most of the demand is met by energy produced by the three fossil fuels: oil, coal, and natural gas. The other substantial contributors to energy production are nuclear and hydropower energy. A very small portion of the total demand is met by the developing renewables, which include wind and solar energy.

For any model, the energy demand associated with the population of the world is simply equal to the population of the world multiplied by the average energy demand per person. For the purpose of this model, the value of the energy demand per person will be determined by a slowly increasing exponential relation over time to represent the rapid advances in technology and cultural development.

In reality, energy demand per person depends on a many factors including income per person, willingness to pay for energy, and most importantly quality of life. In essence, quality of life is a relative measure of how comfortable ones living conditions are. For example, throughout a large portion of Africa, substantial contingents of the population live in harsh conditions where there is no main source of electricity or heating, and there are few jobs. Compared to the United States, there is an extreme disparity in the quality of life between our two cultures because of our highly organized and developed society. We live with centralized heating and electricity, which is essential to our living. We thus use more energy as a result because of our higher quality of life.

The next factor to consider is the demand for each energy source. Specifically, how is the total energy demand distributed to the possible sources?

In this model, world energy demand will be distributed dynamically to the five most important energy sources: oil, coal, natural gas, wind, and the sun. Nuclear and hydropower energy are included but remain will remain constant since the production from these two sources is not predicted to change dramatically over the next few decades.

For purposes of simplicity, the model will assume that the demand associated with each energy source and the level of production associated with each energy source is equal.

To be able to predict the future energy demand associated with each energy source, we must gain an understanding of how decisions are made concerning energy production and consumption. This inevitably becomes a study of market economics. Specifically, how do companies function and how to people make decisions? How do companies choose production output and energy price and how to people choose what to buy?

In a market economy, instead of a central planner making decisions, millions of firms and households make individualized decisions based on personal interests. Companies choose products to produce and the people to employ. Households choose the company to work for and the items to buy. These companies and households interact in the marketplace where prices and self-interests guide their decisions.

Applying market economics to the situation, the fraction of the total energy demand that is distributed to each energy source depends mainly on the price of the particular energy source to consumers and the production capacity of the energy source.

First, let us try to understand how an individual household chooses what energy to buy. Each group of residents evaluates the potential sources and chooses the energy that best coincides with their requirements. For most households, the most important factor that is considered is energy price. The reasoning behind this is simple. Every family and company desires the minimization of costs. Thus, a cheaper price is more desirable but is not the only factor to consider.

Another factor of less importance to individuals but of exceedingly greater importance to the health of this planet is pollution. When choosing what energy to buy, some people consider the pollution associated with using each of the possible energy sources. However, most people are not willing to purchase more expensive energy simply because it is better for the environment. To put it harshly, we think of ourselves before we think of the world around us. But this selfishness is understandable because it the essence of personal survival.

The other important factor that determines energy distribution is production capacity. Production capacity is simply the maximum possible level of energy output. Capacity is determined by companies and is based on the current level of production and the projected change in energy demand. Energy production capacity limits the portion of the total energy demand that each source can meet hence if demand exceeds capacity, the remaining demand will be met by some other source if possible. Capacity will be discussed in detail when the topic of energy costs is introduced.

Since the fraction of the demand that is distributed depends on the price of the energy, a function must be created to effectively perform this procedure. Since the lowest price attracts the most customers, the energy with the lowest price should have the largest consumption rate.

It is also important to understand that the energy with the lowest price will not attract all of the demand. There are many other factors to consider. Most importantly, it is impossible for a single source to meet the world's entire energy demand due to market competition and production limitations.

Using these guidelines, the distribution function for the model will be:

DISTRIBUTION FUNCTION =

1/ [1.8*(1 / Price of Coal Energy)^2 + (1 / Price of Oil Energy)^2 +
2*(1 / Price of Natural Gas Energy)^2 + 3*(1 / Price of Solar Energy)^2 +
3*(1 / Price of Wind Energy)^2]

The coefficients represent the desirability of the energy source and also allow the initial distribution of demand to be relatively accurate when compared to current energy statistics.

The equation for the distribution function is of the form:

$(X_1 + X_2 + X_3 + X_4 + X_5)$^(-1) where each X_i corresponds to a distinct energy source.

Since the sum of all the distributions must equal 1, the distribution corresponding to the energy source represented by X_j will equal $X_j / (\sum X_i)$

However, we need to account for the possibility that certain energy sources are at capacity. We need to determine if the energy source is at capacity. The energy source is at capacity if the Hence, we create the function X at Capacity where:

X at Capacity = IF THEN ELSE((coef(X)*(1/Price of X)^2*DISTRIBUTION FUNCTION) ≥ (CAPACITY of X / World Energy Demand),1,0)

If an energy source is at capacity, the corresponding term in the distribution function needs to be eliminated. This requires a modification of the distribution function. Hence, we introduce the function distribution normalizer:

DISTRIBUTION NORMALIZER =

1 / [1.8*((1 / Price of Coal Energy)^2)*(1 - Coal at Capacity) +
((1 / Price of Oil Energy)^2)*(1 - Oil at Capacity) +
2*((1 / Price of Natural Gas Energy)^2)*(1 - Natural Gas at Capacity) +
3*((1 / Price of Solar Energy)^2)*(1 - Solar at Capacity) +
3*((1 / Price of Wind Energy)^2)*(1-Wind at Capacity) + 10^(-12)]

Similarly, if an energy source is at capacity, the production capacity associated with this energy source must be removed from the energy demand that is being distributed using the distribution normalizer. Hence, we introduce the function available demand:

AVAILABLE DEMAND =

World Energy Demand - [Coal Production Capacity*Coal at Capacity +
Natural Gas Production Capacity*Natural Gas at Capacity +
Oil Production Capacity*Oil at Capacity +
Solar Production Capacity*Solar at Capacity +
Wind Production Capacity*Wind at Capacity) –
(Nuclear Energy Production +
Hydropower Energy Production)

Therefore, the demand associated with energy source X (excluding hydropower energy and nuclear energy) is:

DEMAND of X =

IF THEN ELSE(X at Capacity = 1, Production Capacity of X,
IF THEN ELSE((coef(X)*(1/Price of X)^2*
DISTRIBUTION NORMALIZER*
Available Demand) > Production Capacity of X,
Production Capacity of X,
(coef(X)*(1/Price of X)^2*
DISTRIBUTION NORMALIZER*
Available Demand)))

It should be noted that the distribution function is not necessarily accurate. The equation simply meets the requirement that as the price of the energy increases, the portion of the total energy demand distributed decreases.

The next step is to determine how an energy company determines the price of its product.

The basic rule that governs most decisions in a competitive market is the maximization of profits. The price of a good is set at the value at which the resulting energy demand multiplied by the profit gained per unit sold is maximized.

In economic terms, profit maximization occurs when the marginal cost, or change in cost, associated with increasing production by a single unit equals the marginal revenue, or change in revenue, associated with increasing production by a single unit. Equivalently, this means that the maximization of profits occurs when $d^2(\text{Profits})/dt^2 = 0$.

In order to gain profits from energy production, the price per energy must be greater than the cost per energy. Thus, if the cost per energy increases, so must the price in order to maintain financial gains.

Government policy also affects the price of various sources of energy. For example, the government taxes gasoline to try and maintain a steady level of consumption as a means of controlling pollution output. Pollution will be incorporated into the model but will be limited to CO_2 emissions and will only affect the government policy parameter

So for the model, energy price will depend on the energy cost, the change in the rate of profits, and government policy. Government policy will be represented as a tax that will depend on the rate pollution outputted by each energy source. However, this will only apply to energy generated by fossil fuels since renewable energy contributes little to no pollution in the form of emissions.

Now consider the factors that determine energy cost.

For any company, there exist two types of costs: variable costs and fixed costs. Fixed costs remain the same for any level of production whereas variable costs depend on the level of production. This model will only consider the costs pertaining to resources, production, and capacity.

Production costs depend on the level of energy production. The conversion of base fuels into energy products requires employees and tools. Employees must be paid for their services and tools require maintenance. Thus, the more energy being produced, the greater the amount of money required to produce it. For this model, we will assume that as the production rate increases, the cost per unit energy also increases. This reflects the additional required labor force and the rising costs of living.

In order to produce the energy, resources are required. For fossil fuels, these resources are an extra cost to account for. As fossil fuel reserves are depleted, the cost of buying these resources will increase. This is because economically, a good becomes more rare it becomes more valuable. Thus the cost of purchasing them from suppliers will become greater and greater over time.

Also, as reserves are depleted, the cost of retrieving such resources from the earth will increase. This is because large part of the untapped cache of fossil fuel requires advanced drilling techniques to obtain. Currently, fossil fuels that are being drilled around the planet are relatively easy to obtain. However, it will become more difficult and more extensive to continue such operations as time goes by.

The benefit of using wind and solar energy is that the cost of obtaining the resources required to produce the energy is zero. Obviously, this is because radiation emitted from the sun and wind produced in the atmosphere is not a commodity that you can buy. Ultimately, because wind and solar energy lack the additional cost associated with obtaining resources, they will at some point in time be able to compete, in terms of price, with fossil fuels.

For renewable energies such as wind and solar, total costs are reduced partially by the support of the government as a means of promoting usage. Government support is usually provided in the form of funding for construction projects or research grants that are meant to increase the production capacity and improve the economic feasibility of renewable energy. However, there is a limit to the level of support since the government provides limited funding for such areas depending mainly on political agenda. Thus, as renewable energy production increases, government support will most likely decrease.

The cost of production also depends on the change in capacity. Increasing capacity implies additional power stations and sites to produce the desired energy and this requires funds. Capacity is increased depending on the projected change in demand and how close current production is to capacity. However, there are limits to both capacity and the rate of change of capacity.

The maximum possible capacity only applies to fossil fuel energies and depends entirely on the level of the each sources' reserves. As reserves are depleted the maximum potential production decreases because by reducing the pool of total resources, the amount of possible energy recoverable from consuming all of these resources will diminish.

Of equal importance is the maximum change in capacity. In order to increase capacity, labor, funds and time are required to provide additional energy production. This puts a limitation on the possible change in capacity. This is the main reason why renewables do not constitute a greater portion of the energy market. Capacity is changing very slowly because the cost of creating wind farms and solar plants is expensive and the investment is very risky. This is where the government needs to help by funding research to improve renewable energy technologies and by funding projects that will build new renewable energy sites to increase production capacity. Since it is difficult to determine what affects the maximum change in capacity, the value will be set as a constant for each energy source.

4.1.2 Creating an Adequate Model

For this project, the discussed information was modeled using the theory of system dynamics. System dynamics is a powerful modeling technique that is based on the theory of non-linear dynamics and differential equations. Despite the highly mathematical foundation behind this subject, system dynamics is highly visual in nature, which means that typical models can be understood by individuals with nearly no knowledge of mathematics. This condition is ideal for explaining energy dynamics, because in order to invoke global change each person must understand the severity of the problems surrounding our current energy situation. Each person can improve the situation by acting responsibly and by thinking logically about the consequences of his or her actions.

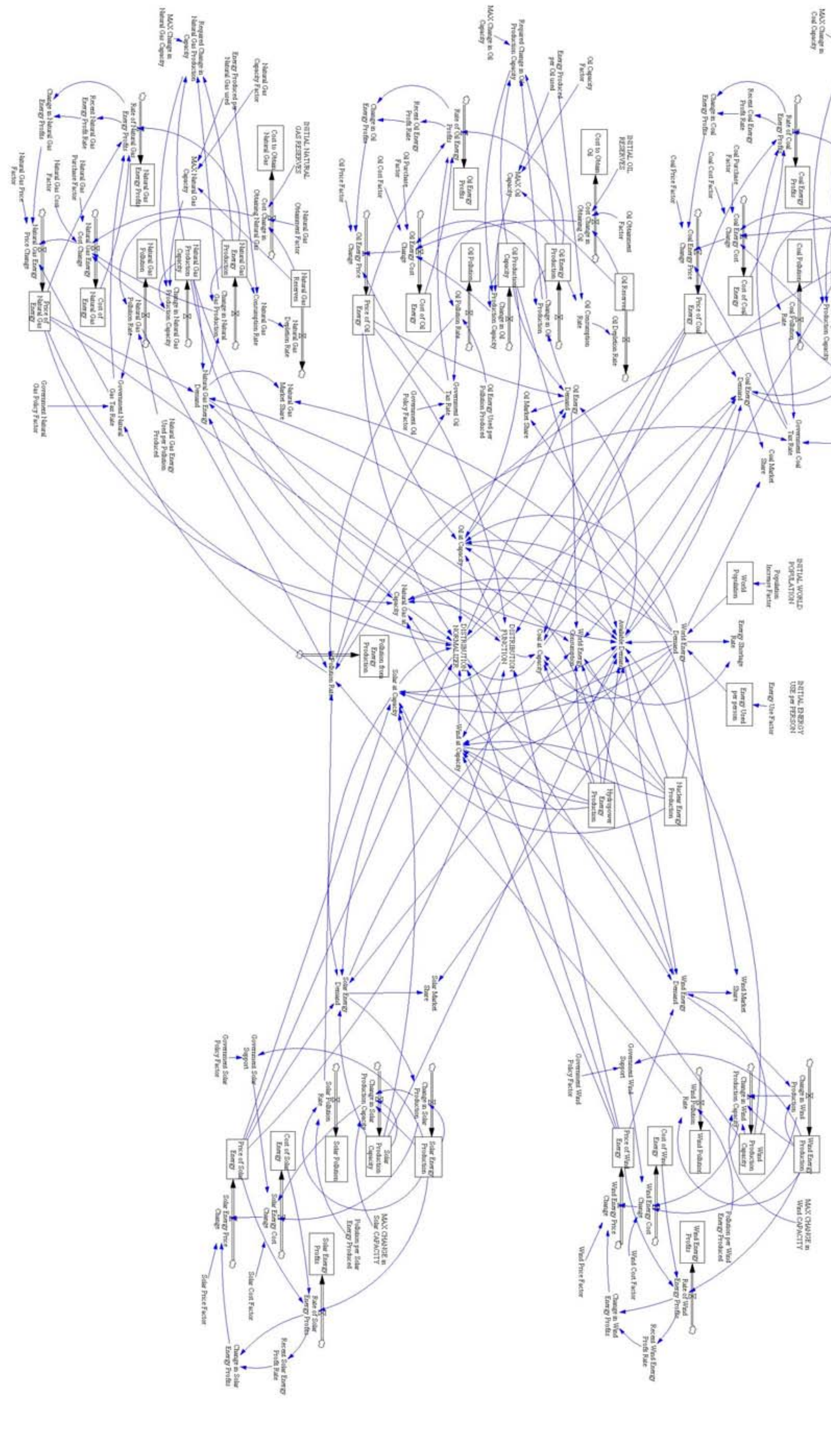
The energy model defines the outlined parameters and establishes dependencies using the conclusions from the previous section. The model was created and simulated using Vensim® which is a software package produced by Ventana Systems, Inc. Additional information about Vensim® can be located at the company's software website: www.vensim.com/software.html

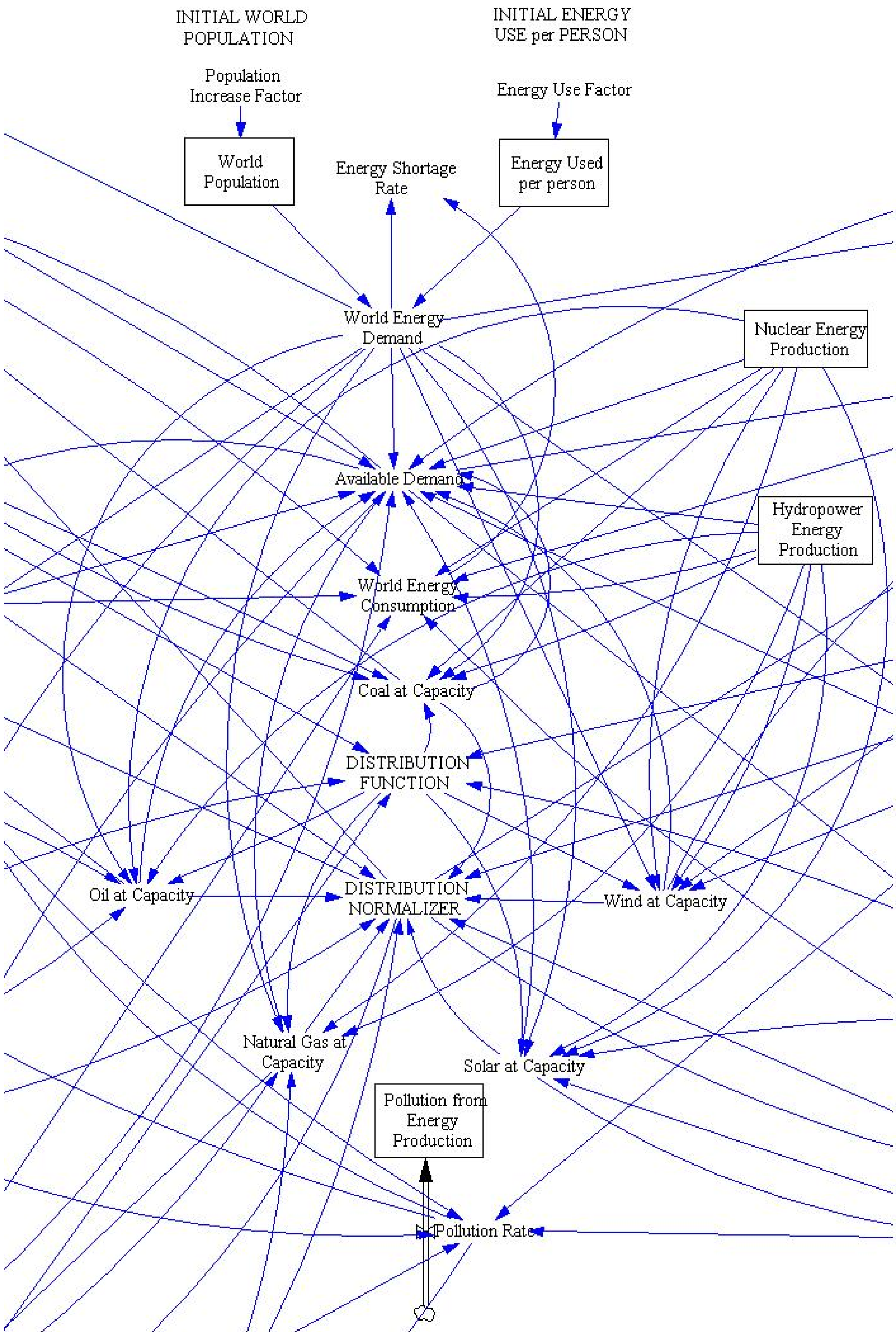
The initial values set for crude oil reserves, natural gas reserves, and coal reserves are based on IEA data from 2003. Similarly, natural gas used per energy produced, coal used per energy produced and crude oil used per energy produced are average values based on IEA data.

The initial population is based on recent world demographics. Initial energy demand is based on IEA data from 2001. Initial energy demand per person is set equal to the initial energy demand / initial population.

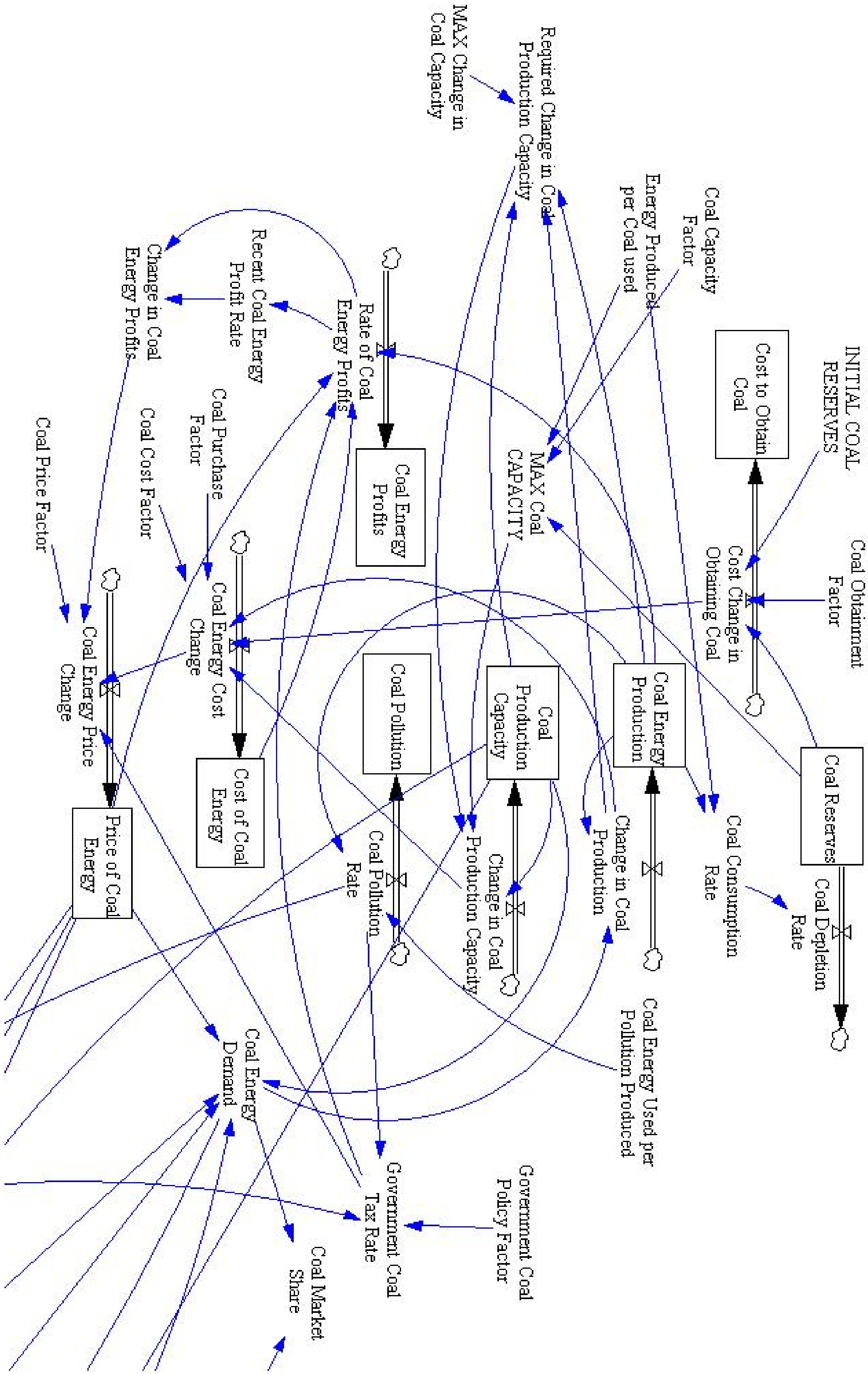
The initial price for each fossil fuel is an average value based on IEA data from 2001. The initial price for each renewable is set at approximately 30% more than the highest priced fossil fuel energy. Initial production values and initial pollution values are based on IEA data from 2003.

The following pages show in detail the model that has been developed:

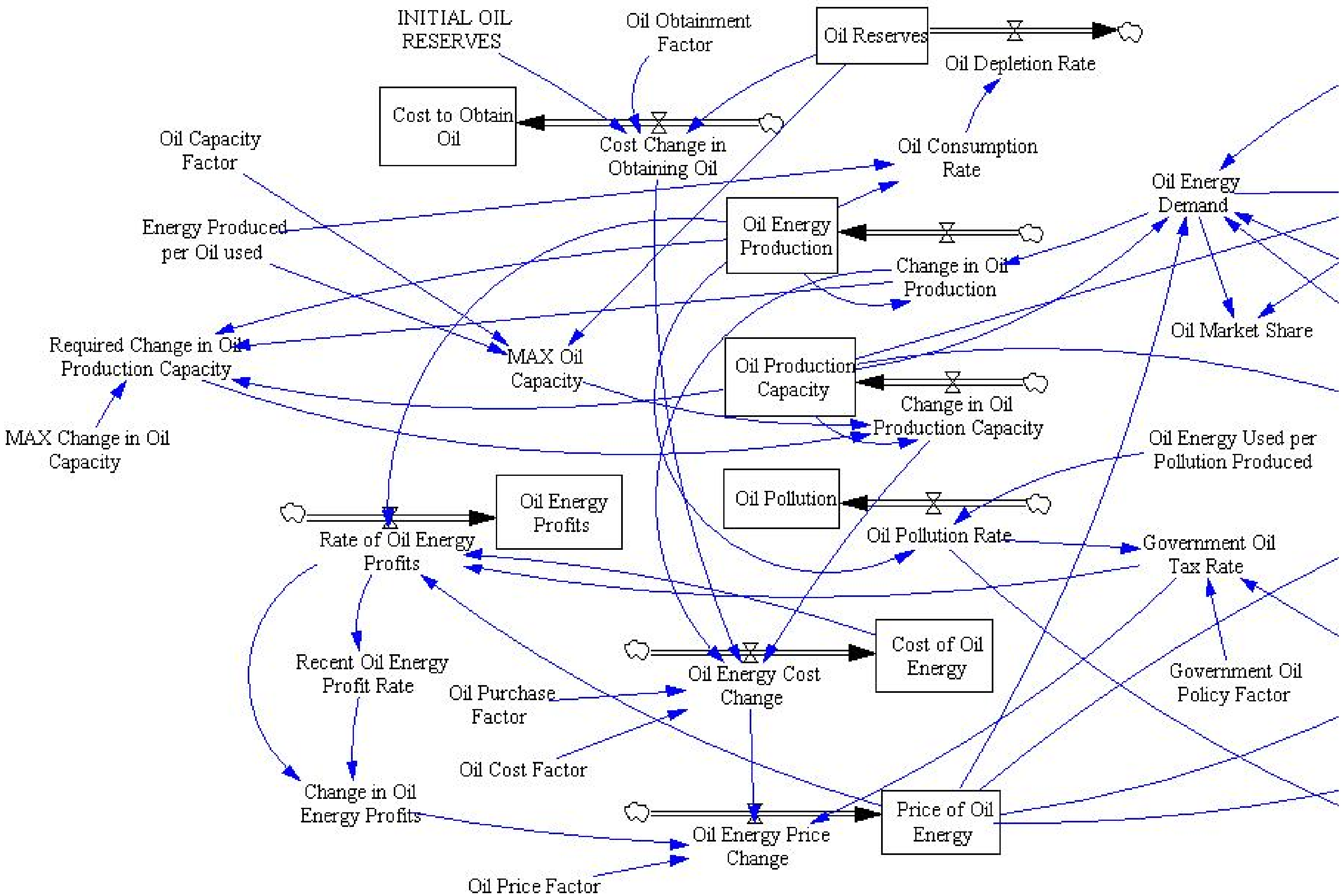


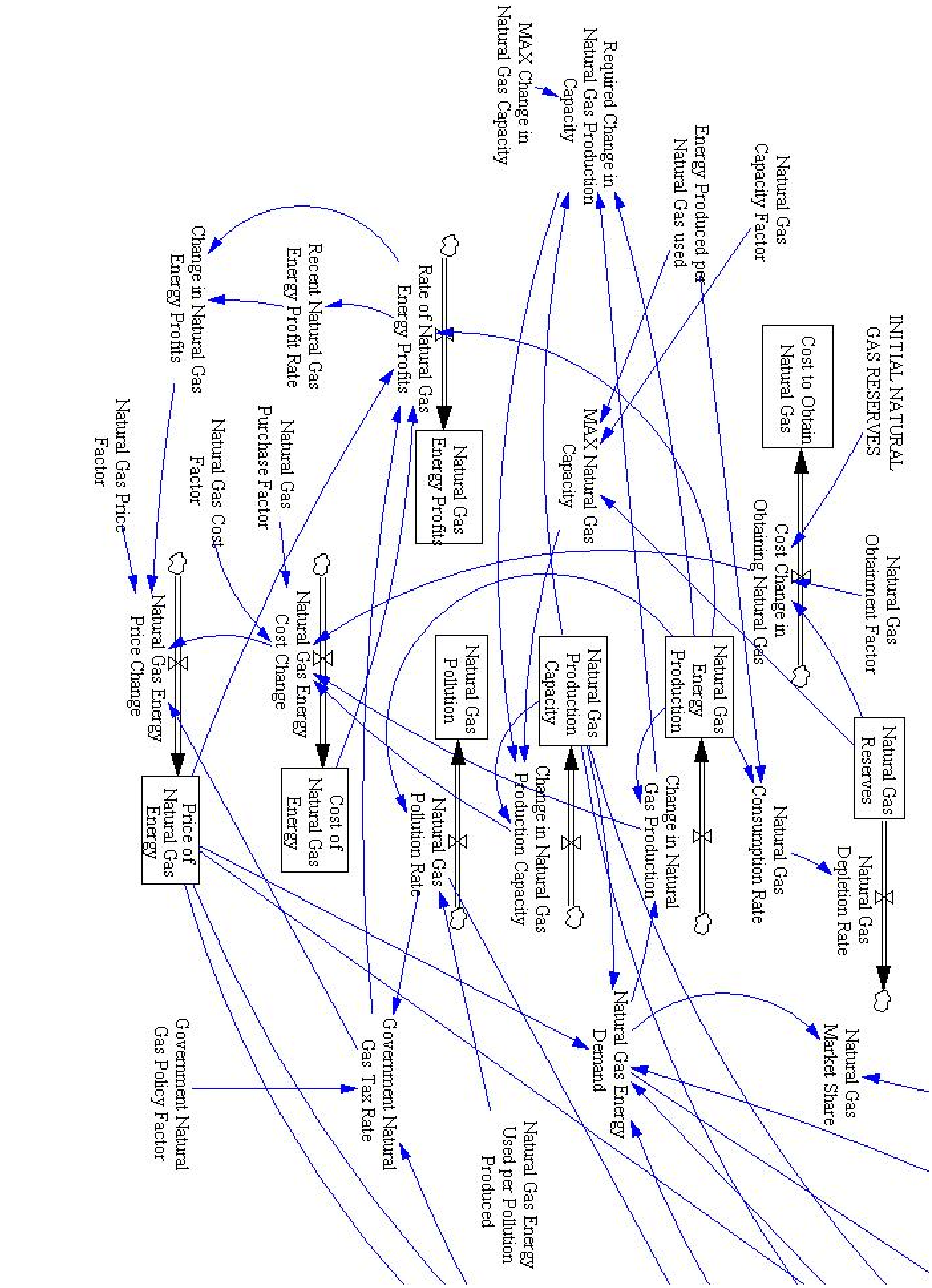


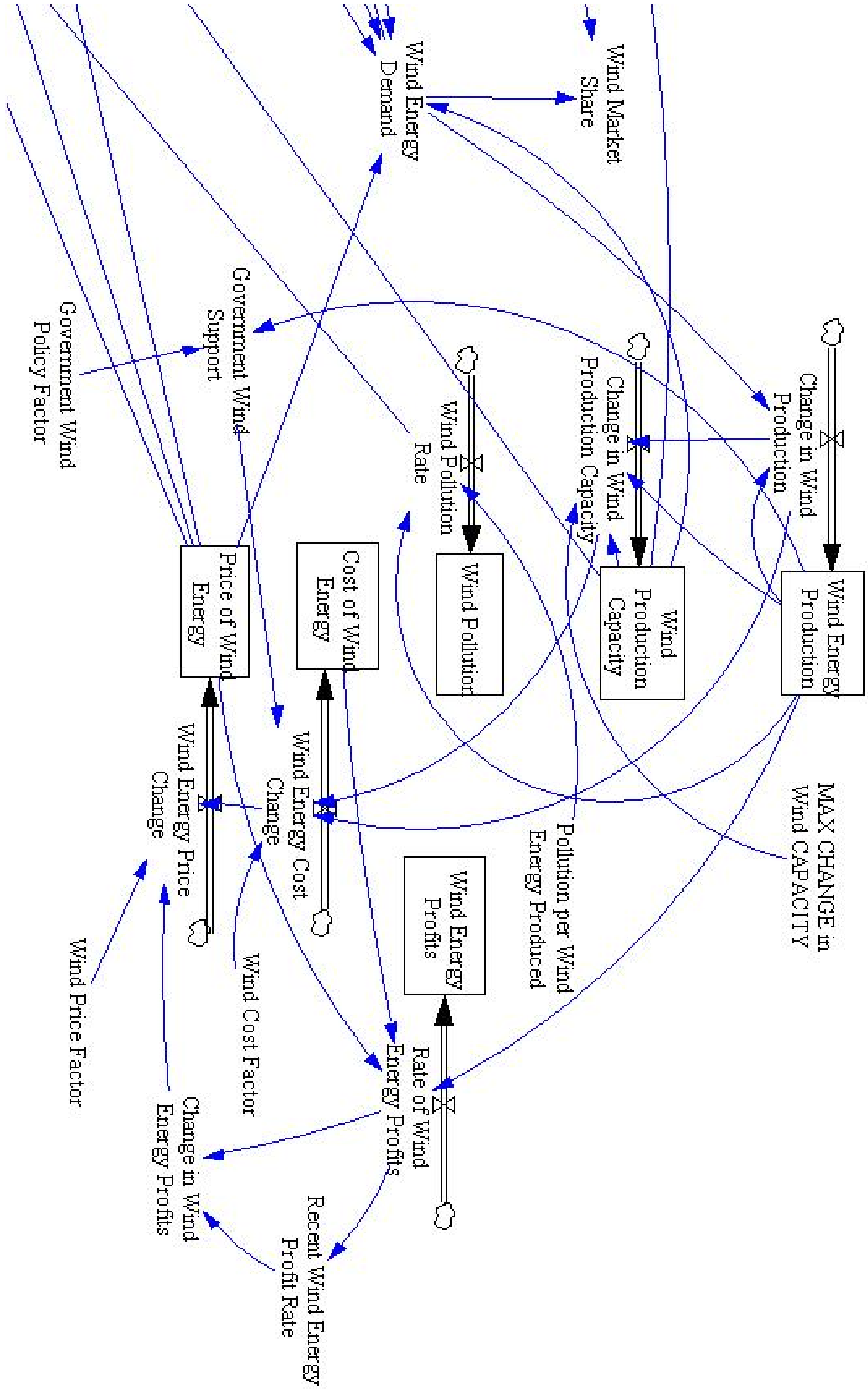
INITIAL WORLD POPULATION
INITIAL ENERGY USE per PERSON
Population Increase Factor
Energy Use Factor
World Population
Energy Shortage Rate
Energy Used per person
World Energy Demand
Nuclear Energy Production
Available Demand
Hydropower Energy Production
World Energy Consumption
Coal at Capacity
DISTRIBUTION FUNCTION
Oil at Capacity
DISTRIBUTION NORMALIZER
Wind at Capacity
Natural Gas at Capacity
Solar at Capacity
Pollution from Energy Production
Pollution Rate

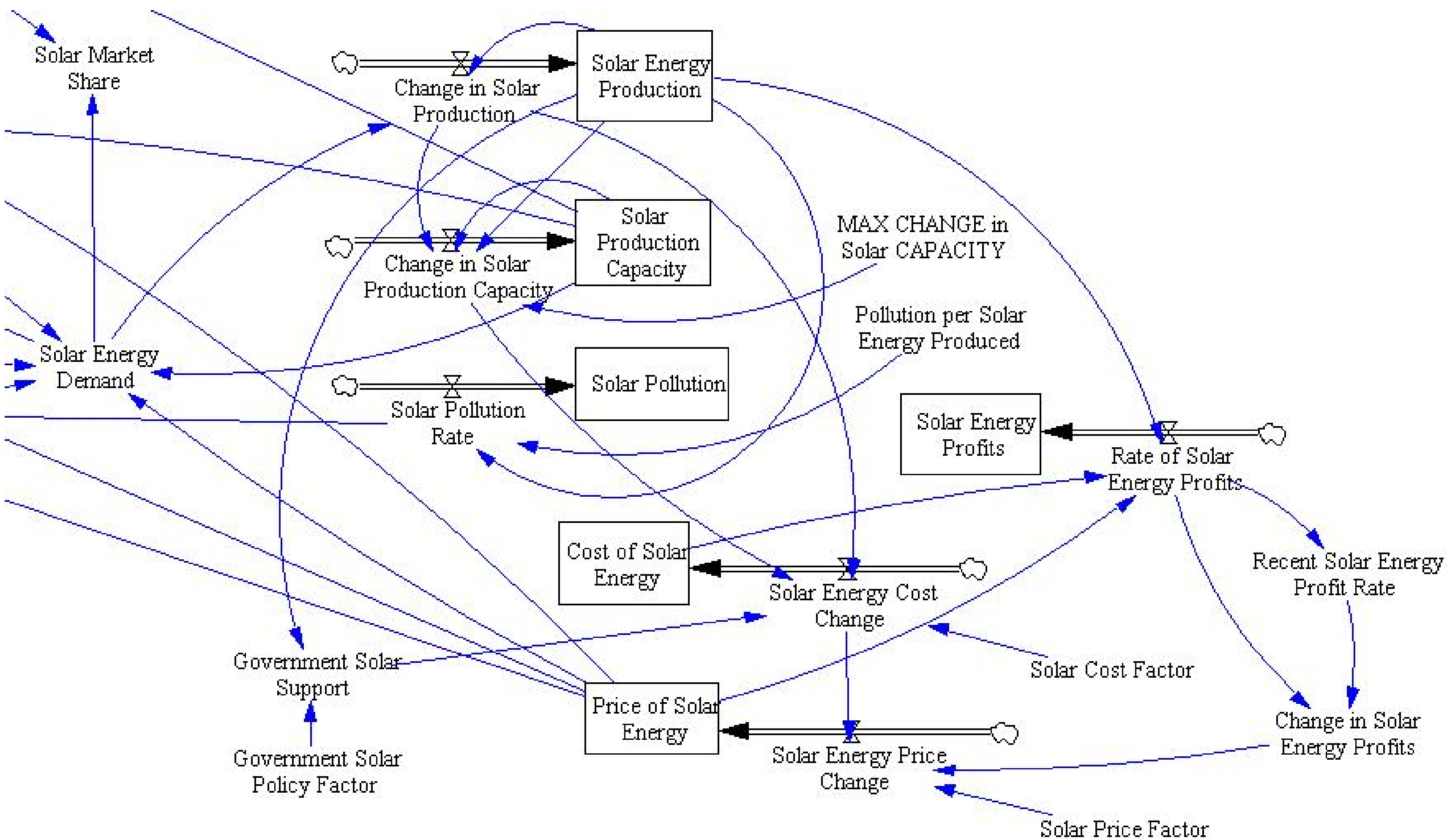


MAX Change in Coal Capacity
Required Change in Coal Production Capacity
Energy Produced per Coal used
Coal Capacity Factor
INITIAL COAL RESERVES
Cost to Obtain Coal
Coal Obtainment Factor
Cost Change in Obtaining Coal
MAX Coal CAPACITY
Rate of Coal Energy Profits
Recent Coal Energy Profit Rate
Change in Coal Energy Profits
Coal Energy Profits
Coal Purchase Factor
Coal Cost Factor
Coal Price Factor
Coal Energy Cost Change
Coal Energy Price Change
Coal Energy Production
Coal Production Capacity
Coal Pollution
Coal Reserves
Coal Consumption Rate
Coal Depletion Rate
Change in Coal Production
Change in Coal Production Capacity
Coal Pollution Rate
Cost of Coal Energy
Price of Coal Energy
Coal Energy Used per Pollution Produced
Coal Energy Demand
Government Coal Tax Rate
Government Coal Policy Factor
Coal Market Share


INITIAL OIL RESERVES
Oil Obtainment Factor
Oil Reserves
Oil Depletion Rate
Cost to Obtain Oil
Cost Change in Obtaining Oil
Oil Capacity Factor
Oil Consumption Rate
Oil Energy Demand
Energy Produced per Oil used
Oil Energy Production
Change in Oil Production
Oil Market Share
Required Change in Oil Production Capacity
MAX Oil Capacity
Oil Production Capacity
Change in Oil Production Capacity
MAX Change in Oil Capacity
Oil Energy Used per Pollution Produced
Oil Energy Profits
Oil Pollution
Rate of Oil Energy Profits
Oil Pollution Rate
Government Oil Tax Rate
Cost of Oil Energy
Recent Oil Energy Profit Rate
Oil Purchase Factor
Oil Energy Cost Change
Government Oil Policy Factor
Oil Cost Factor
Change in Oil Energy Profits
Price of Oil Energy
Oil Energy Price Change
Oil Price Factor


INITIAL NATURAL GAS RESERVES
Cost to Obtain Natural Gas
Natural Gas Capacity Factor
Energy Produced per Natural Gas used
Required Change in Natural Gas Production Capacity
MAX Change in Natural Gas Capacity
MAX Natural Gas Capacity
Natural Gas Obtainment Factor
Cost Change in Obtaining Natural Gas
Natural Gas Reserves
Natural Gas Depletion Rate
Natural Gas Energy Production
Natural Gas Consumption Rate
Change in Natural Gas Production
Natural Gas Production Capacity
Change in Natural Gas Production Capacity
Natural Gas Pollution
Natural Gas Pollution Rate
Natural Gas Energy Profits
Rate of Natural Gas Energy Profits
Recent Natural Gas Energy Profit Rate
Change in Natural Gas Energy Profits
Natural Gas Purchase Factor
Natural Gas Cost Factor
Natural Gas Price Factor
Natural Gas Energy Cost Change
Cost of Natural Gas Energy
Natural Gas Energy Price Change
Price of Natural Gas Energy
Natural Gas Market Share
Natural Gas Energy Demand
Government Natural Gas Tax Rate
Government Natural Gas Policy Factor
Natural Gas Energy Used per Pollution Produced


Wind Energy Demand
Wind Market Share
Government Wind Support
Government Wind Policy Factor
Wind Pollution Rate
Change in Wind Production Capacity
Change in Wind Production
Wind Energy Production
Wind Production Capacity
Wind Pollution
Cost of Wind Energy
Price of Wind Energy
Wind Energy Cost Change
Wind Energy Price Change
Pollution per Wind Energy Produced
MAX CHANGE in Wind CAPACITY
Wind Energy Profits
Wind Cost Factor
Wind Price Factor
Rate of Wind Energy Profits
Change in Wind Energy Profits
Recent Wind Energy Profit Rate

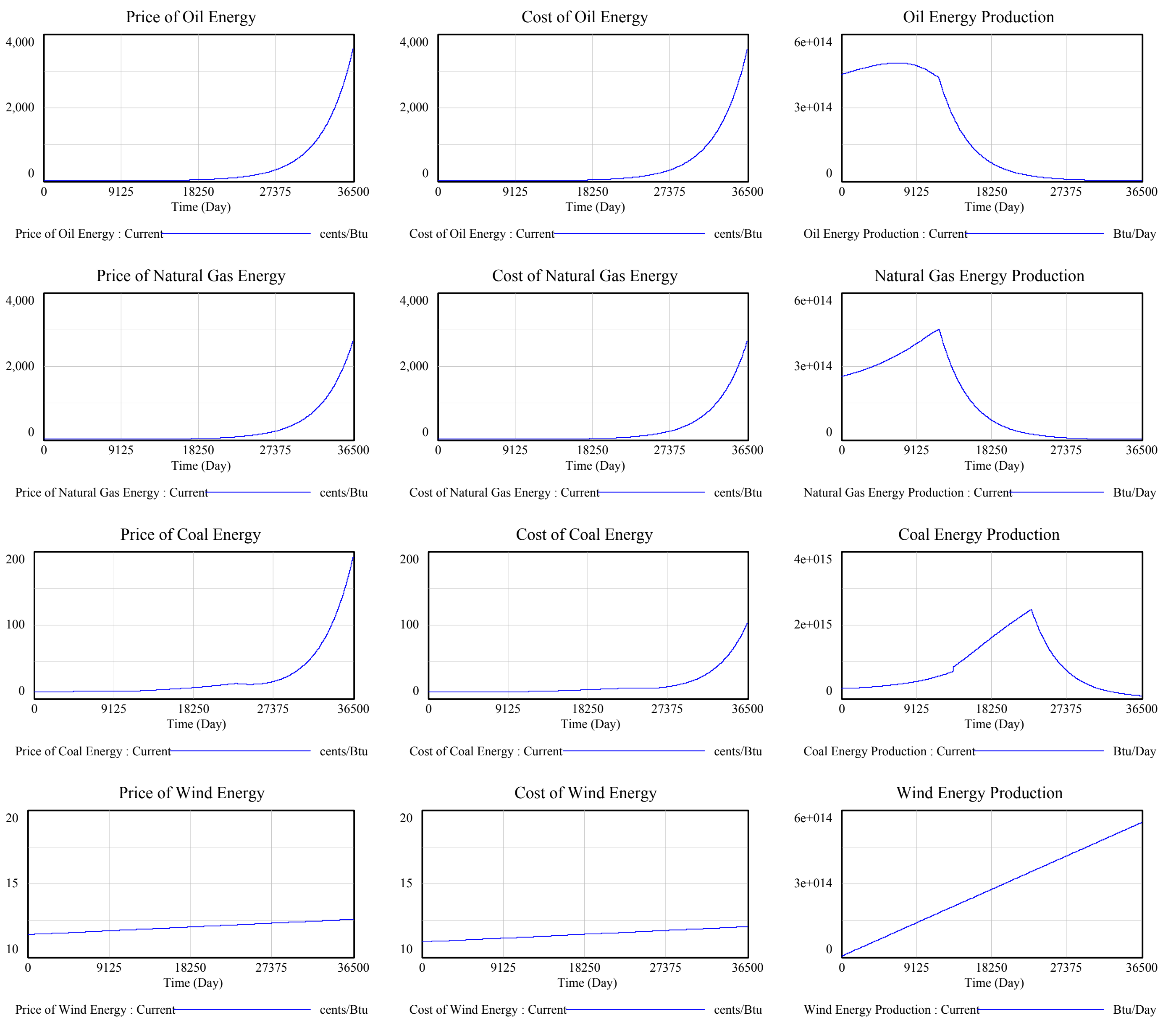

Solar Market Share
Solar Energy Demand
Change in Solar Production
Solar Energy Production
Solar Production Capacity
Change in Solar Production Capacity
MAX CHANGE in Solar CAPACITY
Pollution per Solar Energy Produced
Solar Pollution Rate
Solar Pollution
Solar Energy Profits
Rate of Solar Energy Profits
Recent Solar Energy Profit Rate
Cost of Solar Energy
Solar Energy Cost Change
Solar Cost Factor
Government Solar Support
Government Solar Policy Factor
Price of Solar Energy
Solar Energy Price Change
Change in Solar Energy Profits
Solar Price Factor

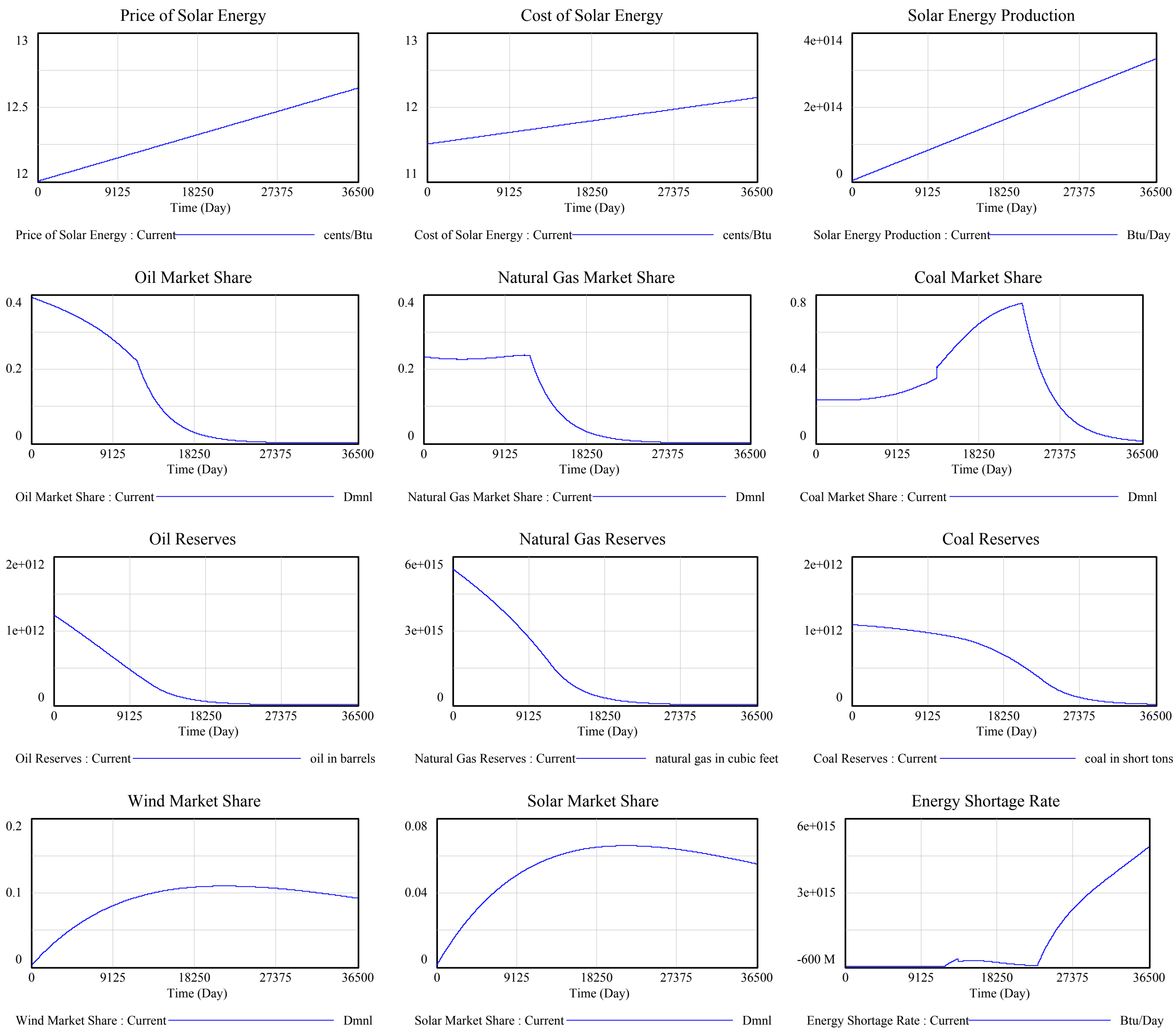
4.1.3 Results from the Model

Important Initial values for first simulation:

> MAX Change in Capacity for each fossil fuel is essentially unlimited.
> MAX Change in Capacity for Wind Energy = $1.5*10^{10}$
> MAX Change in Capacity for Solar Energy = $9.0*10^{9}$
>
> Capacity factor for each fossil fuel = 350

Simulation of the model with the specified initial values produces the following graphs:





Observe that solar energy and wind energy production both increase at constant rates due to the limitation placed on the maximum change in capacity. Also, energy production for each fossil fuel eventually peaks and then drops due to the depletion of reserves.

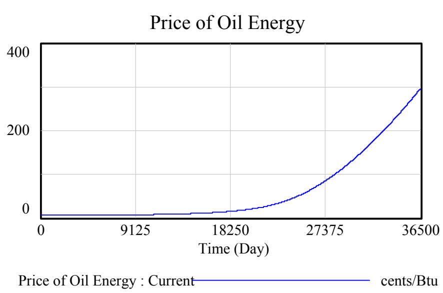
At time t = 37 years, there is a small energy shortage due to the heavy exhaustion of oil and natural gas. Coal makes up for this shortage over the next 25 years, at which point coal reserves are heavily depleted and this causes a massive world-wide energy shortage due to the lack of a suitable energy alternative. Wind and solar energy are not capable of meeting such a huge demand because of the lack of funds and effort put forth by society to increase the role of renewable energy.

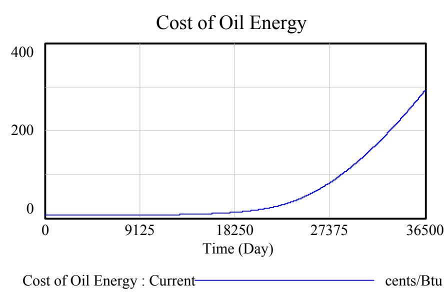
Initial values for the second simulation:

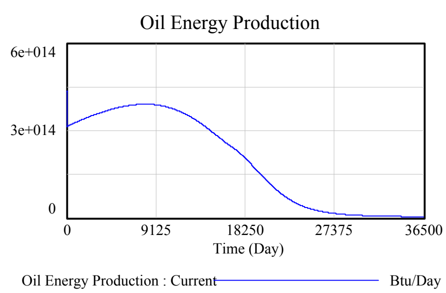
MAX Change in Capacity for each fossil fuel is essentially unlimited.
MAX Change in Capacity for Wind Energy = $1.5*10^{15}$
MAX Change in Capacity for Solar Energy = $9.0*10^{14}$

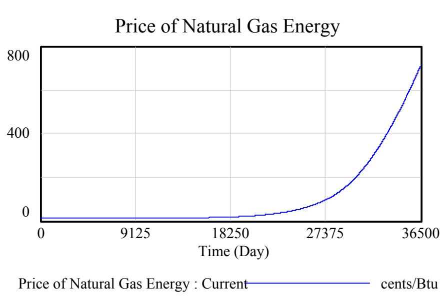
Capacity factor for each fossil fuel = 350

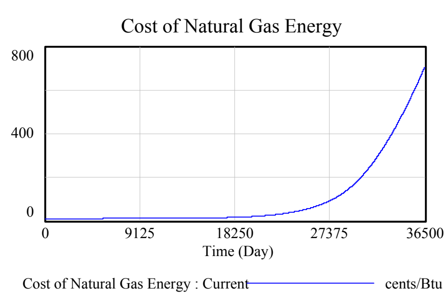
Simulation of the model with the specified initial values produces the following graphs:

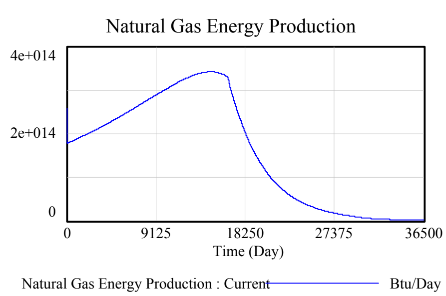


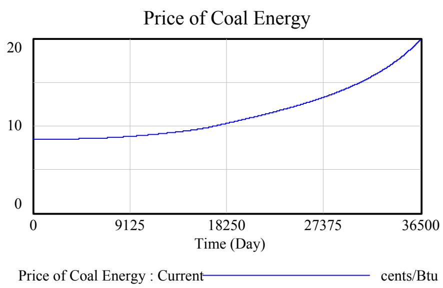


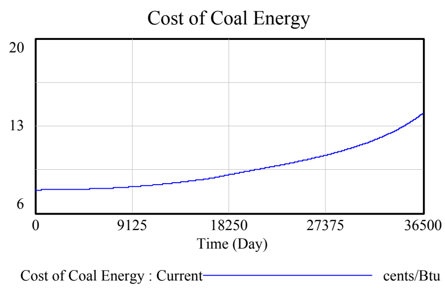


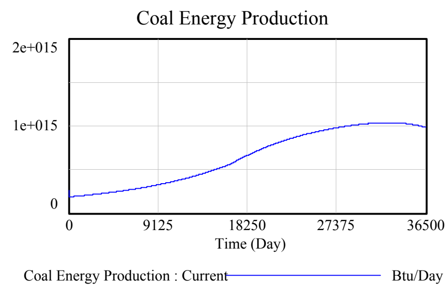


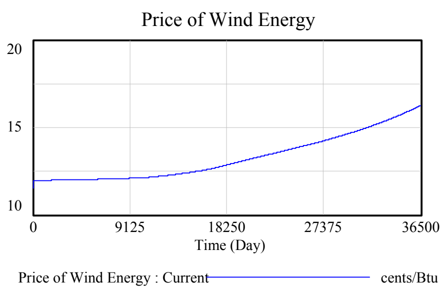


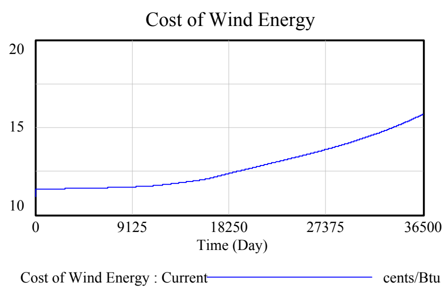


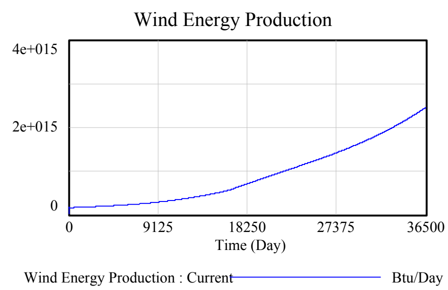

Price of Coal Energy
20
10
0
0
9125
18250
27375
36500
Time (Day)
Price of Coal Energy : Current
cents/Btu

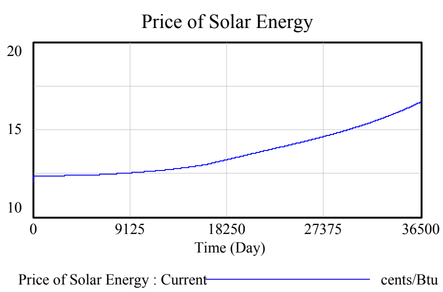

Cost of Coal Energy
20
13
6
0
9125
18250
27375
36500
Time (Day)
Cost of Coal Energy : Current
cents/Btu

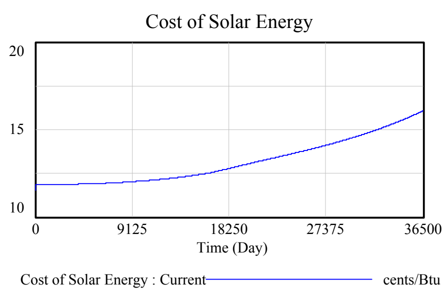

Coal Energy Production
2e+015
1e+015
0
0
9125
18250
27375
36500
Time (Day)
Coal Energy Production : Current
Btu/Day

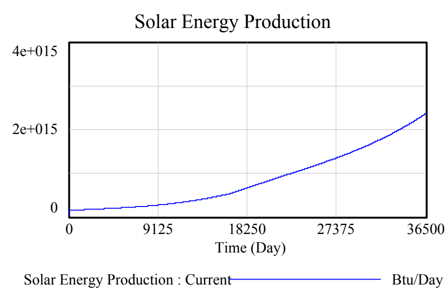

Price of Wind Energy
20
15
10
0
9125
18250
27375
36500
Time (Day)
Price of Wind Energy : Current
cents/Btu

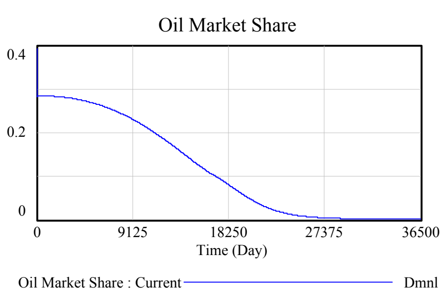

Cost of Wind Energy
20
15
10
0
9125
18250
27375
36500
Time (Day)
Cost of Wind Energy : Current
cents/Btu

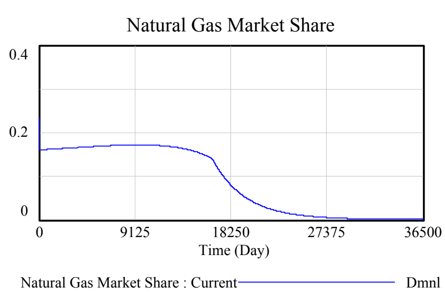

Wind Energy Production
4e+015
2e+015
0
0
9125
18250
27375
36500
Time (Day)
Wind Energy Production : Current
Btu/Day

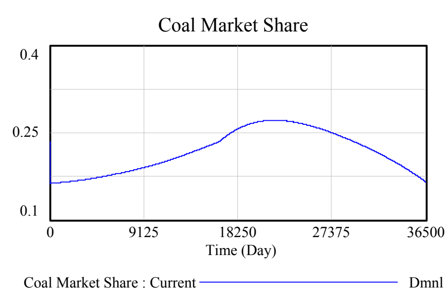

Price of Solar Energy
20
15
10
0
9125
18250
27375
36500
Time (Day)
Price of Solar Energy : Current
cents/Btu

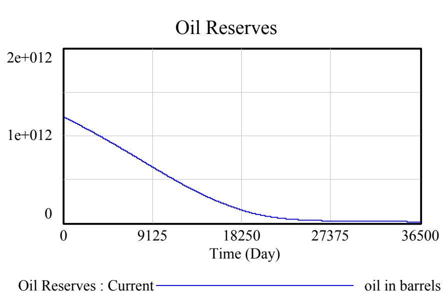

Cost of Solar Energy
20
15
10
0
9125
18250
27375
36500
Time (Day)
Cost of Solar Energy : Current
cents/Btu

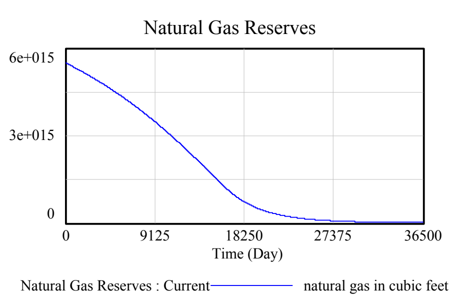

Solar Energy Production
4e+015
2e+015
0
0
9125
18250
27375
36500
Time (Day)
Solar Energy Production : Current
Btu/Day

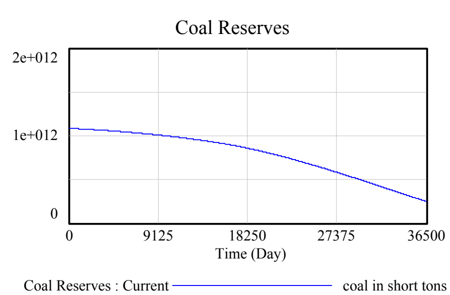

Oil Market Share
0.4
0.2
0
0
9125
18250
27375
36500
Time (Day)
Oil Market Share : Current
Dmnl

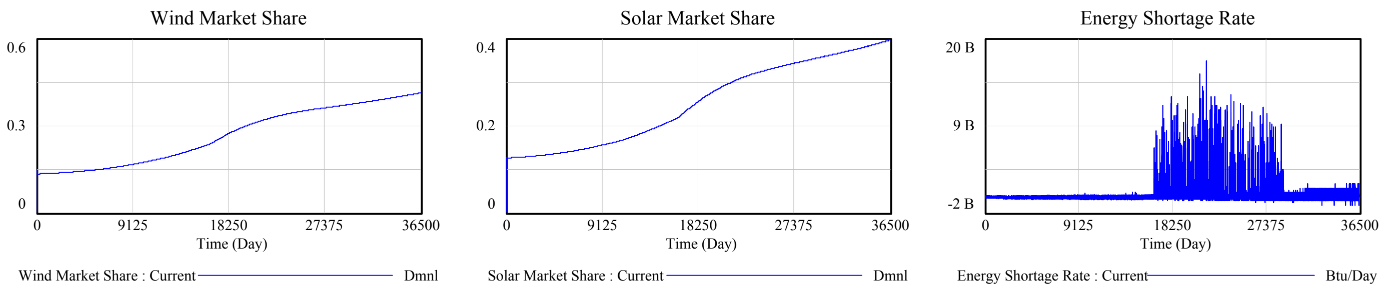

Natural Gas Market Share
0.4
0.2
0
0
9125
18250
27375
36500
Time (Day)
Natural Gas Market Share : Current
Dmnl


Coal Market Share
0.4
0.25
0.1
0
9125
18250
27375
36500
Time (Day)
Coal Market Share : Current
Dmnl


Oil Reserves
2e+012
1e+012
0
0
9125
18250
27375
36500
Time (Day)
Oil Reserves : Current
oil in barrels


Natural Gas Reserves
6e+015
3e+015
0
0
9125
18250
27375
36500
Time (Day)
Natural Gas Reserves : Current
natural gas in cubic feet


Coal Reserves
2e+012
1e+012
0
0
9125
18250
27375
36500
Time (Day)
Coal Reserves : Current
coal in short tons



In this simulation, the value for the maximum change in capacity for both wind and solar energy are large enough to allow a sustained growth over the time period. This shifts the dependence from fossil fuel energy to wind and solar energy over time as shown by the change in market share. As a result, the reserves last longer and there are only minor energy shortages over this time period, which are due to the heavy depletion of fossil fuel reserves.

This is a desirable situation however it assumes that economically suitable renewable technologies have been developed and implemented in order to replace the various fossil fuel technologies. This is possible but will require a lot of time and effort to develop.

4.1.4 Analysis and Conclusions

These simulations produce some very useful data. Most importantly, the data indicates that currently, society as whole is not doing enough to improve the situation. Simulations indicate that at current rates of consumption and possible future rates of consumption, we will face massive energy shortages in about 60 years.

Once fossil fuels reserves are depleted to a certain level, the corresponding capacity will drop in order to prevent immediate depletion. However, with a sudden drop in production from one source, the energy demand that was previously being met by this source must be met by some other capable source. This will repeat for each fossil fuel until all fossil fuel reserves are depleted, at which point society will face massive energy shortages because there are no alternative energy sources that meet the world energy demand. Therefore, over the next 10 to 20 years, it is imperative that renewable energy capacity is increased by as much as possible.

Additional money needs to be spent in developing renewable technologies and implementing them into society. Although renewable energy is more expensive than fossil fuel energy, the difference in price between the two energy sources is not very large. Recent data has shown that in some cases, wind and solar energy is only 30% percent more expensive than fossil fuel generated electricity.

It should be noted that although that energy shortages were successfully avoided in the second simulation, the price of fossil fuel generated energy became extremely large and many people were forced to purchase this more expensive energy because the alternative sources could not support the entire demand. The important question that is derived from this observation is: how can energy price be minimized?

Currently, energy prices are fairly reasonable. However, this will most likely change for the worse as time goes by. One option to address this problem is to increase renewable energy capacity as fast as possible. The problem is that increasing renewable energy capacity at a fast rate will require a lot of resources and manpower which will probably cause renewable energy prices to increase substantially. However, average energy prices will increase anyway over the next 50 years if renewable capacity is increased too slowly. This is because fossil fuel energy prices will increase to incomprehensible levels and people will not be able to afford any form of energy. Hence, the price of energy needs to be set at a value which isn't too small because this will encourage over usage and waste, but it can't be set too high if people can't afford energy, there will be economic issues.

Therefore, using the data gained from this model, the best policy is that of immediate action. The government needs to increase taxes on energy uses of fossil fuels, specifically transportation fuels, heat, and electricity. In Europe, gasoline costs many times more than it does in the United States. As a result, many European countries are investing heavily in the development of renewable energy technologies.

This method of taxation will hopefully encourage people to conserve gas, heat, and electricity. It should also serve as a means to reduce pollution associated with the production of electricity and the use of fuels.

As a further step, the government needs to use this money to support both research and development of renewable technologies and the construction of wind farms and solar energy plants around the country.

People need to stop wasting so much energy and need to gain a better understanding of our current situation. The government needs to project an attitude of responsibility because we are responsible for our actions. We are responsible for our mistakes and we must do what we can to help fix them. Despite all the efforts of a single conscience group, nothing will come of this hard work if the world lacks the understanding and the sense of responsibility required to make these goals possible.

The problem is that most individuals are ignorant when it comes to our energy crisis. We do not understand the world around us and we fail to recognize the impact our actions have on one another and on this planet. What we lack is morality and respect. We do not respect one another and we do not care about much of what goes on outside our own lives because we base our decisions primarily on what is best for us as individuals and not society as a whole. Therefore, we as individuals must develop a sense of morality and respect for our planet because this planet is what has sustained our civilization. If we do not take care of it, it will not take care of us.

5- Conclusion

The need for alternative energy resources has been confirmed based on the data that has been collected. Trends show a continuing increase in energy demand. The demand for energy has risen each of the last ten years and is expected to continue, especially with the advances in technology, growth of developing countries, and the ever increasing population. Accompanying the increase in energy demand is the increased usage of oil, natural gas, and coal. The news of a growing energy demand is terrible because it means the current fossil fuel reserves will be used up quicker. This does not bode well considering the rate at which new reserves are found has been on a steady decline for the last several decades. The diminishing fossil fuel reserves along with the world wide increase in energy usage has driven the price of fossil fuels up.

Predictions demonstrate that these trends are expected to continue until our reserves are totally depleted. The majority of the predictions report that oil production will peak before 2010 and many believe the peak is already occurring. The predictions are similar for natural gas and coal; researchers say that natural gas production will peak shortly after oil and finally coal will as well. The most common prediction is that the oil and gas will be close to being completely depleted by 2050. Society can't wait until then to determine a solution to this problem because by then it will already be too late. The increases in energy demand combined with the decline in the fossil fuel reserves are causing a continued price increase in energy derived from fossil fuels. As fossil fuels continue to become scarce, the price required to obtain them is going to rise rapidly until it reaches outrageous proportions.

The results of this information outline a significant world problem. The problem is that there is a mounting energy crisis; this crisis will become more apparent over the years to come and begin to worsen unless steps are taken to solve this problem. In order to solve this problem alternative energy resources are needed. The leading renewable energy resource in the world today is hydroelectric; however this source has limited growth potential which means it is not a viable option for solving the energy crisis. Biomass and geothermal are similar to hydroelectric because currently they are the next two most used renewable energy sources. However biomass has a limited potential and geothermal, although it has decent potential, is harder to obtain and is not currently feasible as a large scale solution.

The two alternative energy sources that contain the most short term potential are solar energy and wind energy. There has been a minor increase in the amount of wind energy produced over the last several years. Wind farms are becoming more popular and are being implemented around the world. Research is being conducted by the United States and more wind farms are expected to be built as a result of it. There are two off-shore projects planned for the near future; the Cape Cod wind farm and the Long Island wind farm. There are some states that have a huge potential for successful wind farms such as North Dakota and Minnesota. Data has already been collected on Minnesota; which should produce more wind farms in the not so distant future. Windmills have advanced technologically over the years so that they are more durable and efficient today. Wind energy is one of the more viable alternative energy sources, however it still presents some issues and it alone will not solve the energy crisis. Wind energy is part of the solution and at the very least will help delay the depletion of the fossil fuel reserves.

Solar energy is the other alternative energy source that has the potential to be a solution to the energy crisis. The price for solar energy has been declining over the last few years; which means it comes within the same price range as fossil fuels. Technological advances have made solar energy more efficient because the motor that is used to generate power has been improved. There have been numerous solar plants set up in the United States in which data has been collected to see how successful solar power could be. The results were positive; they led to the build of more plants, on which further tests were conducted to evaluate the newest advances. If the proper location was found and the system was efficient enough solar energy could become the leading alternative energy source.

The current technology and state of solar energy won't provide enough energy to have a significant impact on the energy crisis. A new idea has been brought to light that if it were to be successfully implement could provide enough solar energy to solve the energy crisis. This idea is called space mirrors; this is placing mirrors in space and reflecting the sun down to a solar system on earth. This idea is still in it early stages of development so no one knows its true potential. All that is known today is that solar energy has huge potential that needs to be tapped in order to solve provide relief for the world's energy crisis.

Alternative energy sources are still being explored, researched, and developed. This process must continue because in the future they will be all society will have to rely on. Advances in alternative energy must be made in order to produce mass amounts of energy. There are still issues even if the world manages to produce enough alternative energy to meet the energy demand. The world must then find a way to use this energy for all the things that it used fossil fuels for. This means new cars will have to be built, engines will have to be changed along with the process of making certain plastics, chemicals, and metals.

We as individuals shape this world and we have the ability to solve these problems. It is simply a matter of action.

5.1.1 Recommendations for policy makers

It is obvious that renewable energy must be used in order to avoid a major world crisis. Unfortunately, that is much easier said than done. Policy-makers are facing the daunting task of trying to further implement renewable energy for electricity generation. Switching completely over to 100% renewable energy in a short amount of time is difficult. However, serious thought and effort must be put into the implementation of renewable energy, to satisfy the growing demand and declining fossil fuel reserves.

The technology is available to make renewable energy a primary source for our electricity. It is now up to policy-makers to make this possible. The main consideration will be cost. Research and development will be very useful. With more research, solar power plants and wind turbines will become cheaper and more efficient. With an increase in efficiency, these can be built in places with less than optimal conditions, and still satisfy much of the energy demand.

Determining how to raise the funds for renewable energy is a considerable challenge. The easiest way to do this would be to add a renewable energy tax to fossil fuels. While most of the industrialized world imposes large taxes on fuel, the United States does not. The relatively low cost of fuel in the US is apparent with demand for large engine vehicles such as SUVs skyrocketing. The majority of electricity and transportation use fossil fuels, so taxing them could quickly generate money. The biggest problem with more taxes is that it will make fossil fuels even more costly. A small renewable energy tax could be beneficial if combined with other ideas though. The tax would improve the situation from two directions, it would help reduce fossil fuel consumption by encouraging conservation and it would provide capital to renewable energy projects. While the tax may be a minor inconvenience in the short term, it will help to ensure a more prosperous future.

As previously stated, renewable energy needs to be more widely used sooner than later. Policy-makers must set certain goals for the near future and meet or exceed them. To say that by 2010 50% of the US's energy will come from renewable energy would be an optimistic goal. However, there are better ways to integrate renewable energy with fossil fuels.

One method would be to set a certain standard for future power plants. An example of this would be to require 100% of all new power capacity to be built must be of renewable sources by 2010. This will ensure that the United States begins to seriously use renewable energy. As knowledge, technology, and different types of renewable energy increase, fossil fuels will eventually be phased out of electricity production. This will lengthen the amount of time that fossil fuels will last. This extra amount of time will allow the auto industry to develop alternative fuel, or even renewable energy vehicles.

With these policies and methods, the United States and the world may finally be able to end its dependence on fossil fuels before they run out. It can potentially be costly, and it will be an inconvenience to switch over. Considering the alternative, phasing out fossil fuels is the only option available.

5.1.2 Recommendations for Future IQP's

Even the most ambitious plans to implement solar and wind energy on a large scale fail to meet 100% of energy demand (current or future demand). For instance, the massive offshore project planned for Long Island would be capable of producing 20% of the islands energy at the very best. Solar energy may have even less total potential. For instance homes built in Japan with their entire roofs covered in PV panels can only derive a small percentage of their energy from the panels, the rest must come from the grid. Thus further research into not yet proven energy sources such as Fusion should be considered in great depth in a future IQP. While solar and wind power can extend the life of our fossil fuel supplies, they are and will be inadequate in themselves to ultimately replace fossil fuel energy and satisfy demand.

While this project investigates the issue of fossil fuel depletion as it relates to energy demand, it does not address problems occurring in other end markets. If fossil fuels, especially oil are to become extremely scarce, this will undoubtedly have a negative impact on all petrochemical based products. Plastics, rubber, chemical solvents, road paving, building materials, and even clothing are all made out of oil derivatives. A possible solution may lie in the ability to use crop based petroleum (ie. methanol). This idea has recently been proven on a small scale in the development of bio plastics, however it is unknown how well this can scale up or offer substitutability for other petroleum based products.

Another interesting study should explore the potential of a new process referred to as thermal de-polymerization. Thermal de-polymerization is essentially a man-made process that can do in a few hours what it takes nature millions of years to do, make oil. The first commercial implementation of this process began in 2003, turning turkey by-products into oil, gas and other useful materials. One important feature to take note of is that this process is completely energy self-sufficient (other than the energy required to initially build the plant). This means the process can generate more energy than it requires running. Raw materials are also recovered at the same time. This development could be classified as a recycling process requiring minimal sorting of waste materials. A future IQP may want to consider the possibility of using the waste found landfills as a potential resource for this process. If successful this process could yield oil and gas for energy or petrochemical production, reclaim other minerals, and clean up landfill sites for alternate development. The process could possibly be sustainable if the oil produced is used in petrochemical production where the petrochemicals are recycled indefinitely. However if the oil is used in combustion/thermal energy production (and released into the air), the resource would still eventually run out, making this process an impractical solution to solving the long term oil crises for purposes of energy production.

Glossary

ARB	Air Resources Board
ASPO	Association for the Study of Peak Oil
AWEA	American Wind Energy Association
CAES	Compressed Air Energy Storage
CCGT	Combined Cycle Gas Turbine
CEC	California Energy Commission
CO_2	Carbon Dioxide
COE	Cost of Energy
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EES	Economic and Engineering Services
EIA	Energy Information Administration
FPL	Florida Power and Light Company
GDP	Gross Domestic Product
GenCo	Generating Company
GHG	Greenhouse Gases
GW	GigaWatt
HCE	Heat Collector Element
HTF	Heat Transfer Fluid
HTS	High Temperature Superconductive
IEA	International Energy Agency
IOU	Investor-Owned Utility
IPP	Independent Power Producer
IQP	Inter-disciplinary Qualifying Project
IRR	Internal Rate of Return
ISCCS	Integrated Solar Combined Cycle System
ISO	Independent System Operator
KW	KiloWatt
KWH	KiloWatt per Hour
LIFB	Long Island Farm Bureau
LIPA	Long Island Power Authority
MDA	Mc Donnell Douglas
MPH	Miles per Hour
MW	MegaWatt
NO	Nitrous Oxide
NPV	Net Present Value
NREL	National Renewable Energy Laboratory

O & M	Operation and Maintenance
OPEC	Organization of Petroleum Exporting Countries
PTC	Production Tax Credit
SAIC	Science Applications International Corporation
SCA	Solar Concentrator Array
SEGS	Solar Energy Generating System
SNG	Synthetic Natural Gas
SO	Sulfur Oxide
STM	Stirling Thermal Motors
TAG	Technical Assessment Guide
TAN	Total Acid Number
TREIA	Texas Renewable Industries Association
USC	University of Southern California
WRAP	Wind Resource Assessment Program

Bibliography

"About: Definitions," T.R.E.I.A., http://www.treia.org/redefinition.htm.

Akhil, A.A., S.K. Swaminathan, and R.K. Sen, "Cost Analysis of Energy Storage for Electric Utility Applications", Sandia National Laboratories: February 1997.

Annual Energy Outlook 2001. Washington, DC, December 2000, www.eia.doe.gov/oiaf/aeo/coal, November 2003.

"Argentina Mulls Fixing Prices," Oil Daily, September 23, 2002, www.energyintel.com, September 2003.

B. Campbell, "Hard at Work: Independents Plan To Go the Extra Mile," The American Oil & Gas Reporter, January 2001.

Barnes, "Tackling the Rural Energy Problem in Developing Countries," Finance & Development, June 1997.

Bechtold, Richard L., Alternative Fuels Guidebook: Properties, storage, dispensing and vehicle facility modifications (Warrendale, PA, Society of Automotive Engineers, 1997).

Beninga, K, et. al., "Performance Results for the SAIC/STM Prototype Dish/Stirling System," Proceedings of the 1997 ASME International Solar Energy Conference, Washington, D.C., 1997.

Buck, R., P. Heller, and H. Koch, "Receiver Development for a Dish-Brayton System," San Antonio, TX, 1996.

"Business Opportunities in Asia & the Pacific," The Gale Group: Worldwide Projects, Inc., November 1, 2002.

"Calculating the Saving", Cape Wind, www.capewind.org, September 2003.

"California Haunted by Neglect of Infrastructure," Natural Gas Week, December 18, 2000.

"California Wind Farms", Wind Turbines, http://energy.ca.gov/contactus.html, December 1, 2003.

Campbell, C.J., "Industry urged to Watch Regular Oil Production Peaks, Depletion Signals", Oil and Gas Journal, July 14, 2003.

Campbell, C.J, “Oil Depletion”, www.oilcrisis.com/campbell/update2002.htm, December 2003.

Cedigaz, “Natural Gas Statistics for 2001: Cedigaz’ First Estimates,” The Year in Review, March 28, 2002.

“Central Receiver Commercialization Plan”, Bechtel National Inc., for the California Energy Commission: June 1995.

Cohen, G., and S. Frier, “Ten Years of Solar Power Plant Operation in the Mojave Desert”, Proceedings of Solar 97, the 1997 ASES Annual Conference, Washington, D.C. April, 1997.

“Country Report: India”, World Markets Energy Online, August 7, 2002, www.worldmarketsanalysis.com, September 2003.

“Deepwater drilling remains steady worldwide”. Oil and Gas Journal online. http://ogj.pennnet.com. November 30, 2003.

Deffeyes, Kenneth S., Hubbert’s Peak: The impending world oil shortage (Princeton, N.J., Oxford: Princeton University Press, 2003).

Dell, R.M.; Rand, D.A.J., 2001.“Energy storage – a key technology for global energy sustainability”. Journal of Power Sources 100, pp 2-17.

Dincer, Ibrahim, 1999. “Environmental impacts of energy”. Energy Policy 27, pp. 845-854.

Diver, R.B., C.E. Andraka, J.B. Moreno, D.R. Adkins, and T.A. Moss, “Trends in Dish-Stirling Solar Receiver Design,” Reno, NV, 1990.

DRI•WEFA, “World Overview”, Lexington, MA, September 2002.

Energy Information Administration, Annual Coal Report 2002, DOE/EIA (Washington, DC, November 2003).

“Energy Information Administration”, Natural Gas Monthly, Washington, DC, March 2001.

“Energy Information Administration”, Short-Term Energy Outlook, April 2003, www.eia.doe.gov/emeu/steo/pub/contents.html, December 2003.

Energy Information Administration, Quarterly Coal Report, DOE/EIA (Washington, DC, January 2002).

“Egypt—Oil and Gas,” World Markets Energy Online, September 25, 2002, www.worldmarketsanalysis.com, November 2003.

"Environmental and Economic Impacts of Geothermal Energy", Geothermal Energy Program: Environmental and Economic Impacts, http://www.eere.energy.gov/geothermal/geoimpacts.html.

Freeman, Peter John, Electric Power Transmission and Distribution (London, Harrap, 1974).

Fugitive Emissions Testing - Final Report, AeroVironment, Inc., for KJC Operating Company, Monrovia, CA: January 1995.

"Gas Research Institute", GRI 2001Baseline Projection, February 2001.

"Geothermal Energy Basics", EERE: Geothermal Energy - Basics, http://www.eere.energy.gov/RE/geo_basics.html.

"Giant Wind Turbines Harvest Energy for Iowa Utilities", News Releases, http://www.epri.com/corporate/discover_epri/news/releases/windfarm.html.

"Global Insight, Inc.", World Energy Market Analysis: Western Europe, Lexington, MA, September 2002, www.globalinsight.com, November 2003.

"Global Warming," National Air Quality: 2000, http://www.epa.gov/air/aqtrnd00/globwarm.html.

Goldemberg, Jose; Coelho, Suani Teixeira. "Renewable energy – traditional biomass vs. modern biomass". Energy Policy.

Gow, Tracy & Pidwirny, Michael, "Greenhouse Effect," Greenhouse Effect, http://royal.okanagan.bc.ca/mpidwirn/atmosphereandclimate/greenhouse.html.

"Greenhouse Effect & Enhanced Greenhouse Effect," Greenhouse Effect, http://www.science.gmu.edu/~zli/ghe.html.

"Growing Gas-Import Market," Petroleum Economist, November 2002.

Gunton, Thomas, 2004. "Energy rent and public policy: an analysis of the Canadian coal industry. Energy Policy 32, pp 151-163.

Hadley, S.; Short, W., 2001. "Electricity sector analysis in the clean energy futures study". Energy Policy 31, pp 1285-1298.

Hamelinck, C.; Faaij, A., 2002. "Future prospects for production of methanol and hydrogen from biomass". Journal of Power Sources 111, pp 1-22.

"Impacts on Oil", Oil-Gas-Offshore, http://oil.com/, November 18, 2003.

"Inching Forward with the IMF," Business Monitor International: Latin American Monitor, September 2002.

"International Atomic Energy Agency", Power Reactor Information System, www.iaea.org, October 2003.

"IPAA: Lack of Good Prospects Undermines Drilling Activity, Heightens US Gas Supply Concerns," Oil & Gas Journal, November 4, 2002.

J. Greenberg, "Cautious Optimism Characterizes Gulf of Mexico Activity," World Oil, January 2001.

Junginger, M.; Faaij, A.; Turkenburg, W.C. "Global experience curves for wind farms". Energy Policy.

Jean-Baptiste, P.; Ducroux, R., 2003. "Energy Policy and Climate Change". Energy Policy, pp. 155 – 166.

Kates, Robert & Wilbanks, Thomas, "Making the Global Local", Environment, April 2003, Volume 45, Number 3.

Kaul, S.; Edinger, R. "Efficiency versus cost of alternative fuels from renewable resources: outlining decision parameters". Energy Policy.

"Kilowatt-hour," Kilowatt Hour - a What is Definition, http://whatis.techtarget.com/definition/0,,sid9_gci797759,00.html.

Klass, D., 2003. "A Critical Assessment of Renewable Energy Use in the USA". Energy Policy 31, pp. 353 – 367.

"Land Rig Drilling, Dayrate Boom, Produce Huge Profits for Industry," Natural Gas Week, April 30, 2001.

Leaning, John, "State urged to 'step up' wind farm opposition", Cape Cod Times, April 18, 2003.

Lynch, Michael, "Petroleum resources pessimism debunked in Hubbert model", Oil and Gas Journal, July 14, 2003.

M. Landler, "Europe's Central Bank Cuts Rates by Half a Point," The New York Times December 6, 2002.

Mankiw , Gregory, "Principles of Microeconomics" Thomson South-Western, 2004.

Maxwell, T. T., Alternative Fuels: Emissions, Economics and Performance (Warrendale, PA, Society of Automotive Engineers, 1995).

McKendry, P., 2002. "Energy production from biomass (part 1): overview of biomass". Bioresource Technology 83, pp. 37-46.

McKendry, P., 2002. "Energy production from biomass (part 2): conversion technologies". Bioresource Technology 83, pp. 47-54.

McKendry, P., 2002. "Energy production from biomass (part 3): gasification technologies". Bioresource Technology 83, pp. 55-63.

McMullan, J.T.; Williams, B.C.; McCahey, S, 2001. "Strategic considerations for clean coal R&D". Energy Policy 29, pp. 441-452.

Meinecke, W., and M. Bohn, Solar Energy Concentrating Systems: Applications and Technologies, Heidelberg, Germany, 1995.

Menanteau, P.; Finon, D.; Lamy, M., 2003. "Price versus quantities: choosing policies for promoting the development of renewable energy" Energy Policy 31, pp. 799-812.

National Research Council (U.S.), Coal: Energy for the Future (Washington, D.C., National Academy Press, 1995).

National Research Council (U.S.), Fuels to Drive Our Future (National Academy Press, 1990).

National Energy Modeling System: An Overview 2000, Washington, DC, March 2000, www.eia.doe.gov/oiaf/aeo/overview, December 2003.

Natural Gas Annual 1999, Washington, DC, October 2000.

Natural Gas Fundamentals, From Resource to Market "The Effect of Carbon Dioxide," Global Warming, http://mysite.freeserve.com/pollution/page3.html.

"Natural Gas Supply," NaturalGas.org, http://www.naturalgas.org/business/analysis.asp#liquifiedng.

"O&M Cost Reduction in Solar Thermal Electric Plants" - 2nd Interim Report on Project Status, KJC Operating Company, for Sandia National Laboratories: July 1, 1996.

P.I. Vasquez, "Tensions Rise in Venezuela; Groups Plan Nationwide Strike," The Oil Daily, October 4, 2002.

"Permits", September 2003, Cape Wind, www.capewind.org, October 2003.

"Petroleum Economics, Ltd.", World Long Term Oil & Energy Outlook, London, UK, June 2002.

Poulton, M. L., Alternative Fuels for Road Vehicles (Southampton, UK; Boston: Computational Mechanics Publications, 1994).

"Protecting Our Environment, Cape Wind, www.capewind.org, September 2003.

Radler. "Worldwide Reserves Increase as Production Holds Steady," Oil & Gas Journal, December 23, 2002.

Rifkin, Jeremy, The Hydrogen Economy: The creation of the worldwide energy web and the redistribution of power on Earth. (New York, J.P. Tarcher/Putnam, 2002).

Sesto, Ezio; Casale, Claudio, 1998. "Exploitation of wind as an energy source to meet the world's electricity demand". Journal of Wind Engineering and Industrial Aerodynamics 74-76, pp. 375-387.

Sims, R.; Rogner, H.; Gregory, K., 2003. "Carbon emission and mitigation cost comparisons between fossil fuel, nuclear, and renewable energy resources for electricity generation". Energy Policy 31, pp. 1315 – 1326.

Sims, R.E.H. "Renewable energy: a response to climate change". Solar Energy.

"Solar Electric Generating System IX Technical Description", LUZ International Limited: 1990.

"South Pars 11-12 Bids Sought," Platts: International Gas Report, January 17, 2003.

"Status Report on Solar Thermal Power Plants", Pilkington Solar International: 1996.

Sterman, John D., "Business Dynamics: Systems Thinking and Modeling for a Complex World", Irwin McGraw-Hill, Boston, 2000.

Stevenson, William D., Elements of Power System Analysis (New York, McGraw-Hill, 1982).

"Study Links Air Pollution, Ozone, and Asthma, Sinus News, http://www.sinusnews.com/Articles2/air-pollution-ozone-asthma.html.

The Sleeping Giant: Iran as a Future Gas Major, Cambridge Energy Research Associates, Private Report, Cambridge, MA, July 2002.

W. Fisher, "Energy and Environment into the Twenty First Century," Environmental Geo Sciences, 1999.

Walker, G., “Sterling Engines”, Clarendon Press, Oxford, England, 1980.

Washom, B., “Parabolic Dish Stirling Module Development and Test Results,” Proceedings of the IECEC, San Francisco, CA (1984).

West, C.D., “Principles and Applications of Stirling Engines,” Van Nostrand Reinhold Company, New York, NY, 1986.

“What is Geothermal Energy?” What is Geothermal Energy - INEEL, http://geothermal.id.doe.gov/what-is.shtml.

William, Bob, “Debate over peak-oil issue boiling over”, Oil and Gas Journal, July 14, 2003.

“Wind Energy Technologies”, Energy Efficiency and Renewable Energy, http://www.eere.energy.gov/RE/wind.html, November 6, 2003.

“Wind Energy Technology”. Global Wind Energy Market Report by the American Wind Energy Association. http://www.techsectortrends.com/document_139.html

“Wind Resource Analysis Program 2002”, Minnesota, 2002, http://www.state.mn.us/mn/externalDocs/WRAP_Report_110702040352_WRAP 2002, November 2003.

World Bank, “Global Economic Prospects and the Developing Countries”, Washington, DC, 2003.

“World Energy Consumption”, International Energy Outlook 2003, http://www.eia.doe.gov/oiaf/ieo/world.html, October 22, 2003.

“World Market Research Center”, Automotive Eastern Europe, London, UK, August 2002, www.Wmrc.com, November 2003.

“World Market Research Center”, China Automotive, London, UK, September 4, 2002, www.wmrc.com, October 2003.

“World Market Research Center”, World Market Automotive, London, UK, August 23, 2002, www.wmrc.com, December 2003.

Zarnikau, J., 2003. “Consumer demand for ‘green power’ and energy efficiency”. Energy Policy 31, pp 1661-1672.

Appendix A

(001) Available Demand =
World Energy Demand - (Coal Production Capacity*Coal at Capacity +
Natural Gas Production Capacity*Natural Gas at Capacity +
Oil Production Capacity*Oil at Capacity + Solar Production Capacity*
Solar at Capacity + Wind Production Capacity*Wind at Capacity) –
(Nuclear Energy Production + Hydropower Energy Production)
Units: Btu / Day

(002) Change in Coal Energy Profits = Rate of Coal Energy Profits - Recent Coal Energy Profit Rate
Units: cents / Day

(003) Change in Coal Production = Coal Energy Demand - Coal Energy Production
Units: Btu / (Day*Day)

(004) Change in Coal Production Capacity =
IF THEN ELSE((Coal Production Capacity > MAX Coal CAPACITY),
(MAX Coal CAPACITY - Coal Production Capacity),
(IF THEN ELSE(((Coal Production Capacity +
Required Change in Coal Production Capacity) >
MAX Coal CAPACITY),
(MAX Coal CAPACITY –
Coal Production Capacity),
Required Change in Coal Production Capacity)))
Units: Btu / (Day*Day)

(005) Change in Natural Gas Energy Profits =
Rate of Natural Gas Energy Profits - Recent Natural Gas Energy Profit Rate
Units: cents / Day

(006) Change in Natural Gas Production = Natural Gas Energy Demand -Natural Gas Energy Production
Units: Btu / (Day*Day)

(007) Change in Natural Gas Production Capacity =
IF THEN ELSE((Natural Gas Production Capacity > MAX Natural Gas Capacity),
(MAX Natural Gas Capacity - Natural Gas Production Capacity),
(IF THEN ELSE(((Natural Gas Production Capacity +
Required Change in Natural Gas Production Capacity) >
MAX Natural Gas Capacity),
(MAX Natural Gas Capacity –
Natural Gas Production Capacity),
Required Change in Natural Gas Production Capacity)))
Units: Btu / (Day*Day)

(008) Change in Oil Energy Profits = Rate of Oil Energy Profits - Recent Oil Energy Profit Rate
Units: cents / Day

(009) Change in Oil Production = Oil Energy Demand - Oil Energy Production
Units: Btu / (Day*Day)

(010) Change in Oil Production Capacity =
IF THEN ELSE((Oil Production Capacity > MAX Oil Capacity),
(MAX Oil Capacity - Oil Production Capacity),
(IF THEN ELSE(((Oil Production Capacity +
Required Change in Oil Production Capacity) >
MAX Oil Capacity),
(MAX Oil Capacity - Oil Production Capacity),
Required Change in Oil Production Capacity)))
Units: Btu / (Day*Day)

(011) Change in Solar Energy Profits = Rate of Solar Energy Profits - Recent Solar Energy Profit Rate
Units: cents / Day

(012) Change in Solar Production = Solar Energy Demand - Solar Energy Production
Units: Btu / (Day*Day)

(013) Change in Solar Production Capacity =
IF THEN ELSE((Solar Production Capacity - Solar Energy Production) <
(2*Change in Solar Production),
IF THEN ELSE (MAX CHANGE in Solar CAPACITY <
(2*Change in Solar Production),
MAX CHANGE in Solar CAPACITY,
2*Change in Solar Production),
0)
Units: Btu / (Day*Day)

(014) Change in Wind Energy Profits = Rate of Wind Energy Profits - Recent Wind Energy Profit Rate
Units: cents / Day

(015) Change in Wind Production = Wind Energy Demand - Wind Energy Production
Units: Btu / (Day*Day)

(016) Change in Wind Production Capacity =
IF THEN ELSE((Wind Production Capacity - Wind Energy Production) <
(2*Change in Wind Production),
IF THEN ELSE(MAX CHANGE in Wind CAPACITY <
(2*Change in Wind Production),
MAX CHANGE in Wind CAPACITY,
2*Change in Wind Production),
0)
Units: Btu / (Day*Day)

(017) Coal at Capacity =
IF THEN ELSE((1.8*((1 / Price of Coal Energy)^2)*DISTRIBUTION FUNCTION) >=
(Coal Production Capacity / (World Energy Demand - (Nuclear Energy
Production + Hydropower Energy Production))),
1,
0)
Units: Dmnl

(018) Coal Capacity Factor = 3650
Units: Day

(019) Coal Consumption Rate = Coal Energy Production / Energy Produced per Coal used
Units: coal in short tons / Day

(020) Coal Cost Factor = 10^(-15)
Units: Day*cents / (Btu*Btu)

(021) Coal Depletion Rate = Coal Consumption Rate
Units: coal in short tons / Day

(022) Coal Energy Cost Change =
Cost Change in Obtaining Coal*Coal Purchase Factor + Coal Cost Factor*
(Change in Coal Production Capacity + Change in Coal Production)
Units: cents / (Day*Btu)

(023) Coal Energy Demand =
IF THEN ELSE(Coal at Capacity = 1, Coal Production Capacity,
IF THEN ELSE((1.8*(1 / Price of Coal Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand) > Coal Production Capacity,
Coal Production Capacity,
1.8*(1 / Price of Coal Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand))
Units: Btu / Day

(024) Coal Energy Price Change =
(1 + Government Coal Tax Rate)*(-Coal Price Factor*Change in Coal Energy Profits +
Coal Energy Cost Change)
Units: cents / (Day*Btu)

(025) Coal Energy Production = INTEG (Change in Coal Production, 2.5908*10^14)
Units: Btu / Day

(026) Coal Energy Profits = INTEG (Rate of Coal Energy Profits, 0)
Units: cents

(027) Coal Energy Used per Pollution Produced = 38961.2
Units: Btu / kg CO2

(028) Coal Market Share = Coal Energy Demand / World Energy Demand
Units: Dmnl

(029) Coal Obtainment Factor = 1 / 500
Units: dollars / (Day*coal in short tons)

(030) Coal Pollution = INTEG (Coal Pollution Rate, 6.6497*10^9)
Units: kg CO2

(031) Coal Pollution Rate = Coal Energy Production / Coal Energy Used per Pollution Produced
Units: kg CO2 / Day

(032) Coal Price Factor = 10^(-16)
Units: 1 / Btu

(033) Coal Production Capacity = INTEG (Change in Coal Production Capacity, 2.65*10^14)
Units: Btu / Day

(034) Coal Purchase Factor = 1/10
Units: (coal in short tons)*cents / (Btu*dollars)

(035) Coal Reserves = INTEG (-Coal Depletion Rate, INITIAL COAL RESERVES)
Units: coal in short tons

(036) Cost Change in Obtaining Coal =
Coal Obtainment Factor*(INITIAL COAL RESERVES - Coal Reserves) / Coal Reserves
Units: dollars / (Day*coal in short tons)

(037) Cost Change in Obtaining Natural Gas =
Natural Gas Obtainment Factor*(INITIAL NATURAL GAS RESERVES –
Natural Gas Reserves) / Natural Gas Reserves
Units: dollars / (Day*natural gas in cubic feet)

(038) Cost Change in Obtaining Oil =
Oil Obtainment Factor*(INITIAL OIL RESERVES - Oil Reserves) / Oil Reserves
Units: dollars / (Day*oil in barrels)

(039) Cost of Coal Energy = INTEG (Coal Energy Cost Change, 7.9)
Units: cents / Btu

(040) Cost of Natural Gas Energy = INTEG (Natural Gas Energy Cost Change, 8.5)
Units: cents / Btu

(041) Cost of Oil Energy = INTEG (Oil Energy Cost Change, 4.5)
Units: cents / Btu

(042) Cost of Solar Energy = INTEG (Solar Energy Cost Change, 11.5)
Units: cents / Btu

(043) Cost of Wind Energy = INTEG (Wind Energy Cost Change, 11)
Units: cents / Btu

(044) Cost to Obtain Coal = INTEG (Cost Change in Obtaining Coal, 40)
Units: dollars / coal in short tons

(045) Cost to Obtain Natural Gas = INTEG (Cost Change in Obtaining Natural Gas, 5.01)
Units: dollars / (natural gas in cubic feet)

(046) Cost to Obtain Oil = INTEG (Cost Change in Obtaining Oil, 34)
Units: dollars / (oil in barrels)

(047) DISTRIBUTION FUNCTION =
1 / (1.8*(1 / Price of Coal Energy)^2 + (1 / Price of Oil Energy)^2 +
2*(1 / Price of Natural Gas Energy)^2 + 3*(1 / Price of Solar Energy)^2 +
3*(1 / Price of Wind Energy)^2)
Units: (cents*cents) / (Btu*Btu)

(048) DISTRIBUTION NORMALIZER =
1 / (1.8*((1 / Price of Coal Energy)^2)*(1 - Coal at Capacity) +
((1 / Price of Oil Energy)^2)*(1 - Oil at Capacity) +
2*((1 / Price of Natural Gas Energy)^2)*(1 - Natural Gas at Capacity) +
3*((1 / Price of Solar Energy)^2)*(1 - Solar at Capacity) +
3*((1 / Price of Wind Energy)^2)*(1 - Wind at Capacity) + 10^(-12))
Units: cents*cents / (Btu*Btu)

(049) Energy Produced per Coal used = 27.76*10^6
Units: Btu / coal in short tons

(050) Energy Produced per Natural Gas used = 1033
Units: Btu / natural gas in cubic feet

(051) Energy Produced per Oil used = 5.8*10^6
Units: Btu / oil in barrels

(052) Energy Shortage Rate = World Energy Demand - World Energy Consumption
Units: Btu / Day

(053) Energy Use Factor = 3.301*10^-5
Units: 1 / Day

(054) Energy Used per person = INTEG (Energy Use Factor*Energy Used per person,
INITIAL ENERGY USE per PERSON)
Units: Btu / (people*Day)

(055) FINAL TIME = 36500
Units: Day
The final time for the simulation.

(056) Government Coal Policy Factor = 1
Units: Dmnl

(057) Government Coal Tax Rate =
Government Coal Policy Factor*Coal Pollution Rate / Pollution Rate
Units: Dmnl

(058) Government Natural Gas Policy Factor = 1
Units: Dmnl

(059) Government Natural Gas Tax Rate =
Government Natural Gas Policy Factor*Natural Gas Pollution Rate / Pollution Rate
Units: Dmnl

(060) Government Oil Policy Factor = 1
Units: Dmnl

(061) Government Oil Tax Rate = Government Oil Policy Factor*Oil Pollution Rate / Pollution Rate
Units: Dmnl

(062) Government Solar Policy Factor = 10
Units: Dmnl

(063) Government Solar Support = Government Solar Policy Factor / (Solar Energy Production^(1/6))
Units: Dmnl

(064) Government Wind Policy Factor = 10
Units: Dmnl

(065) Government Wind Support = Government Wind Policy Factor / (Wind Energy Production^(1/6))
Units: Dmnl

(066) Hydropower Energy Production = INTEG (0, 7.6274*10^13)
Units: Btu / Day

(067) INITIAL COAL RESERVES = 1.083*10^12
Units: coal in short tons

(068) INITIAL ENERGY USE per PERSON = 170251
Units: Btu / (Day*people)

(069) INITIAL NATURAL GAS RESERVES = 5501*10^12
Units: natural gas in cubic feet

(070) INITIAL OIL RESERVES = 1213*10^9
Units: oil in barrels

(071) INITIAL TIME = 0
Units: Day
The initial time for the simulation.

(072) INITIAL WORLD POPULATION = 6.5*10^9
Units: people

(073) MAX Change in Coal Capacity = 10^24
Units: Btu / (Day*Day)

(074) MAX Change in Natural Gas Capacity = 10^24
Units: Btu / (Day*Day)

(075) MAX Change in Oil Capacity = 10^24
Units: Btu / (Day*Day)

(076) MAX Change in Solar CAPACITY = 9*10^14
Units: Btu / (Day*Day)

(077) MAX Change in Wind CAPACITY = 1.5*10^15
Units: Btu / (Day*Day)

(078) MAX Coal Capacity = (Coal Reserves*Energy Produced per Coal used / Coal Capacity Factor)
Units: Btu / Day

(079) MAX Natural Gas Capacity =
(Natural Gas Reserves*Energy Produced per Natural Gas used /
Natural Gas Capacity Factor)
Units: Btu / Day

(080) MAX Oil Capacity = (Oil Reserves*Energy Produced per Oil used / Oil Capacity Factor)
Units: Btu / Day

(081) Natural Gas at Capacity =
IF THEN ELSE((2*((1 / Price of Natural Gas Energy)^2)*
DISTRIBUTION FUNCTION) >=
(Natural Gas Production Capacity / (World Energy Demand –
(Hydropower Energy Production + Nuclear Energy Production))),
1,
0)
Units: Dmnl

(082) Natural Gas Capacity Factor = 3650
Units: Day

(083) Natural Gas Consumption Rate =
Natural Gas Energy Production / Energy Produced per Natural Gas used
Units: natural gas in cubic feet / Day

(084) Natural Gas Cost Factor = 10^(-15)
Units: Day*cents / (Btu*Btu)

(085) Natural Gas Depletion Rate = Natural Gas Consumption Rate
Units: natural gas in cubic feet / Day

(086) Natural Gas Energy Cost Change =
Cost Change in Obtaining Natural Gas*Natural Gas Purchase Factor +
Natural Gas Cost Factor*(Change in Natural Gas Production Capacity +
Change in Natural Gas Production)
Units: cents / (Day*Btu)

(087) Natural Gas Energy Demand =
IF THEN ELSE(Natural Gas at Capacity = 1, Natural Gas Production Capacity,
IF THEN ELSE((2*(1 / Price of Natural Gas Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand) >
Natural Gas Production Capacity,
Natural Gas Production Capacity,
2*(1 / Price of Natural Gas Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand))
Units: Btu / Day

(088) Natural Gas Energy Price Change =
(1 + Government Natural Gas Tax Rate)*(-Natural Gas Price Factor*
Change in Natural Gas Energy Profits + Natural Gas Energy Cost Change)
Units: cents / (Day*Btu)

(089) Natural Gas Energy Production = INTEG (Change in Natural Gas Production, 2.56775*10^14)
Units: Btu / Day

(090) Natural Gas Energy Profits = INTEG (Rate of Natural Gas Energy Profits, 0)
Units: cents

(091) Natural Gas Energy Used per Pollution Produced = 67951.6
Units: Btu / (kg CO2)

(092) Natural Gas Market Share = Natural Gas Energy Demand / World Energy Demand
Units: Dmnl

(093) Natural Gas Obtainment Factor = 1 / 400
Units: dollars / (Day*natural gas in cubic feet)

(094) Natural Gas Pollution = INTEG (Natural Gas Pollution Rate, 3.7788*10^9)
Units: kg CO2

(095) Natural Gas Pollution Rate =
Natural Gas Energy Production / Natural Gas Energy Used per Pollution Produced
Units: kg CO2 / Day

(096) Natural Gas Price Factor = 10^(-16)
Units: 1 / Btu

(097) Natural Gas Production Capacity =
INTEG (Change in Natural Gas Production Capacity, 2.6*10^14)
Units: Btu / Day

(098) Natural Gas Purchase Factor = 1 / 10
Units: natural gas in cubic feet*cents / (Btu*dollars)

(099) Natural Gas Reserves =
INTEG (-Natural Gas Depletion Rate, INITIAL NATURAL GAS RESERVES)
Units: natural gas in cubic feet

(100) Nuclear Energy Production = INTEG (0, 7.51781*10^13)
Units: Btu / Day

(101) Oil at Capacity =
IF THEN ELSE((((1/Price of Oil Energy)^2)*DISTRIBUTION FUNCTION) >=
(Oil Production Capacity / (World Energy Demand –
(Nuclear Energy Production + Hydropower Energy Production))),
1,
0)
Units: Dmnl

(102) Oil Capacity Factor = 3650
Units: Day

(103) Oil Consumption Rate = Oil Energy Production / Energy Produced per Oil used
Units: oil in barrels / Day

(104) Oil Cost Factor = 10^(-15)
Units: Day*cents / (Btu*Btu)

(105) Oil Depletion Rate = Oil Consumption Rate
Units: oil in barrels / Day

(106) Oil Energy Cost Change =
Cost Change in Obtaining Oil*Oil Purchase Factor + Oil Cost Factor*
(Change in Oil Production Capacity + Change in Oil Production)
Units: cents / (Day*Btu)

(107) Oil Energy Demand =
IF THEN ELSE(Oil at Capacity = 1, Oil Production Capacity,
IF THEN ELSE(((1 / Price of Oil Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand) > Oil Production Capacity,
Oil Production Capacity,
(1 / Price of Oil Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand))
Units: Btu / Day

(108) Oil Energy Price Change =
(1 + Government Oil Tax Rate)*(-Oil Price Factor*Change in Oil Energy Profits + Oil Energy Cost Change)
Units: cents / (Day*Btu)

(109) Oil Energy Production = INTEG (Change in Oil Production, 4.3312*10^14)
Units: Btu / Day

(110) Oil Energy Profits = INTEG (Rate of Oil Energy Profits, 0)
Units: cents

(111) Oil Energy Used per Pollution Produced = 57253.1
Units: Btu / kg CO2

(112) Oil Market Share = Oil Energy Demand / World Energy Demand
Units: Dmnl

(113) Oil Obtainment Factor = 1 / 400
Units: dollars / (Day*oil in barrels)

(114) Oil Pollution = INTEG (Oil Pollution Rate, 7.5655*10^9)
Units: kg CO2

(115) Oil Pollution Rate = Oil Energy Production / Oil Energy Used per Pollution Produced
Units: kg CO2 / Day

(116) Oil Price Factor = 10^(-16)
Units: 1 / Btu

(117) Oil Production Capacity = INTEG (Change in Oil Production Capacity, 4.4*10^14)
Units: Btu / Day

(118) Oil Purchase Factor = 1 / 10
Units: oil in barrels*cents / (Btu*dollars)

(119) Oil Reserves = INTEG (-Oil Depletion Rate, INITIAL OIL RESERVES)
Units: oil in barrels

(120) Pollution from Energy Production = INTEG (Pollution Rate, 0)
Units: kg CO2

(121) Pollution per Wind Energy Produced = 10^7
Units: Btu / (kg CO2)

(122) Pollution per Solar Energy Produced = 10^7
Units: Btu / (kg CO2)

(123) Pollution Rate =
Wind Pollution Rate + Solar Pollution Rate + Oil Pollution Rate +
Natural Gas Pollution Rate + Coal Pollution Rate
Units: kg CO2 / Day

(124) Population Increase Factor = 1.3*10^-5
Units: 1 / Day

(125) Price of Coal Energy = INTEG (Coal Energy Price Change, 8.5)
Units: cents / Btu

(126) Price of Natural Gas Energy = INTEG (Natural Gas Energy Price Change, 9)
Units: cents / Btu

(127) Price of Oil Energy = INTEG (Oil Energy Price Change, 4.9)
Units: cents / Btu

(128) Price of Solar Energy = INTEG (Solar Energy Price Change, 12)
Units: cents / Btu

(129) Price of Wind Energy = INTEG (Wind Energy Price Change, 11.5)
Units: cents / Btu

(130) Rate of Coal Energy Profits =
((1 - Government Coal Tax Rate)*Price of Coal Energy - Cost of Coal Energy)*
Coal Energy Production
Units: cents / Day

(131) Rate of Natural Gas Energy Profits =
((1 - Government Natural Gas Tax Rate)*Price of Natural Gas Energy –
Cost of Natural Gas Energy)*Natural Gas Energy Production
Units: cents / Day

(132) Rate of Oil Energy Profits =
((1 - Government Oil Tax Rate)*Price of Oil Energy - Cost of Oil Energy)*
Oil Energy Production
Units: cents / Day

(133) Rate of Solar Energy Profits =
(Price of Solar Energy - Cost of Solar Energy)*Solar Energy Production
Units: cents / Day

(134) Rate of Wind Energy Profits =
(Price of Wind Energy - Cost of Wind Energy)*Wind Energy Production
Units: cents / Day

(135) Recent Coal Energy Profit Rate =
DELAY FIXED(Rate of Coal Energy Profits, 1, Rate of Coal Energy Profits)
Units: cents / Day

(136) Recent Natural Gas Energy Profit Rate =
DELAY FIXED(Rate of Natural Gas Energy Profits, 1,
Rate of Natural Gas Energy Profits)
Units: cents / Day

(137) Recent Oil Energy Profit Rate =
DELAY FIXED(Rate of Oil Energy Profits, 1, Rate of Oil Energy Profits)
Units: cents / Day

(138) Recent Solar Energy Profit Rate =
DELAY FIXED(Rate of Solar Energy Profits, 1, Rate of Solar Energy Profits)
Units: cents / Day

(139) Recent Wind Energy Profit Rate =
DELAY FIXED(Rate of Wind Energy Profits, 1, Rate of Wind Energy Profits)
Units: cents / Day

(140) Required Change in Coal Production Capacity =
IF THEN ELSE((Coal Production Capacity - Coal Energy Production) <
(2*Change in Coal Production),
IF THEN ELSE(MAX Change in Coal Capacity <
(2*Change in Coal Production),
MAX Change in Coal Capacity,
2*Change in Coal Production),
0)
Units: Btu / (Day*Day)

(141) Required Change in Natural Gas Production Capacity =
IF THEN ELSE((Natural Gas Production Capacity - Natural Gas Energy Production) <
(2*Change in Natural Gas Production),
IF THEN ELSE(MAX Change in Natural Gas Capacity <
(2*Change in Natural Gas Production),
MAX Change in Natural Gas Capacity,
2*Change in Natural Gas Production),
0)
Units: Btu / (Day*Day)

(142) Required Change in Oil Production Capacity =
IF THEN ELSE((Oil Production Capacity - Oil Energy Production) <
(2*Change in Oil Production),
IF THEN ELSE(MAX Change in Oil Capacity <
(2*Change in Oil Production),
MAX Change in Oil Capacity,
2*Change in Oil Production),
0)
Units: Btu / (Day*Day)

(143) SAVEPER = TIME STEP
Units: Day [0,?]
The frequency with which output is stored.

(144) Solar at Capacity =
IF THEN ELSE((3*((1 / Price of Solar Energy)^2)*DISTRIBUTION FUNCTION) >=
(Solar Production Capacity / (World Energy Demand –
(Nuclear Energy Production + Hydropower Energy Production))),
1,
0)
Units: Dmnl

(145) Solar Cost Factor = 10^(-15)
Units: (cents*Day) / (Btu*Btu)

(146) Solar Energy Cost Change =
(1 - Government Solar Support)*Solar Cost Factor*
(Change in Solar Production Capacity + Change in Solar Production)
Units: cents / (Btu*Day)

(147) Solar Energy Demand =
IF THEN ELSE(Solar at Capacity = 1, Solar Production Capacity,
IF THEN ELSE((3*(1 / Price of Solar Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand) > Solar Production Capacity,
Solar Production Capacity,
3*(1 / Price of Solar Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand))
Units: Btu / Day

(148) Solar Energy Price Change =
(-Solar Price Factor*Change in Solar Energy Profits + Solar Energy Cost Change)
Units: cents / (Btu*Day)

(149) Solar Energy Production = INTEG (Change in Solar Production, 8.76712*10^11)
Units: Btu / Day

(150) Solar Energy Profits = INTEG (Rate of Solar Energy Profits, 0)
Units: cents

(151) Solar Market Share = Solar Energy Demand / World Energy Demand
Units: Dmnl

(152) Solar Pollution = INTEG (Solar Pollution Rate, 0)
Units: kg CO2

(153) Solar Pollution Rate = Solar Energy Production / Pollution Produced per Solar
Units: (kg CO2) / Day

(154) Solar Price Factor = 10^(-16)
Units: 1 / Btu

(155) Solar Production Capacity = INTEG (Change in Solar Production Capacity, 9*10^11)
Units: Btu / Day

(156) TIME STEP = 1
Units: Day [0,?]
The time step for the simulation.

(157) Wind at Capacity =
IF THEN ELSE((3*((1/Price of Wind Energy)^2)*DISTRIBUTION FUNCTION) >=
(Wind Production Capacity / (World Energy Demand –
(Hydropower Energy Production + Nuclear Energy Production))),
1,
0)
Units: Dmnl

(158) Wind Cost Factor =
10^(-15)
Units: (cents*Day)/(Btu*Btu)

(159) Wind Energy Cost Change =
(1-Government Wind Support)*Wind Cost Factor*
(Change in Wind Production Capacity + Change in Wind Production)
Units: cents / (Btu*Day)

(160) Wind Energy Demand =
IF THEN ELSE(Wind at Capacity = 1, Wind Production Capacity,
IF THEN ELSE((3*(1 / Price of Wind Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand) > Wind Production Capacity,
Wind Production Capacity,
3*(1 / Price of Wind Energy)^2*
DISTRIBUTION NORMALIZER*
Available Demand))
Units: Btu / Day

(161) Wind Energy Price Change =
(-Wind Price Factor*Change in Wind Energy Profits + Wind Energy Cost Change)
Units: cents / (Btu*Day)

(162) Wind Energy Production = INTEG (Change in Wind Production, 1.45205*10^12)
Units: Btu / Day

(163) Wind Energy Profits = INTEG (Rate of Wind Energy Profits, 0)
Units: cents

(164) Wind Market Share = Wind Energy Demand / World Energy Demand
Units: Dmnl

(165) Wind Pollution = INTEG (Wind Pollution Rate, 0)
Units: kg CO2

(166) Wind Pollution Rate = Wind Energy Production / Pollution per Wind Energy Produced
Units: (kg CO2) / Day

(167) Wind Price Factor = 10^(-16)
Units: 1 / Btu

(168) Wind Production Capacity = INTEG (Change in Wind Production Capacity, 1.5*10^12)
Units: Btu / Day

(169) World Energy Consumption =
Wind Energy Demand + Solar Energy Demand + Oil Energy Demand +
Natural Gas Energy Demand + Coal Energy Demand + Nuclear Energy Production +
Hydropower Energy Production
Units: Btu / Day

(170) World Energy Demand = Energy Used per person*World Population
Units: Btu / Day

(171) World Population =
INTEG (Population Increase Factor*World Population,
INITIAL WORLD POPULATION)
Units: people