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WPI

Alternative Energy

MH 1206

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Preface

Abstract:

In this report, we will take a closer look at different energy sources from fossil fuel to renewable energy. We will evaluate their strength and weakness in economic, productivity and environmental perspective. In the report, we will also address some of the energy challenges we are facing and some possible solutions. We will also make a prediction of the future of energy base on our observation.

Executive Summary

The world's energy demands have increase by 40% in the last two decades, and according to the energy consumption trend it will likely to increase for another 30% in the next three decades.

Our society relies heavily on fossil energy now; more than 80% of the world total energy consumption is from fossil fuel such as coal, oil and gas. However, the amount of fossil fuel is limited; it will eventually run out someday. Therefore, we will need to find an alternative energy source to replace this fossil fuel.

The problem with alternative energy now is the high price and low productivity. Both of these issues could be improved by advance our technologies, however, we will need to put this issue clear so that investors would invest their money on the technologies development.

First, this matter involves the existence of the human race; nowadays we could not survive without the presence of fossil fuel. Once our fossil energy ran out, it will be too late to start developing other sources of alternative energy; therefore we need to get started as soon as we can.

Second, we could not rely solely on fossil energy to satisfy our energy consumption. Now we are already using an excessive amount of fossil fuel, the greenhouse gas emitted by fossil energy has caused the increasing global average temperature, we have to do something about it before this problem become a thread to our survival.

Base on these reasons, our team did a comparison between difference kinds of fossil and renewable fuels. We also did a research on the most advance renewable energy source such as Space Solar Power Satellites and Jet stream. Our team also proposed some innovative renewable energy sources and some possible solutions to deal with the current energy crisis.

Introduction

Every day, from the first moment I open my eyes, there is one thing I cannot live without. I need it to ring my alarm, I need it to heat the water in the shower, I need it to cook my breakfast and also I need it to drive me all the way to school. Energy, the invisible yet crucial element in our modern society, has been ignored by most of us for a long time, since we believe it's something that the government needs to consider. But one day I finally realized: isn't it so selfish that we only think for ourselves? What about our children, and children's children? If we don't plan ahead, they will be born in a world that without enough energy to rely on, everything would be too late by then. This project gives us a chance to look further and think about what we can do to solve some energy problem we have right now. We may not develop a career that within the energy related filed. However, we definitely will, throughout the whole process of this project, gain more knowledge in different aspect, become more proficient in researching skills and develop our own ideas, which are all very important in every area. We hope that we can even inspire other people to pay more attention on energy, also on our future.

The increasing energy demand is a significant problem we are facing right now, since 1990s, the world energy consumption has increased by 40%, and statistic suggests that the demand will continue to increase in the next few decades. How are we going to satisfy this energy demands?

Regional energy use (kWh/capita & TWh) and growth 1990–2008 (%)[3][9]									
	kWh/capita			Population (million)			Energy use (1,000 TWh)		
	1990	2008	Growth	1990	2008	Growth	1990	2008	Growth
USA	89,021	87,216	– 2%	250	305	22%	22.3	26.6	20%
EU-27	40,240	40,821	1%	473	499	5%	19.0	20.4	7%
Middle East	19,422	34,774	79%	132	199	51%	2.6	6.9	170%
China	8,839	18,608	111%	1,141	1,333	17%	10.1	24.8	146%
Latin America	11,281	14,421	28%	355	462	30%	4.0	6.7	66%
Africa	7,094	7,792	10%	634	984	55%	4.5	7.7	70%
India	4,419	6,280	42%	850	1,140	34%	3.8	7.2	91%
Others*	25,217	23,871	nd	1,430	1,766	23%	36.1	42.2	17%
The World	19,422	21,283	10%	5,265	6,688	27%	102.3	142.3	39%

Source: IEA/OECD, Population OECD/World Bank

Our goal for this project is to find out alternative energy to solve the energy problems people are facing right now, and we try to predict the energy trend and social pattern in

the future from the data we collected. First, we analyze the current status of fossil fuel and predict their future trend. Second, we introduce some renewable energy and analyze if people can rely on them to meet the energy demand in the future. Last, we make predictions of future energy distribution and social patterns. Our career goal for this project is to think like the energy administrative of the country, and solve the problems as an engineer by using the knowledge we have learned in WPI.

We cannot rely solely on fossil energies since they are limited; therefore we need to develop renewable energy sources. Considering the fossil energy is running out, why is the renewable energy source was not widely used in our society? In the history of energy, people switched from burning wood for energy, to burning coal, oil and gas. The reason for this change is that these kinds of fuels can provide more energy and is more suitable for modern machinery. People do not want to switch to renewable energy because they are not willing to abandon the efficiency and convenience of fossil fuel, and they do not want to invest a large amount of money to develop other form of energy that is less efficient. According to the report by Pew research center, the amount of people that support the development of alternative energy has decrease for 82% to 68% from 2006 to 2011. [1]

Do people really understand the pros and cons of fossil energy or renewable energy? In the later chapter, we will explain different kinds of energy sources in detailed.

[1] PEW Research center, Washington Post, Nov 3-6, 2011

Chapter1. Fossil Fuels

"Fossil fuels are fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. The age of organisms and their resulting fossil fuels are typically millions of years, and sometimes exceed 650 million years." [2]

[2] Paul Mann, Lisa Gahagan, and Mark B. Gordon, "Tectonic setting of the world's giant oil and gas fields," in Michel T. Halbouty (ed.) Giant Oil and Gas Fields of the Decade, 1990–1999, Tulsa, Okla.: American Association of Petroleum Geologists, p.50, accessed 22 June 2009.

1.1 Coal

1.1.1 Introduction

Coal is composed primarily of carbon along with variable quantities of other elements, chiefly hydrogen, sulfur, oxygen and nitrogen. Coal is separated into 4 categories distinguished by their carbon content. These four categories are called Anthracite, Bituminous, Subbituminous and Lignite. Anthracite has the largest carbon percentage, and has the highest heat value in general, but it only accounts for about 1% of global coal reserves, and is mined in only a few countries around the world. Bituminous is the most widely use coal type, which has a lower carbon concentration and lower heat value than Anthracite in general. Subbituminous has low carbon content and high water content, and they are used primarily as fuel for steam-electric power generation. Lignite, often referred to as brown coal, is considered the lowest rank of coal and it is used almost exclusively as a fuel for steam-electric power generation.

Type	Carbon percentage	Heat Value (BTUs/pound)
Anthracite	86% - 98%	~15,000
Bituminous	45% - 86%	10,500 – 15,500
Subbituminous	35% - 45%	8,300 – 13,000
Lignite	25% - 35%	4,000 – 8,300

Source: Wikipedia, *Coal*

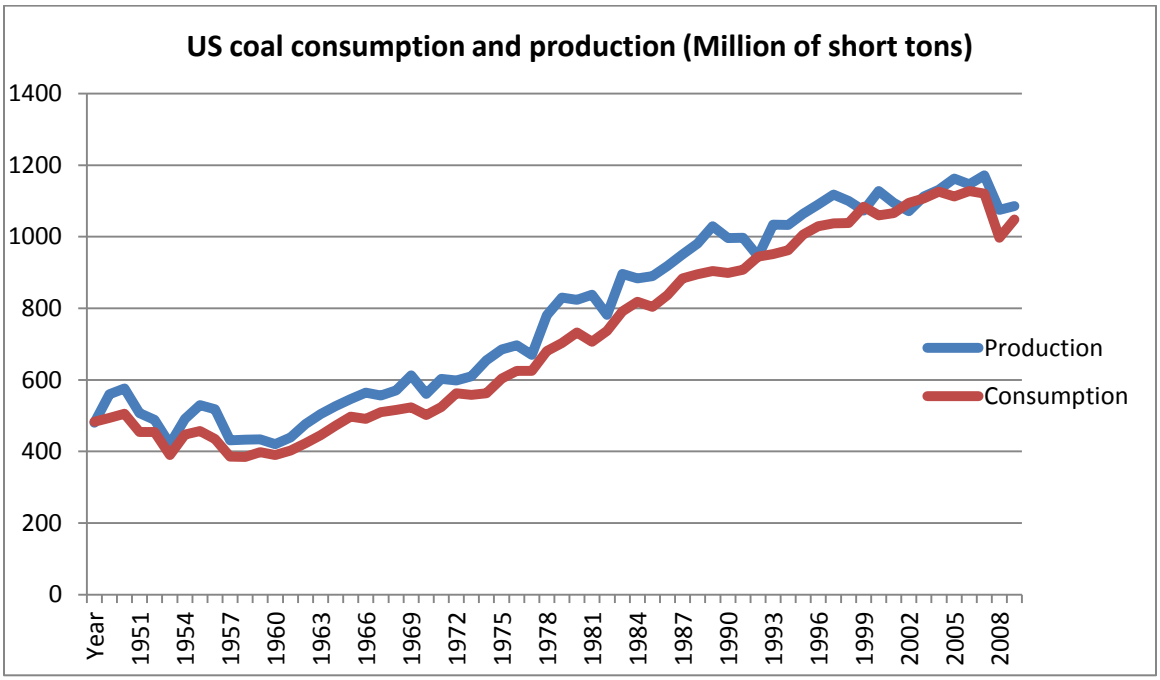
In the economic perspective, coal is the most affordable fuel for power generation in many countries, and it will likely to remain in this position for at least a couple decades. One of the major disadvantages of using coal as an energy source is the excessive carbon dioxide emission; it is one of the largest worldwide anthropogenic sources of carbon dioxide releases. Gross carbon dioxide emissions from coal usage are slightly more than those from petroleum and about double the amount from natural gas. The amount of carbon dioxide emits from coal for one unit of energy generated is twice as much compare to using natural gas to generate one unit of energy. Coal-fired electric power generation emits around 2,000 pounds of carbon dioxide for every megawatt hour generated.

1.1.2 Coal usage and statistic

According to the United States Geological Survey, we have 1.7 trillion tons of identified coal resources in the US (coal for which geological evidence and engineering studies provide reliable information about location, rank, quality, and quantity). And geologists

predict that more coal will be discovered as technology advance, the estimated amount of coal in US might be roughly 4 trillion tons. But not all of those coals are recoverable; experts estimate that only 484 billion tons of those coals are potentially recoverable, mainly located in the state Illinois and Montana. This is called the demonstrated reserve base.

The overall consumption and production of coal in the US has been continuously increasing since 1949, but it has been slightly decrease in the past few years. Overall, we expect the consumption and production of coal continues to increase at least in the next couple decades due to the increasing energy demand.

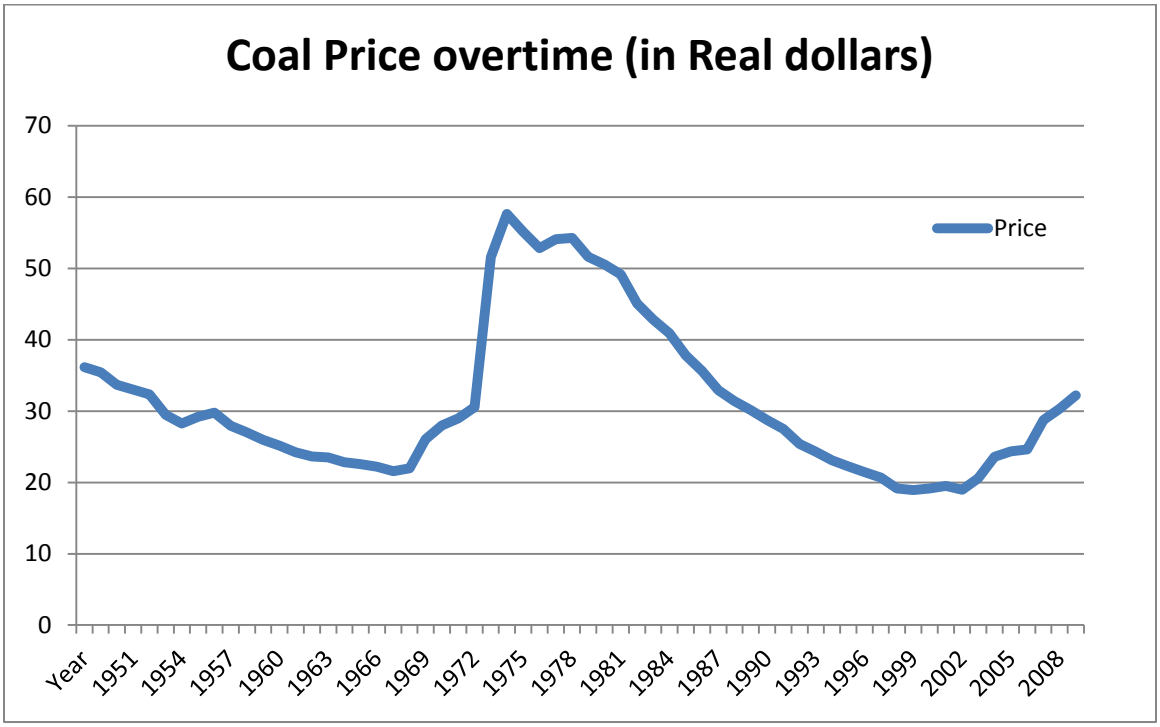


United State Environmental Protection Agency (EPA), Technology Transfer Network

Nowadays coal is the largest source of energy for the generation of electricity worldwide; in 2008, about 41% of electricity was generated by coal. Around 7.1 billion tons of coals were used worldwide last year. Since 2000, global coal consumption has grown faster than any other fuel. The five largest coal users - China, USA, India, Russia and Japan - account for 77% of total global coal use. In 2009, coal accounted for 27% of the total energy used worldwide; the second most popular fuel after oil.

Despite the consumption and production of coal is stably rising, the price of coal is not stable. Since 1949, the lowest price for coal was $19 (real dollar) per short tons, which occurred in about 2002. The highest price is $57.65 (real dollar) per short ton, which occurred in the mid 1970's. Below is a graph of coal price vs. years, we could see from

the graph that the price went up significantly in between 1970 and 1975, and it is going up again since 2002. So, what are the reasons that cause the coal price to fluctuate?



United State Environmental Protection Agency (EPA), Technology Transfer Network

One reason for the coal price to rise significantly in the mid 70's is because the oil crisis that started in October 1973. The prices of other energy sources rise as the result of the high oil price. The same reason might be causing the coal price to go up again since 2002. Another reason that cause the coal price to rise in the mid 70's was the United Kingdom introduced the Three-day Week measure in 1973 in order to conserve electricity. As the result, the National Union of Mineworkers had encouraged their members to work to rule – work the minimum amount that was set by law, so the coal stocks began to drop. As the demand for coal continue to increase, the price of coal rise significantly.

One interesting observation from the two graphs above is that despite the high coal price in the 1970s, the consumption of coal still increased. This suggests that coal is an essential energy source in our country; it is not replaceable by other type of energy source, at least not yet.

According to IEA (International Energy agency) statistics, coal-based electricity is, on average, 7% cheaper than gas and around 19% cheaper than nuclear. IEA and European Commission studies show that onshore wind costs between US$50 and US$156 per MWh, but this energy production was difficult to transport to a more populated area.

Solar photovoltaic will cost between US$226 to US$2031, they are too expensive and unstable. In certain locations hydro resources can produce electricity at a cost comparable to coal, however estimates vary greatly according to geographic conditions and the final price can be as high as US$240 and US$262 per MWh. In comparison, electricity from coal costs between US$56 to US$82 per MWh, and it is stable and dependable.[3]

	US Congressional Budget Office 2008	European Commission 2008	EPRI 2008	House of Lords 2008	MIT 2009	Average Cost
Coal	56	59	64	82	62	65
Gas	58	72	80	78	65	70
Nuclear	73	87	73	90	84	81
Biomass	n/a	180	80	180	n/a	145

Comparison of Electricity Generation Costs (US$ per MWh) [3]

1.1.3 The Future of Coal

Recent technology allows reduction of carbon dioxide and other harmful gas emission from coal firing electricity generation. This technology is referred to as Clean Coal. Clean coal is a series of technologies that improve the environmental performance of coal-based electricity plants. These technologies include devices that increase the operational efficiency of a power plant, as well as those technologies that reduce emissions. Early work to develop clean coal technologies focused on efforts to reduce traditional pollutant emissions like sulfur dioxide (SO_2), nitrogen oxides (NOx), and particulate matter. Clean coal technology is still under development, it will continue to improve in response to environmental challenges.

The clean coal technology involved a series of procedures that will reduce the amount of harmful gas emitted during the electricity generation. Those main kinds of substance that we want to reduce are:

- Carbon Dioxide ($CO_{2)}$: the main source of greenhouse effect.
- Sulfur dioxide (SO_2): form acid rain while released into the atmosphere.
- Oxides of nitrogen (NO_x)
- Particulate matter: impurities substance in coal that released to the atmosphere.
- Mercury (Hg): extremely toxic to human and other animals.

[3] World coal Association, *COSTS OF COAL-FIRED ELECTRICITY*, January 2011, Vol. 73

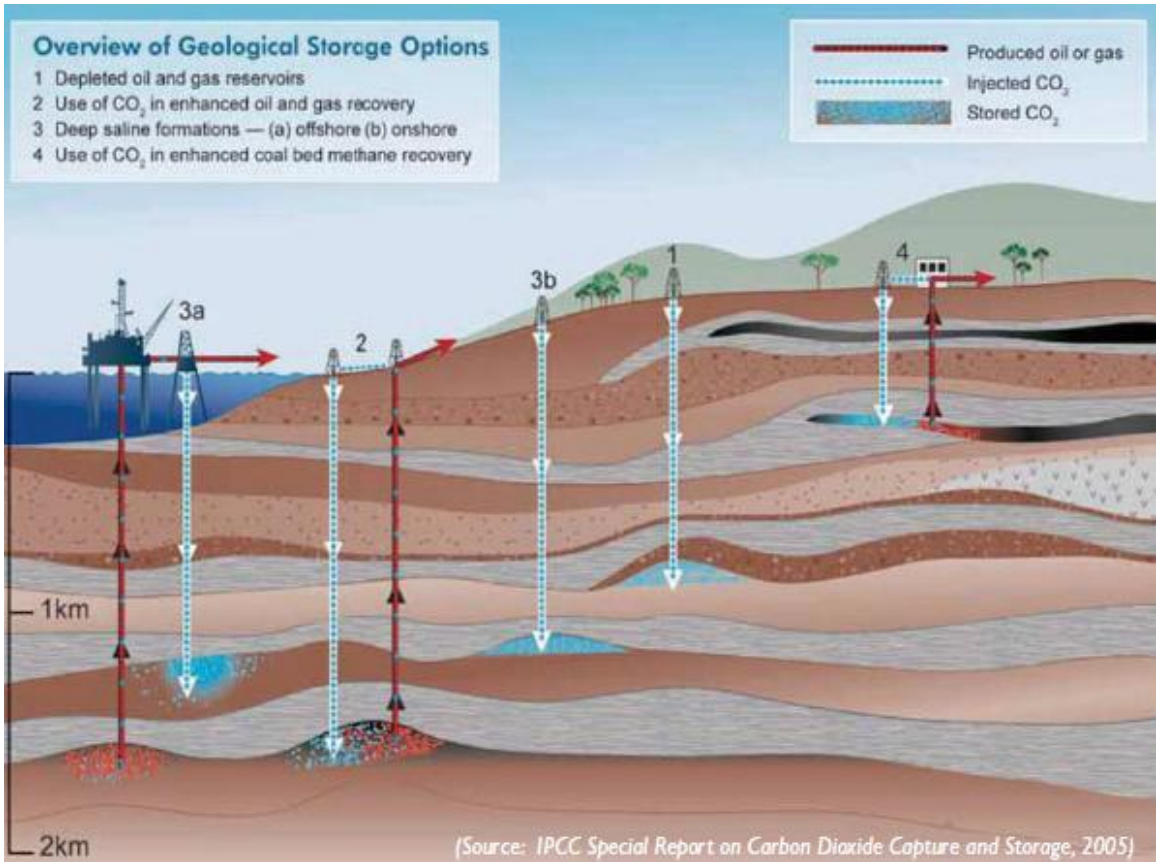
Clean coal technology involves a series of steps to eliminate the impurity in the coal before it burn, therefore reduce the amount of harmful gas produced during the combustion process. The process that reduced Sulfur dioxide is called SO_2 Scrubbing, which is mixing the flue gas with water and limestone. The SO_2 and the limestone will react and produce a solid material that can be used to manufacture drywall. The process to eliminate Oxides of nitrogen is called the NO_x control, the oxides of nitrogen gas is mixed with ammonia and a catalyst to form harmless nitrogen gas and water vapor.

The technique to reducing mercury emission involves injection of activated carbon into flue gas stream. The mercury sticks to the carbon that is removed by an electrostatic precipitator or fabric filter just as removing the particulates matter. Using electrostatic precipitator involves electrically charging the particle so that the electrostatic precipitator can remove them. And fabric filters means using filter to filter out the small particles that are mixed in the flue gas.

Another clean coal technology is call Integrated gasification combined cycle (IGCC), this technique involved turning coal and other carbon based fuels into gas—synthesis gas (syngas). It then removes impurities from the syngas before it is combusted; result in reduction of sulfur dioxide and mercury emission. With additional process equipment, the carbon in the syngas can be shifted to hydrogen via the water-gas shift reaction, resulting in nearly carbon free fuel. The resulting carbon dioxide from the shift reaction can be compressed and permanently stored underground using carbon capture and storage (CCS).

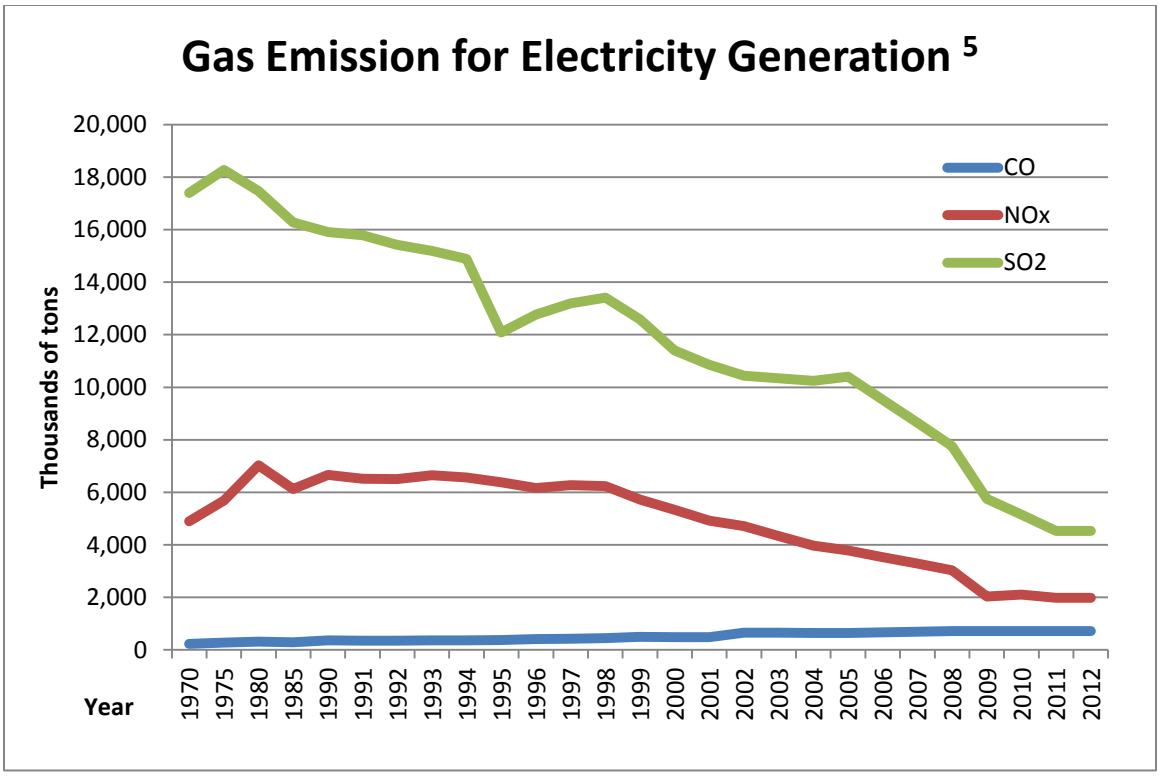
The carbons capture and storage process was used to capture and safely store the carbon dioxide to prevent it from going into the atmosphere. The captured CO_2 is compressed, dewatered and transported via pipeline to geologic storage sites, which are the saline formation a mile or more below the earth's surface. [4] Also, this compressed CO_2 can be used to enhance the oil and gas recovery, and to fill the depleted oil and gas reservoir.

[4] American's Power, *Our Commitment to a Clean Energy Future: Clean Coal Technology*.

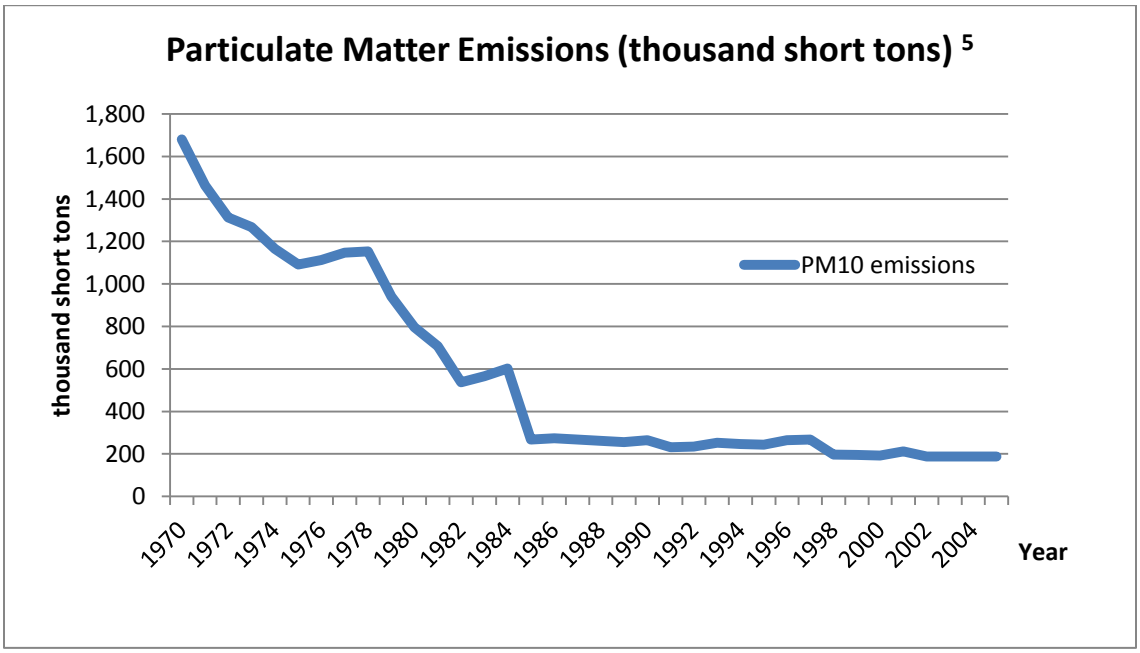


As the technologies of clean coal become more and more sophisticated, the amount of harmful gas release due to coal-firing electricity generation has been reduced. According to U.S. Environmental Protection Agency figures[5], emissions of traditional pollutants regulated by the Clean Air Act, have dropped significantly - even as the use of coal to generate electricity has nearly tripled to meet growing energy demand. That's proof of the success of clean coal technology. And the coal-based electricity sector's work to develop and deploy new technologies to capture and safely store CO_2 is also evidence of the industry's commitment to expanding the use of advanced clean coal technologies.

[5]Data of the graphs is from http://www.epa.gov/ttnchie1/trends/



* SO_2 emission has decreased by 75% since 1975.
* NO_x emission has decreased by 70% since 1980.
* CO emission increased slightly since 1970.



* Particulate Matter emission decreased by 85% since 1970.

The cost estimate by FutureGen Alliance on the clean coal power plant is $1,187 Million, and this is just for one power plant, so clean coal technologies is expensive with current technology. The IGCC technique with carbon captures and stored was claimed that could generate electricity with $79 per megawatt-hour compare to $95 per megawatt-hour for pulverized coal (with carbon dioxide emission charge). Recent testimony in regulatory proceedings shows the cost of IGCC from $96 to 104/MWhr, that's before addition of carbon capture and sequestration cost. Using carbon capture and store technique to capture carbon dioxide at a 90% rate is expected to have a $30/MWh additional cost.

So to sum up, clean coal is a necessary technology that needs to be developed and improved since we are moving toward a clean energy era. For now, the price of clean coal is too high, but with development of new technologies in the future and the increasing oil price; clean coal might be the most widely used energy source for electricity generation because of its small environmental impact and reasonable price.

1.2 Natural GAS

1.2.1 Introduction

Composition of Natural Gas

Most American families cannot live without natural gas which is a valuable energy source to provide heating and electricity. Vehicles can also use natural gas as a fuel. Natural gas is a hydrocarbon gas mixture consisting 70% to 90% of methane, with other hydrocarbons, carbon dioxide, oxygen, nitrogen and hydrogen sulphide[6].

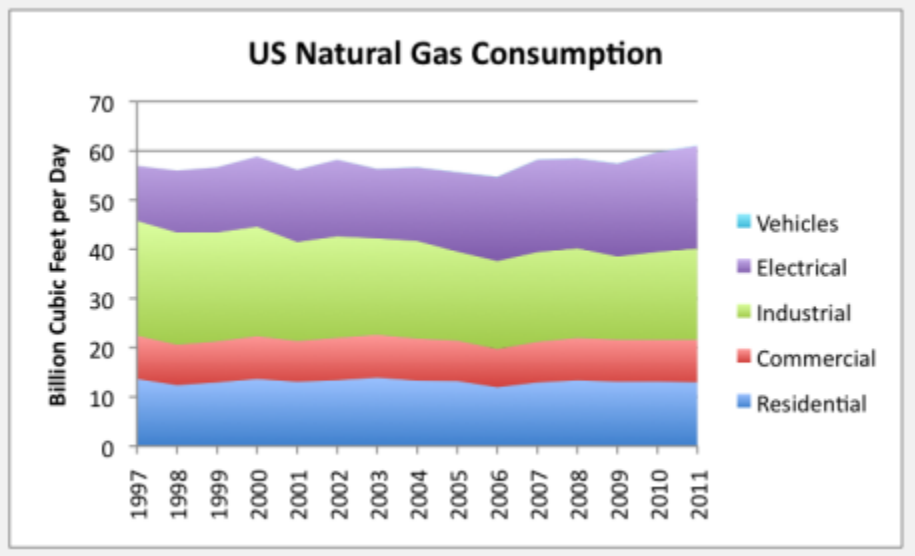
Typical Composition of Natural Gas

Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

(Source: Naturalgas.org.)

[6] "NaturalGas.org." *NaturalGas.org*. N.p., n.d. Web. 25 Feb. 2013. <http://www.naturalgas.org/overview/background.asp>.

Major Uses of Natural Gas



(Source: http://ourfiniteworld.com/2012/03/23/why-us-natural-gas-prices-are-so-low-are-changes-needed)

People are using natural gas in three principal field, residential using, commercial using, and industrial using, for heating, hot water and cooking. From the figure above, we notice that US natural gas consumption has little growth over past 15 years. Consumption rose by about 2% (from the figure above) in 2011 compared to 2010. Back to 1997, Industrial demand used to be the largest part of natural gas use; however, this has been trending downward. The usage of natural gas in residential and commercial did not grow as the population grows because furnaces have been becoming more efficient.

Advantages of Natural Gas

There are many advantages of using natural gas in US. First, natural gas is easy to use in many applications high British thermal unit (Btu) content and a well-developed infrastructure. Second, the supply of natural gas is not dependent on unstable countries, and the delivery system is less subject to interruption in the US. Third, natural gas is

efficient compared to other fuels.

Type Fuel	Btu/lb.	Btu/Unit
Propane	21,550	91,800 /gal.
Natural Gas	73,890	1,000 /cu. ft.
Lignite Coal	8,700	17,400,000 /ton
Fuel Oil	19,230	134,000 /gal.
Wood: Paper Birch[1]	8,600	23,600,000 /cord[3]
Paper Birch	8,600	18,200,000 /cord[4]
White Spruce[2]	8,600	18,500,000 /cord[3]
White Spruce	8,600	15,000,000 /cord[4]
Electricity	—	3,413 /kWh

[1] Specific gravity = .55
[2] Specific gravity = .43
[3] Oven dry, moisture content = 0%
[4] Air dry, average moisture content = 20%

Wood values from the U.S. Forest Service/Alaska State Forester pamphlet entitled "Wood As a Fuel," 1979

(Data Source: http://www.uaf.edu/files/ces/publications-db/catalog/eeh/EEM-04253.pdf)

Forth, natural gas is clean burning compared to other fossil fuels (coal and oil).

	Source (lbs/Billion Btu)			Percent Emissions in Natural Gas	
Pollutant	**Natural Gas**	**Oil**	**Coal**	**Percent Oil**	**Percent Coal**
Carbon Dioxide	117,000	164,000	208,000	71	56
Carbon Monoxide	40	33	208	21	19
Nitrogen Oxides	92	448	457	21	20
Sulfur Dioxides	0.6	1122	2591	0.05	0.02
Particulates	7	84	2744	8.33	0.26

(Data Source: http://www.swarthmore.edu/academics/environmental-studies-capstone/environmental-and-health-concerns/comparison-against-other-fossil-fuels.xml)

Fifth, the price of natural gas is reasonable. The price of natural gas may be higher than the price of coal, but natural gas will always be beneficial due to the efficiency and cleanness. In addition, the gas-fired generation is easier to build than the coal-fired generation and will cost less than the coal-fired one[7].

[7] Zammerilli, Anthony. "Projecting the Economic Impact of Marcellus Shale Gas Development in West Virginia: A Preliminary Analysis Using Publicly Available Data." *National Energy Technology Laboratory*. N.p., 31 Mar. 2010. Web. 25 Feb. 2013.

1.2.2 Future of Natural Gas

Future Demand for Natural Gas

Natural gas, which emits up to 60 percent less CO2 than coal when used for electricity generation, and domestic natural gas are now a cheaper fuel for electricity generation than coal, will become the world's second fuel as demand shifts to lower-carbon sources. From Exxon Mobil's prediction, we see that oil, gas, and coal continue to be the most widely used fuels in the next 40 years. Natural gas will be the fastest-growing considerable energy source with global demand rising by about 60% from 2010 to 2040, and it will grow fast enough to overtake coal. I tried to estimate the demand in 2040 by using population growth and natural gas consumption growth. I selected top ten

	Amount used each year (10^9 cu m)						
Country	2001	2003	2005	2007	2009	Everage Growth	Everage Growth Rat
United States	640.90	633.60	604.00	652.90	646.60	1.14	0.08%
Russia	408.10	405.80	438.70	481.00	439.60	6.30	0.65%
Germany	94.34	99.55	96.84	97.44	96.26	0.38	0.17%
United Kingdom	92.85	95.15	91.16	91.10	87.45	-1.08	-0.52%
Canada	82.25	90.95	92.76	92.90	94.62	2.47	1.22%
Japan	80.42	86.51	83.67	100.30	94.67	2.85	1.42%
Italy	71.18	76.88	82.64	84.89	78.12	1.39	0.81%
Iran	65.59	79.00	98.19	111.80	140.00	14.88	6.59%
Saudi Arabia	53.69	60.06	68.32	75.90	77.10	4.68	3.14%
Netherlands	49.72	50.40	47.46	46.42	48.60	-0.22	-0.20%
China	27.40	33.91	44.93	70.51	87.08	11.94	10.04%
Total (US & Russia	1049.00	1039.40	1042.70	1133.90	1086.20	7.44	0.30%
Total (Other)	617.44	672.41	705.97	771.26	803.90	37.29	2.29%
Total	1666.44	1711.81	1748.67	1905.16	1890.10	44.73	1.09%

(Data collected from https://www.cia.gov/library/publications/the-world-factbook/rankorder/2181rank.html)

countries which spend most natural gas each year from 2001 to 2009. Unite States and Russia together consume more natural gas than the sum of the rest countries and their growth through this 9 years is as small as 0.3%. The rest countries have a growth of 2.29%, and the total growth is 1.09%. I use the average growth and average growth rate to predict their consumption in 2040, and then I found that the total consumption of selected countries will increase by 72%.

	each year				
Country	2009	Everage Growth	Everage Growth Rat	Prediction of 2040	Increasing by
United States	646.60	1.14	0.08%	681.94	5.47%
Russia	439.60	6.30	0.65%	634.90	44.43%
Germany	96.26	0.38	0.17%	108.16	12.37%
United Kingdom	87.45	-1.08	-0.52%	53.97	-38.28%
Canada	94.62	2.47	1.22%	171.31	81.05%
Japan	94.67	2.85	1.42%	183.02	93.32%
Italy	78.12	1.39	0.81%	121.15	55.08%
Iran	140.00	14.88	6.59%	601.34	329.53%
Saudi Arabia	77.10	4.68	3.14%	222.24	188.25%
Netherlands	48.60	-0.22	-0.20%	41.66	-14.29%
China	87.08	11.94	10.04%	457.10	424.92%
Total (US & Russia	1086.20	7.44	0.30%	1316.84	21.23%
Total (Other)	803.90	37.29	2.29%	1959.95	143.81%
Total	1890.10	44.73	1.09%	3276.79	73.37%

(Calculated from the table above)

The population growth must be one key component to increase the demand of natural gas since more people are going to use more, so I took the ten selected countries' population statistics from esa.un.org and made a chart. I find that all countries have a bigger increase in natural gas consumption than in population except America. Therefore, the consumption of natural gas per person over most countries is increasing especially for developing countries such as China and India.

	Population in Thousands				
Country	2000	2005	2010	2040	Increase from 2010
United States	282496	296820	310384	383460	23.54%
Russia	146758	143843	142958	131280	-8.17%
Germany	82349	82541	82302	77305	-6.07%
United Kingdom	58874	60203	62036	71525	15.30%
Canada	30667	32283	34017	41882	23.12%
Japan	125720	126393	126536	114340	-9.64%
Italy	56986	58671	60551	60182	-0.61%
Iran	65342	69732	73974	85893	16.11%
Saudi Arabia	20045	24041	27448	42183	53.68%
Netherlands	15863	16305	16613	17344	4.40%
China	1269117	1307593	1341335	1360906	1.46%

(Data collected from: http://www.census.gov/population/)

By viewing the increasing natural gas demand, we probably want to know if there is enough natural gas for us. According to estimates by the Energy Information Administration, the U.S. has more than 2,000 trillion cubic feet of technically recoverable natural gas which will be enough to satisfy all of America's natural gas demands for the next 90 years at current consumption levels[8].

Price Change for Natural Gas

The following figure shows the US price of natural gas from 2006 to 2011. The natural gas price had a significant growing in 2008 and dropping in 2009. In 2008, oil and gas prices skyrocketed concurrently took place. Oil and gas companies were searching new wells to drill.

[8] "U.S. Energy Information Administration." *U.S. Energy Information Administration (EIA)*. N.p., n.d. Web. 26 Feb. 2013. <http://www.eia.gov/>.

Show Data By: Data Series / Area	Graph / Clear	2006	2007	2008	2009	2010	2011
Wellhead Price		6.39	6.25	7.97	3.67	4.48	3.95
Imports Price		6.88	6.87	8.70	4.19	4.52	4.24
By Pipeline		6.83	6.83	8.57	4.13	4.46	4.09
As Liquefied Natural Gas		7.19	7.07	10.03	4.59	4.94	5.63
Exports Price		6.83	6.92	8.58	4.47	5.02	4.65
By Pipeline		6.90	6.96	8.62	4.34	4.75	4.35
As Liquefied Natural Gas		6.02	6.23	7.69	8.40	9.53	10.50
Pipeline and Distribution Use Price							
Citygate Price		8.61	8.16	9.18	6.48	6.18	5.62
Residential Price		13.73	13.08	13.89	12.14	11.39	11.02
Percentage of Total Residential Deliveries included in Prices		98.1	98.0	97.5	97.4	97.4	96.2
Commercial Price		12.0	11.34	12.23	10.06	9.47	8.93
Percentage of Total Commercial Deliveries included in Prices		80.8	80.4	79.9	77.8	77.5	67.2
Industrial Price		7.87	7.68	9.65	5.33	5.49	5.11
Percentage of Total Industrial Deliveries included in Prices		23.4	22.2	20.5	18.8	18.0	17.1
Vehicle Fuel Price		8.72	8.50	11.75	8.13	6.25	
Electric Power Price		7.11	7.31	9.26	4.93	5.27	4.87

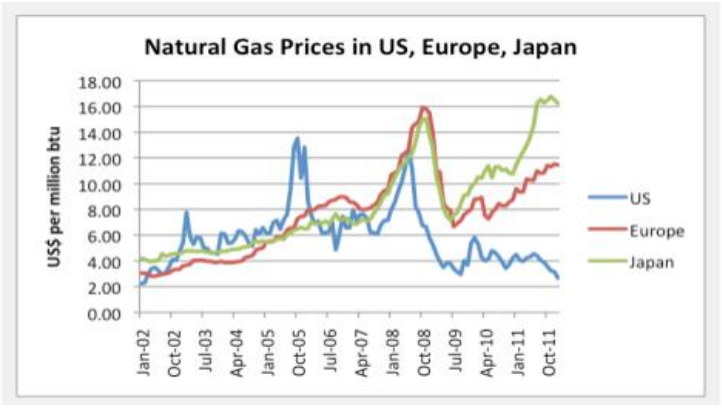
(Source: EIA Natural Gas Price)

As the chart shows above, the US demand for natural gas has been relatively flat for the last 10 years, and the price is low. The US pricing system bases on short-term supply and demand and has a limitation of storage facilities. As a result, supply always overwhelms the system, and prices drop exceptionally low in response. The figure (below) shows the price of natural gas this year. The current price near $2.89 per million British thermal units is less than a third of the $8.90 that prevailed in 2008. Between January and July in 2012, the price is even lower than $2 which is likely to be less than the cost of producing natural gas. Because of the significant low price of natural gas and the environmental impacts, natural gas will cost less than coal in the long term. In addition, more and more companies have switched their power plants to gas-fired generation instead of coal-fired generation. Both the demand and supply of natural gas is going to shift to right. It takes time for companies to drill new natural gas wells, so recently the demand should shift more than the supply does. Therefore, the price of natural gas is likely to increase during the next year. Coal and natural gas are substitutes,

so the price of coal is going to drop as the demand of natural gas is increasing.

(Source: Natural Gas Intelligence)

As we can learn from the figure below, recent Natural gas price in the US is much lower compared to the price in Europe and Japan. This suggests that there is likely to be strong demand for US exports of natural gas. As mentioned before, the usage of natural gas per person over most countries is increasing since the US population grows faster than the market of natural gas. This also implies that the export market will be one of the biggest potential profitable ways for natural gas producers. America has converted liquified natural gas import facilities to LNG export facilities. That will allow producers to make world prices, which are 4-6 times higher than North American prices. Cheniere Energy Partners is revamping its Sabine Pass liquified natural gas terminal in Louisiana to be able to export the fuel, the first facility in the lower 48 states[9] that will have the ability to ship surplus U.S. gas abroad.

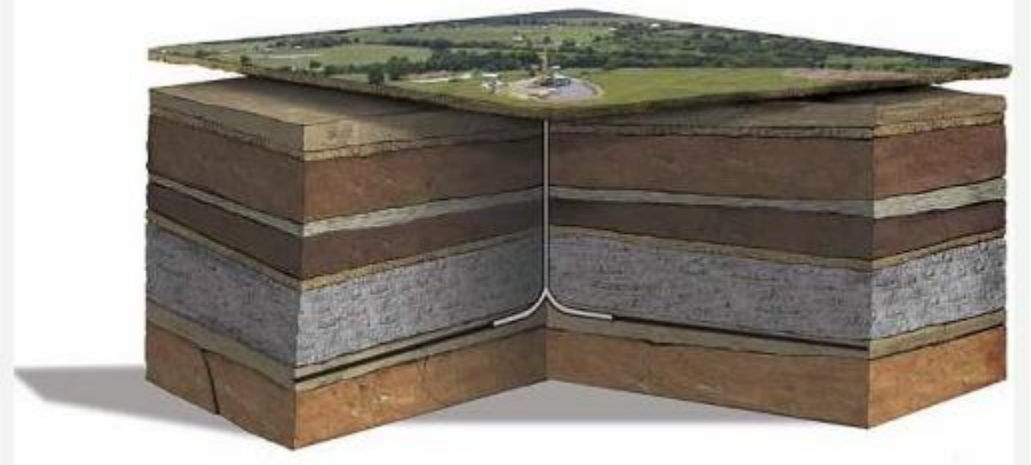


(Sources: World Bank Commodity Price Data (pink sheet))

[9] MITTELSTAEDT, MARTIN. "Natural Gas Market Prices on the Mend." *The Globe and Mail*. N.p., 23 Sept. 2012. Web. 26 Feb. 2013. <http://www.theglobeandmail.com/globe-investor/investment-ideas/natural-gas-market-prices-on-the-mend/article4562344/>.

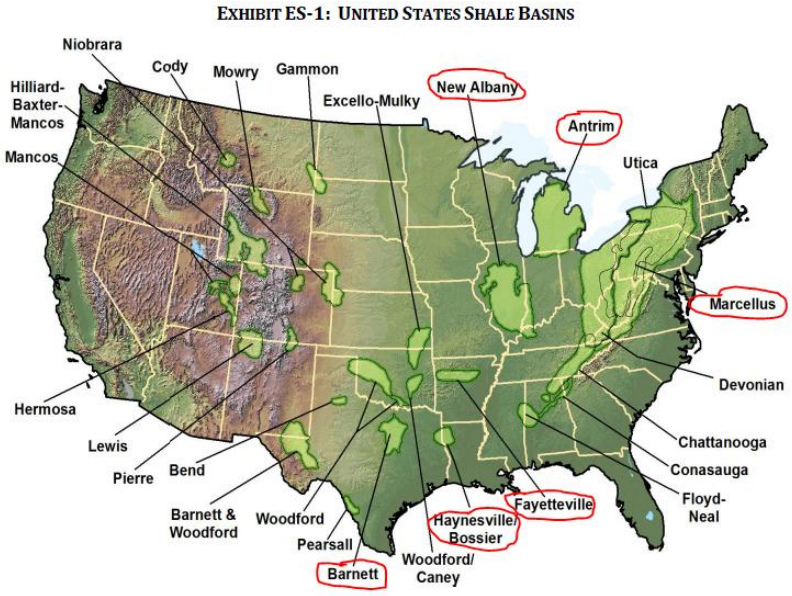
1.2.3 Shale gas

Shale gas refers to natural gas that is trapped within shale formations. Shale is a



(Source: http://www.cleanbiz.asia/image/shale-gas-well-illustration)

fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable. Shale is characterized by its fissility (breaks less than one centimeter). Mudstones are similar in composition but do not show the fissility. Shale gas is one of the most rapidly expanding trends in onshore gas exploration and production today.



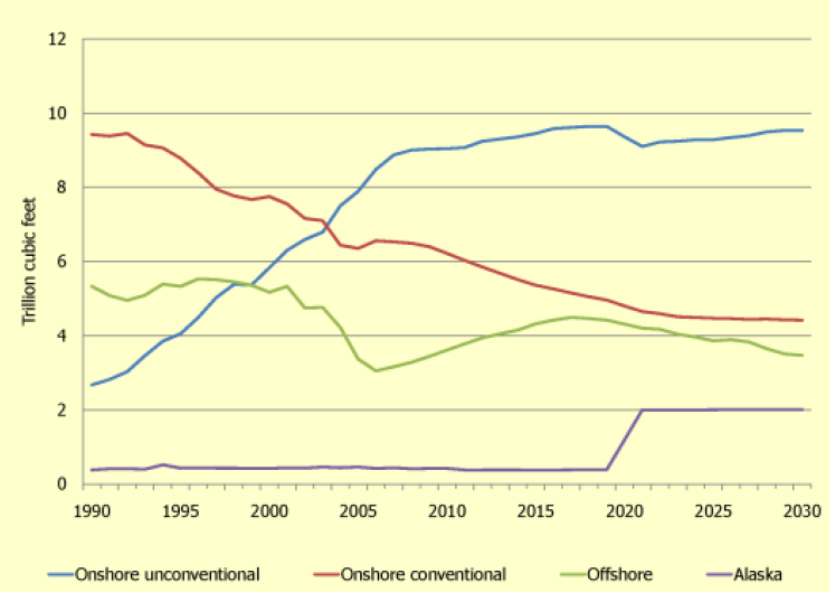
(Source: Shale Gas Primer 2009)

Of the natural gas consumed in the United States in 2009, 87% was produced domestically; thus, the supply of natural gas is not as dependent on foreign producers as is the supply of crude oil, and the delivery system is less subject to interruption. The availability of large quantities of shale gas will further allow the United States to consume a predominantly domestic supply of gas[10].

Production of Shale Gas

Over the last decade, production from unconventional sources has increased almost 65%, from 5.4 trillion cubic feet per year (tcf/yr) in 1998 to 8.9 tcf/yr in 2007. This means unconventional production now accounts for 46% of the total U.S. production.

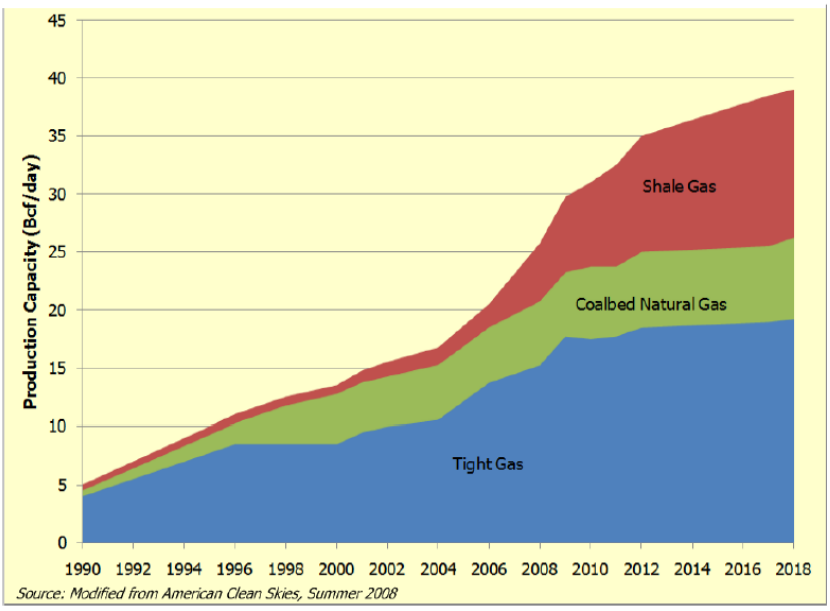
EXHIBIT 6: NATURAL GAS PRODUCTION BY SOURCE (TCF/YEAR)



(Source: Shale Gas Primer 2009)

[10] "Fracking the Karoo – The People Say No!". Karoospace.co.za. Retrieved 26 January 2012.

EXHIBIT 8: UNITED STATES UNCONVENTIONAL GAS OUTLOOK (BCF/DAY)



(Source: Shale Gas Primer 2009)

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	Graph / Clear			2007	2008	2009	2010	View History
U.S.	☐			1,293	2,116	3,110	5,336	2007-2010
Alabama	☐			0	0	0	0	2007-2010
Alaska	☐			0	0	0	0	2007-2010
Arkansas	☐			94	279	527	794	2007-2010
Colorado	☐			0	0	1	1	2007-2010
Kentucky	☐			2	2	5	4	2007-2010
Louisiana	☐			1	23	293	1,232	2007-2010
North	☐			1	23	293	1,232	2007-2010
Michigan	☐			148	122	132	120	2007-2010
Montana	☐			12	13	7	13	2007-2010
New Mexico	☐			2	0	2	6	2007-2010
East	☐			2	0	1	3	2007-2010
West	☐			0	0	1	3	2007-2010
North Dakota	☐			3	3	25	64	2007-2010
Ohio	☐			0	0	0	0	2007-2010
Oklahoma	☐			40	168	249	403	2007-2010
Pennsylvania	☐			1	1	65	396	2007-2010

Texas				988	1,503	1,789	2,218	2007-2010
RRC District 1				0	0	11	41	2007-2010
RRC District 2 Onshore							7	2010-2010
RRC District 3 Onshore				0	0	0	0	2007-2010
RRC District 4 Onshore				0	0	5	26	2007-2010
RRC District 5				437	769	954	1,053	2007-2010
RRC District 6				0	3	28	219	2007-2010
RRC District 7B				90	141	145	140	2007-2010
RRC District 7C							0	2010-2010
RRC District 8				1	4	3	7	2007-2010
RRC District 9				460	586	643	725	2007-2010
State Offshore				0	0	0	0	2007-2010
West Virginia				0	0	11	80	2007-2010
Wyoming				0	0	0	0	2007-2010
Eastern States* (IL, IN, OH, PA, WV)				2	2			2007-2008
Western States (AR, KS, LA, MT, OK)				0	0			2007-2008

(Source: EIA)

Is It Profitable to Produce Shale Gas?

Two factors have come together in recent years to make shale gas production economically viable. The first one is the advances in horizontal drilling. Two major drilling techniques are used to produce shale gas. Horizontal drilling is used to provide greater access to the gas trapped deep in the producing formation. A vertical well is drilled to the targeted rock formation and the drill bit is turned to bore a well that stretches through the reservoir horizontally, exposing the well to more of the producing shale. The second factor is the advances in hydraulic fracturing. Hydraulic fracturing is a technique in which water, chemicals, and sand are pumped into the well to unlock the hydrocarbons trapped in shale formations by opening cracks (fractures) in the rock and allowing natural gas to flow from the shale into the well. When used in conjunction with horizontal drilling, hydraulic fracturing enables gas producers to extract shale gas at reasonable cost. Without these techniques, natural gas does not flow to the well rapidly, and commercial quantities cannot be produced from shale.

Since new technologies are developed to increase the efficiency of producing shale gas, the cost will be less and the supply of natural gas will grow rapidly. Therefore, the price of natural gas will decline. The price of natural gas had been decreasing since 2008.

Shale Gas in Countries Other Than America

Technically Recoverable Shale Gas Resources by Country			
Country	Reserves		
Total	6603		
China	1275		
United States	862		
Argentina	774		
Mexico	681		
South Africa	485		
Australia	396		
Canada	388		
Libya	290		
Algeria	231		
Brazil	226		
Poland	187		
France	180		
Norway	83		
Chile	64		
India	63		
Paraguay	62		
Pakistan	51		
Bolivia	48		
Ukraine	42		
Sweden	41		
Denmark	23		
Uruguay	21		

U.K	20		
Colombia	19		
Tunisia	18		
Netherlands	17		
Turkey	15		
Morocco	11		
Venezuela	11		
Germany	8		
Western Sahara	7		
Lithuania	4		
Reserves Are in trillions of cubic feet			

(Collect data from: http://petroleuminsights.blogspot.com/2011/05/estimated-shale-gas-technically.html)

The chart above shows the countries that have the most technically recoverable shale gas resources. As we can see, China recently has the most undeveloped shale gas resources. As China holds the biggest market of shale gas, the developing of shale gas in Chinas will influence the economy of the world. China has set its companies a target of producing 30 billion cubic meters a year from shale, equivalent to almost half the country's gas consumption in 2008. Potential gas-bearing shale are said to be widespread in China, although as yet undeveloped. In November 2009, US President Barack Obama agreed to share US gas-shale technology with China, and to promote US investment in Chinese shale-gas development (White House Blog). Then, China launched a national shale gas research centre in August 2010. Till April, 2012, Shell already drilled few wells in Sichuan and find some resources. According to the demand chart before, the demand of natural gas in China will increase by 4 times in the next 30 years. Since China just started developing shale gas, the demand should increase more than the supply in the next 20 years, and as a result, the price of natural gas in China will increase in the next 20 years.

The situation in India is similar to the situation in China. Companies including Reliance Industries Limited (E&P), RNRL, have expressed interest in exploring for shale gas in India. Reliance Industries paid a reported US$1.7 billion for a 40% share in Atlas Energy's leasehold in the Marcellus shale gas play in the eastern US. A complication to shale gas

in India is that the government-issued leases for conventional petroleum exploration do not include unconventional sources such as shale gas. During US President Obama's visit to India in November 2010, India and US decided to cooperate in the fields of clean-tech and shale gas. In January 2011, India's biggest energy explorer Oil & Natural Gas Corporation ONGC has discovered the country's first shale gas reserve at Durgapur in Burdwan district of West Bengal. The gas reserve spread over 12,000 square km in the Durgapur-Ranigunj area – is the world's third shale gas find (ONGC). Both India and China are developing countries, and India might have a bigger increase on its natural gas demand than China. Therefore, the price of natural gas in India may increase in more than 20 years[11].

Poland has the largest reserves of shale gas in Europe. As of 2010, Poland imports two-thirds of its natural gas from Russia. ConocoPhillips has announced plans to explore for shale gas in Poland, along with Lane energy[12]. Norwegian company Statoil is in a joint venture with Chesapeake Energy to produce Marcellus Formation shale gas in the eastern US, and has indicated interest in bringing knowledge gained in the US to European shale gas prospects. Russian giant Gazprom announced in October 2009 that it may buy a US shale-gas producing company to gain expertise which it could then apply to Russian shale gas prospects. In the Barnett Shale in Texas, French oil firm Total SA entered a joint venture with Chesapeake Energy, and Italy's ENI purchased an interest in Quicksilver Resources. Potential host formations for shale gas in Europe include shales in northeast France, the Alum Shale in northern Europe, and Carboniferous shales in Germany and the Netherlands[13].

According to all the information above, in the next 50 years, American gas companies are going to have connections through the world. Countries other than America will experience an increasing demand and price of natural gas. Since US shale gas technology is developed, and has a large amount of low price resources. America is going to increase a significant amount of export within the next 10 years, and as long as this happens, other countries' natural gas price will decline in a short term. Since the demand of energy is shift towards natural gas, the price will go up in the long term[14].

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[11] "U.S. Census Bureau – World POPClock Projection". July 2012–July 2013 data.

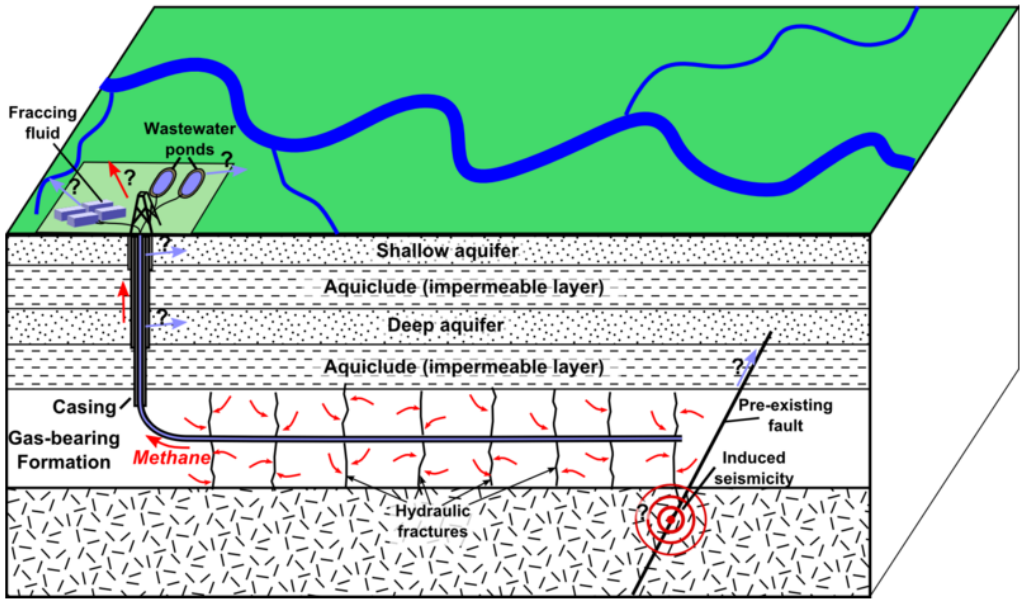
[12] http://www.naturalgas.org/overview/background.asp. Retrieved 2012-07-14.

[13] White House Blog, *The US and China: towards a clean energy economy*, 17 November 2009.

[14] Fjaer, E. (2008). "Mechanics of hydraulic fracturing". Petroleum related rock mechanics. Developments in petroleum science (2 ed.). Elsevier. p. 369. ISBN 978-0-444-50260-5. Retrieved 2012-05-14.

Environmental Concerns

However, there are some potential environmental issues that are also associated with the production of shale gas. Shale gas drilling will cause significant water supply issues. The drilling and fracturing of wells requires tons of water. In some areas of the country, significant use of water for shale gas production may affect the availability of water for other uses, and can affect aquatic habitats. Shell Oil intended to explore for shale gas using hydraulic fracturing in the Karoo region of the Western and Northern Cape provinces, but it was opposed because of local residents' concern about the environment.



(Source: http://en.wikipedia.org/wiki/File:HydroFrac.png)

Drilling and fracturing also produce large amounts of wastewater, which may contain dissolved chemicals and other contaminants that require treatment before disposal or reuse. Because of the quantities of water used, and the complexities inherent in treating some of the chemicals used, wastewater treatment and disposal is an important and challenging issue.

If mismanaged, the hydraulic fracturing fluid can be released by spills, leaks, or various other exposure pathways. The use of potentially hazardous chemicals in the fracturing fluid means that any release of this fluid can result in the contamination of surrounding areas, including sources of drinking water, and can negatively impact natural habitats[15].

[15] ONGC finds maiden shale gas reserves in India"Business standard, 28 January 2011.

One of the solutions is to install protective telescoping casing that isolates the gas well from water supply aquifers, and it can greatly reduce the actual hazards associated with hydraulic fracturing. Down hole hydraulic fracturing will not be a threat to drinking water if the protective casing is properly installed. Another solution that might be helpful is an expansion of public outreach by regional petroleum industry operators regarding the proper installation of protective casing. The use of a lower-cost secondary drilling rig capable of installing the desired telescoping casing diameters to below the assumed aquifer depth of 1,000 ft could both reduce the cost of the larger land-based rig, and relax the exploration and production schedule. Addressing potential lost-circulation problems with the spud rig would reduce more costly production downtime needed for plugging the formation and reduce costs associated with replacing damaged water supplies.

1.3 OIL

1.3.1 Introduction

Oil, or petroleum, is composed primarily of hydrocarbon molecules, which are a mixture of hydrogen and carbon atoms. Specifically: 84-87% carbon and 11-14% hydrogen. There are also trace elements of nitrogen, oxygen, and sulfur.[16] Middle East has much of the oil to be extracted; Russia and United States are also top world oil producers. As for consumers, United States is absolutely the top one, following by China and Japan.

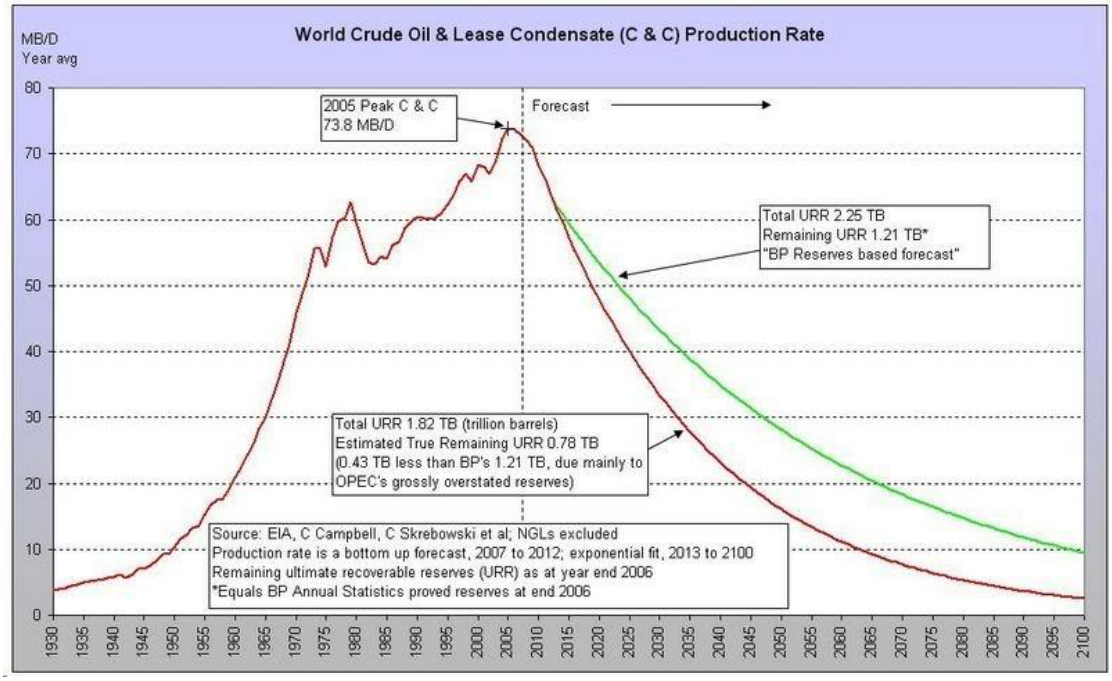
If you look around, oil is been used in every aspect in our daily life: residential, commercial, transportation, and power generation; it is also crucial for manufacturing and industrial. Since it is not renewable, people have to find a way to alternate oil for the long term. For the short term, we should focus on how to improve the efficiency of current ways of usage.

1.3.2 Oil Consumption and Price

When one talks about oil as energy, the first question come to my mind is: how much oil is left in the world? The first graph in the appendix shows the global proved reserves of oil from 1980 to 2011. We can easily see from the graph that despite the growth in oil production over the years, reserves continue to grow. However, will these much oil provide us enough energy for our descendants to live on this planet, for example, a century? With this question, I search through several articles and finally got caught by a topic named “The Society of Petroleum Engineers estimates remaining official world reserves represent 41.6 more years of oil.” After 2012, two scenarios are shown. In figure 1, the green line is a forecast using BP Annual Statistics Review 2006 proven reserves data. The dark red line, the most likely scenario, is based partly on the BP data, but large downward revisions are made to OPEC reserves and small upward revisions are made to the reserves of many countries to derive a more accurate estimate of proven and probable reserves. This estimate is assumed to be equal to the ultimate recoverable reserves (URR).

[16] http://envhist.wisc.edu/cool_stuff/energy/oil_gas.shtml#oil

Figure 1



Despite on how they got this "horrify" conclusion, it seems that after 4 decades, we have to find a way to be independent from this nowadays' top energy source.

However, many believe that this new discovery is not entirely relevant to the question "how much oil is left". Because long before that final drop of oil is burned out, the energy industry says we'll reach a "peak oil" level --- the time when the production capacity of suppliers is maxed out. It is already be realized that "Led by rapidly industrializing China, global oil consumption has increased over two percent every year." [17]In order for prices to remain relatively stable, supply must keep up with demand. Therefore, when production finally peaks, either the price will become higher and higher or people have already found a new top source to substitute oil.

Since we mentioned price, it brings us to another question. Even if we had enough amount of oil, can people afford it? The situation is not so optimistic. The second graph tells us about the price change from 2000 to 2008. Apparently the price keeps increasing and from our daily life we can found things that suggesting that this trend won't stop. When talk about price, there must be supply and demand and the oil price represents a balance between supply and demand for crude. The demand is overwhelmingly down to the health of the global economy, and the big picture is: if the debt crisis in the West

[6] http://northernstar-online.com/blog/how-much-**oil**-is-still-left

threatens to derail the so-far unstoppable growth in booming Brazil, China India and emerging markets, the demand will fall. In short-term, supply is influenced by political uncertainty and long-term by technical breakthroughs in drilling and refining (Oil price predictions: What next for crude by Ed Monk and Andrew Oxlade). This leads us to another topic: will there be new technology to gain higher efficiency in both finding and using oil?

One problem with oil is that, like a nice ripe orange, ready for squeezing, but you can only get a small amount of juice. There's got to be more, you just can't get at it. The only way to find out if a trap contains oil or gas is to drill into it with a well. Today, we use rotary drilling in which a bit on the end of a length of drill pipe is rotated. A mixture of water and mud, called drilling fluid, is pumped down the pipe to flow through the bit. The drilling fluid, also called "mud", lubricates the bit, washes away the cuttings, and maintains pressure in the hole to prevent the well from becoming a blowout. The mud flows back to the surface through the gap between the drill pipe and the hole. This gap is called the annulus. Wells are very expensive to drill, and some deep wells may even cost millions of dollars. The nanotechnology can help the global oil business out of this frustration. However, is said to be "promising but untested" for discovering oil. [18] More problem comes when one start to extract more oil --- the cost. "Costs to extract extra oil vary between $10 and $80 a barrel, depending on the method, the IEA estimates. Oil is now trading around $65 a barrel, making some of the costlier recovery not feasible." (New technology aims to increase oil production, Houston, 7/29/2009) Although new technology can help people discover more oil or gain higher efficiency, the price is, again, a significant problem.

While oil becoming our top energy resource, we are hurting the environment in the meantime. For example, oil spills that may be due to releases of crude oil from tankers, offshore platforms, drilling rigs and wells or the spill of any oily refuse or waste oil[19]. The way of cleaning up may very because no two oil splits are the same due to the type of oil, location, weather, etc. However, I sadly found out that one of the four main methods of response is "leave the oil alone so that it breaks down by natural means" [20]

[18] http://www.msnbc.msn.com/id/32208227/ns/technology_and_science-future_of_energy/t/new-technology-aims-increase-oil-production/#.UEjh3VRvmO0

[19] Lingering Lessons of the Exxon Valdez Oil Spill". Commondreams.org. 2004-03-22. Retrieved 2012-08-27.

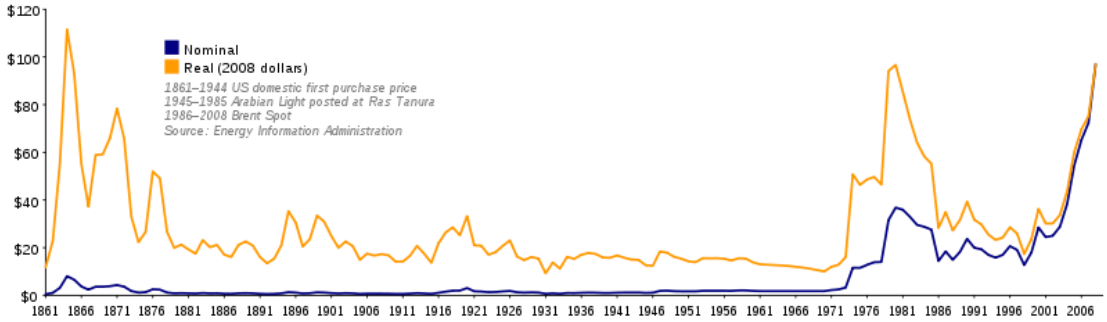
[20] How do you clean up an oil spill? Presented by the University of Delaware Sea Grant Program. http://www.ceoe.udel.edu/oilspill/cleanup.html

1.3.3 How to Deal With Oil Crisis

Based on my former research, according to the prediction, by year 2050 the consumption rate of oil will be increased to a level that almost reach the max decreasing production rate. Another oil crisis might occur around that time, how should we deal with it?

Let's learn from the oil crisis that already happened. One of them started in October 1973, when the members of Organization of Arab Petroleum Exporting Countries (or the OAPEC) proclaimed an oil embargo, which was in response to the U.S. decision to re-supply the Israeli military during the Yom Kippur war. [21] The 1973 "oil price shock", along with the 1973–1974 stock market crash, has been regarded as the first event since the Great Depression to have a persistent economic effect. [22](See image below)

Figure 2 Graph of oil prices from 1861–2007, showing a sharp increase in 1973, and again during the 1979



Source: http://en.wikipedia.org/wiki/File:Oil_Prices_1861_2007.svg

This energy crisis led to a greater interest in renewable energy and spurred research in solar power and wind power. It also led to greater pressure to exploit North American oil sources, and increased the West's dependence on coal and nuclear power. One problem with solar power is that it is not available at night, and energy storage is an important issue because modern energy systems usually assume continuous availability of energy. [23] Well-designed thermal mass systems (see figure 3[24] below) can store solar

[21] CHE | Perspectives | Responding to Crisis". Envhist.wisc.edu. 2010-04-26. Retrieved 2012-08-07

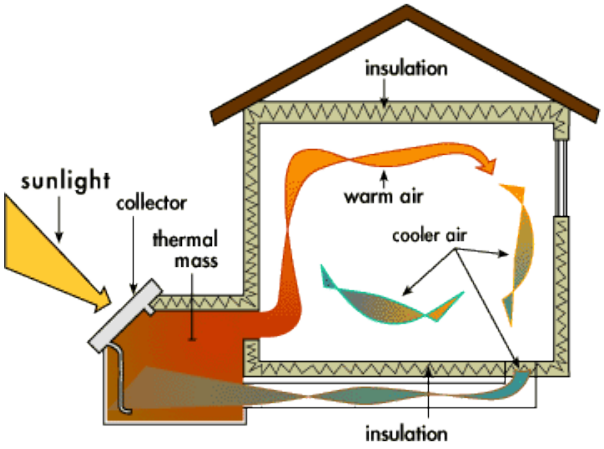
[22] Perron, P.; University, Princeton; Program, Econometric Research (1988) (PDF). *The Great Crash, the Oil Price Shock and the Unit Root Hypothesis*. Econometric Research Program, Princeton University Princeton, New Jersey. Retrieved 3 February 2012

[23] Carr (1976), p. 85

[24] http://www.consumerenergycenter.org/home/construction/solardesign/indirect.html

energy in the form of heat at useful temperatures and can also lower peak demand, reduce overall heating and cooling requirements.[25]

Figure 3 The heated air circulates throughout the room by convection



Source: http://www.consumerenergycenter.org/home/construction/solardesign/indirect.html

Also, phase change materials such as paraffin wax and Glauber's salt are another thermal storage media. Take paraffin wax (figure 4) as an example, they are found in the solid state at room temperature and begin to enter the liquid phase past approximately 37 °C (99 °F), which make them able to store and release energy. Wind power, though seems more affordable and environmentally friendly, can still cause real damage to the nature. Industrial wind turbines can destruct fragile ecosystems and animal habitats. Eagles, hawks and migrating birds would kill by the turbine. Not only animal, people can also influence by the noise from wind turbines and get a health problem known as "wind turbine syndrome".

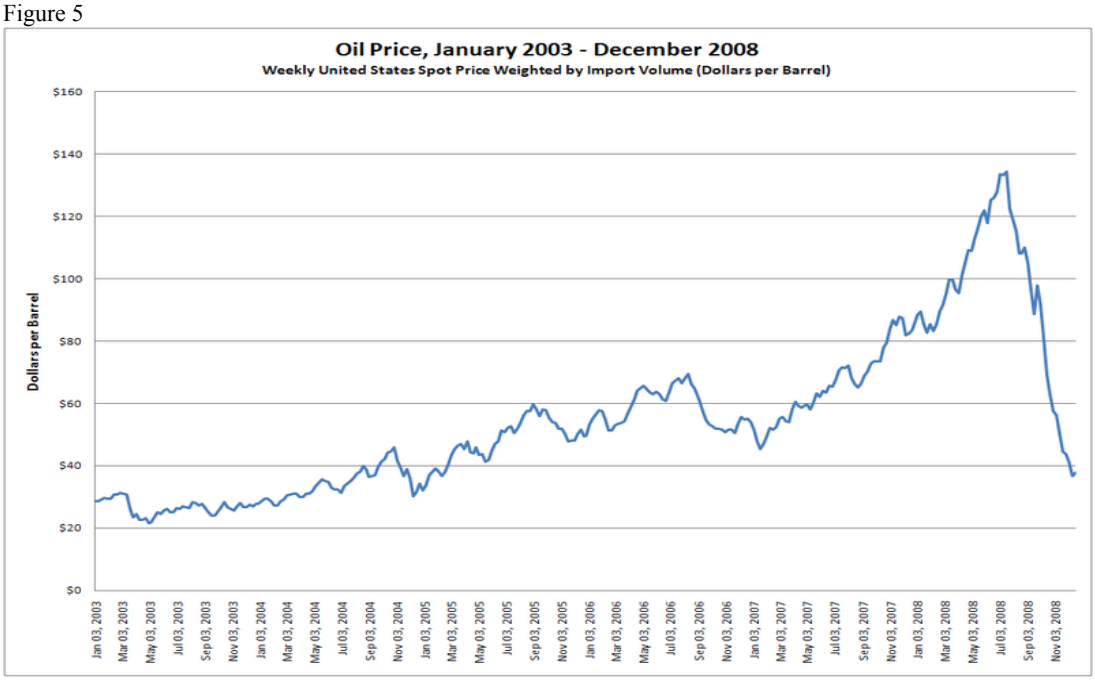
Figure 4 Paraffin wax

Source: http://en.wikipedia.org/wiki/File:Paraffin.jpg

[25] "Request for Participation Summer 2005 Demand Shifting with Thermal Mass" Demand Response Research Center. Retrieved 2007-11-26.

If we look at the 2000s energy crisis (figure 5), we' would found out a big part of the mitigations besides finding alternative fuel focus on people, or say the way people using fuel. For example, the interest in mass transit had been increasing since 1970s. Another recourse used and discussed in the past to avoid the negative impacts of oil shocks in the many developed countries which have high fuel taxes has been to temporarily or permanently suspend these taxes as fuel costs rise. The problem is that, locally decreasing fuel tax can decrease fuel prices, but globally prices are set by supply and demand, and therefore fuel tax decreases have no effect on fuel prices, and fuel tax increases actually decreases fuel prices by reducing demand. [26]This method of softening price shocks is even less viable to countries with much lower gas taxes, such as the United States.

Figure 5



Source: http://en.wikipedia.org/wiki/File:Price_of_oil_(2003-2008).png

Transportation demand management has the potential to be an effective policy response to fuel shortages[27] or price increases and has a greater probability of long term benefits than other mitigation options. As the cost of moving information by moving human workers continues to rise, while the cost of moving information electronically continues to fall, presumably market forces should cause more people to substitute virtual travel for physical travel. Matthew Simmons explicitly calls for "liberating the

[26] Why Are Gasoline Prices High (And What Can Be Done About It)

[27] Gueret, Thomas Travel Demand Management Insights IEA conference 2005

workforce" by changing the corporate mindset from paying people to show up physically to work every day, to paying them instead for the work they do, from any location.[28] This would allow many more information workers to work from home either part-time or full-time, or from satellite offices or Internet cafes near to where they live, freeing them from long daily commutes to central offices. However, in a future scenario with pervasive adoption of teleworking, where 50% of information workers telecommute 4 days per week, the energy saving are estimated at about only 1% in both United State and Japan (with present energy savings estimated at 0.01–0.04% the United States and 0.03–0.36% in Japan, from current estimated teleworking populations and practices.) By comparison, a 20% increase in automobile fuel economy would save 5.4%.[29]

In my own opinion, we should always choose the solution with relatively higher efficiency and lower cost. In this case, though the telework adoption seems to save a little amount of energy, when we implement it with other “solution” such as using hybrid car, we will see a much better result. I believe, since people are always the consumer, the way we behave do matters in energy saving. Changing social pattern might not be a way to deal with oil crisis once and for all, but at least we could try and see how things will change.

[28] Lundberg, Jan. "The maturation of Matt Simmons, energy-industry investment banker and peak oil guru". energybulletin.net. Archived from the original on 11 April 2008. Retrieved 5 October 2011.

[29] Matthews, H. Scott. "Telework Adoption and Energy Use in Building and Transport Sectors in the United States and Japan". Journal of Infrastructure Systems. Retrieved 15 July 2010.

Chapter2. Renewable Energy

"Renewable energy is energy that comes from natural resources such as sunlight, wind, rain, tides, waves and geothermal heat. About 16% of global final energy consumption comes from renewable resources, with 10% of all energy from traditional biomass, mainly used for heating, and 3.4% from hydroelectricity. New renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for another 3% and are growing very rapidly." 30

[30] REN21 (2011). "Renewables 2011: Global Status Report"

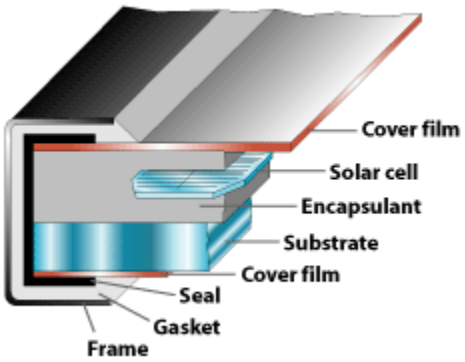
2.1 Solar Energy

2.1.1 Introduction

Sunlight is by far the largest carbon-free energy source on the planet. More energy from sunlight strikes the Earth in 1 hour (4.3 × 1020 J) than all the energy consumed on the planet in a year (4.1 × 1020 J). Earth receives about 10 times as much energy from sunlight each year as that contained in all the known reserves of coal, oil, natural gas, and uranium combined[31]. Therefore effectively capturing the solar energy will solve our current energy shortage problem.

Flat-Plate Photovoltaic system

Flat-Plate Photovoltaic System is the simplest and most common method to collect solar energy. The Flat-Plate Photovoltaic Cell could capture sunlight that is both direct and diffused. The advantage of Flat-Plate PV system is the relative easy installation. However, this method requires larger size of the Photovoltaic cell, which is the most expensive component of soar power capture system.



Typical flat-plate module design [31]

Concentrator Photovoltaic System

Concentrator photovoltaic (PV) systems use less solar cell material than other PV system. Concentrator use inexpensive material such as glass or metal to reflect larger area of sunlight onto the smaller area PV panel, this method can effectively reduce the size of the Photovoltaic cell, which can reduce the total cost. Another advantage is that the solar cell's efficiency increases under concentrated light. How much that efficiency

[31] Solar Energy, Renewable Energy and the Environment. Robert Foster , Majid Ghassemi , and Alma Cota. CRC Press 2009

increases depends largely on the design of the solar cell and the material used to make it.

The disadvantage of the method is that it require dynamically adjust the orientation of the panel and reflecting surface in order to achieve high power output, this required sophisticated tracking and control component, which might be expensive.

Concentrating Solar (Thermal) Power

Concentrating solar power (CSP) technologies use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. This thermal energy can then be used to produce electricity via a steam turbine or heat engine that drives a generator.[32]

There are several approaches for the concentrating solar power; one is the Linear Concentrator Systems. The Linear Concentrator System use large mirrors to capture solar energy and reflect this energy to the receiving tube. The receiving tube contains liquid that will eventually be vaporized and used to spin a steam turbine for electricity generation.

AREVA Solar's Compact Linear Fresnel Reflector technology at the company's Kimberlina Solar Thermal Power Plant in Bakersfield, California. (AREVA Solar) [33]

Another CSP technique is Dish/Engine Systems for Concentrating power, this technique can produce a lot less energy than other CSP techniques, but the advantage is its

[32] 2: US Department of Energy. *Solar Energy Technologies,*http://www.eere.energy.gov/basics/renewable_energy/solar.html
[33] Frank, Brian. Suncatchers: A Solar Tech Rundown. January 20, 2012

portability. There are two units in this system, one is the parabolic dish that concentrates and reflects the solar energy onto the receiver. The other is the power conversion unit, including the receiver and the engine/generator. This unit will convert the solar energy capture by parabolic dish and convert them into electricity.

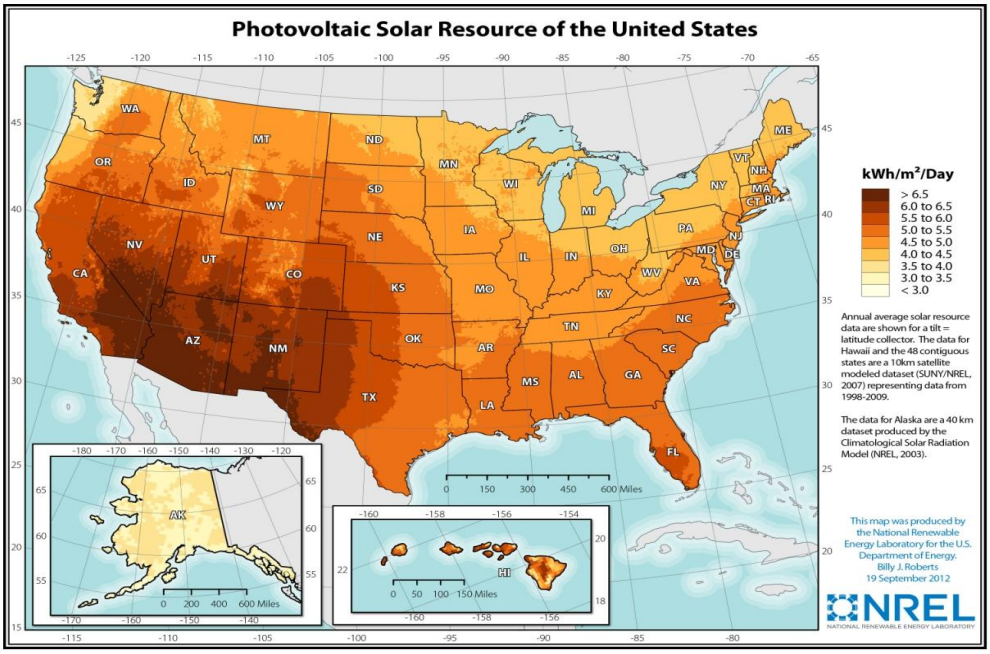
Dish-engine solar system. The solar dish generates electricity by focusing the sun's rays onto a receiver, which transmits the heat energy to a Stirling engine, which in turn drives a generator to make electricity. (Sandia National Laboratory) [3]

The third technique is Power Tower System, this technique is similar to the linear concentrator system, but in a larger scale. Numerous large, flat, sun-tracking mirrors, known as heliostats, focus sunlight onto a receiver at the top of a tall tower, the tall tower then will use this heat to produce water vapor to spin a steam turbine. Individual commercial plants can be sized to produce up to 200 megawatts of electricity.

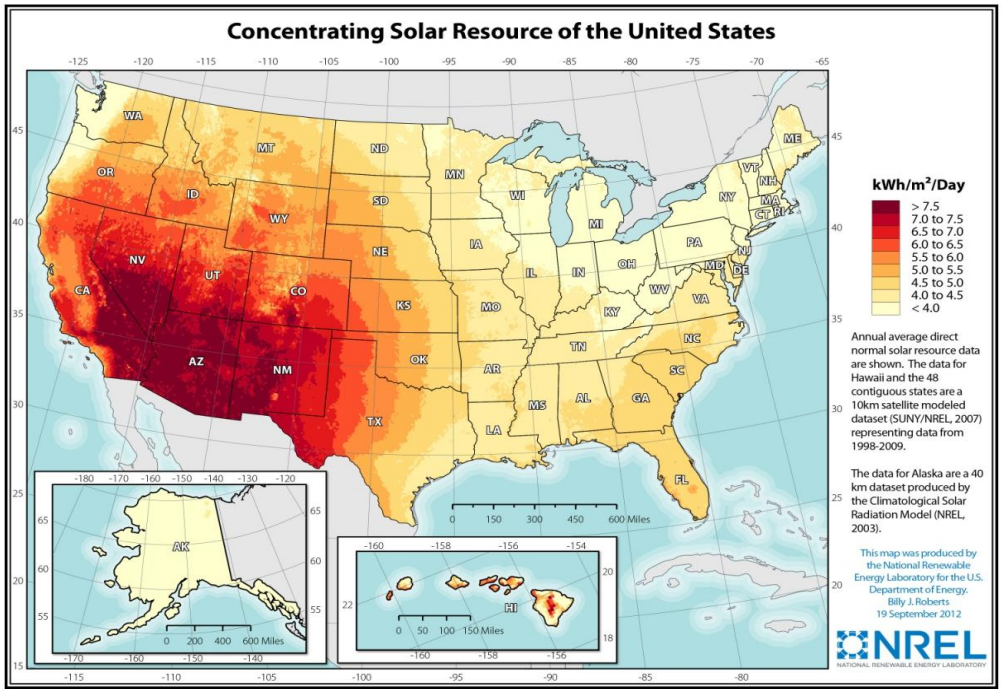
Stretched membrane heliostats with silvered polymer reflectors will be used as demonstration units at the Solar Two central receiver in Daggett, CA. (Sandia National Laboratory) [32]

Limitation of Solar Energy

Not every place can use solar energy to replace their energy consumption. There is geological limitation for solar energy generation. For example in the US, below are two maps to indicate the potential of solar energy across the US (Both PV and solar thermal). As we can see, only the south-east of the US has the potential to develop solar power.



National Renewable Energy Laboratory – Potential PV Resource of the US



National Renewable Energy Laboratory – Potential Concentrating Solar Resource of the US

2.1.2 The city of the future: DeZhou Solar Valley

In a city in China called DeZhou, even the streetlight and traffic light has solar panel on it. Built on what used to be farmland, it is the "biggest Solar Energy Production Base in the Whole World", and in 2010, the Washington post describe the DeZhou solar valley as the "China's clean-technology answer to California's Silicon Valley."[34]

DeZhou's solar valley is the vision of one man ---the multi-millionaire, green entrepreneur Huang Ming. His company Haiming is the biggest producer of solar water heaters in the world, and has been the inspiration of many clean energy companies in DeZhou. They have promoted 300 million m^2 of solar water heaters all over China, including some of their colleague companies. Covering an area of over 330 hectares (815 acres) in total, China Solar Valley leads the way in solar industrialization, including the seven wonders in solar area (figure 2.1.2-1), namely, an unprecedented solar thermal manufacturing base, the first automatic production line of evacuated tubes in the world, a company-owned solar museum, a PV lighting road of over 10 kilometers, a demonstration area for solar architectures, a professional testing center well beyond international requirements, an international renewable energy communication center—the main site of 2010 International Solar Cities Congress (ISCC). [35]

Figure 2.1.2-1

Take the most significant building in solar valley, (figure 2.1.2-2 below) "the Sun-Moon Mansion" as an example.

[34] *With Solar Valley project, China embarks on bold green technology mission, by Andrew Higgins*, Monday, May 17, 2010

[35] http://www.himin.com/english/News/ShowArticle.asp?ArticleID=49&Page=3

Figure 2.1.2-2

It is the largest solar structure in the world, featured with solar water heating, solar air-conditioning, and ceiling radiation for heating and cooling and provides spaces for displays, research and development, work, meetings, education, hotel, recreation, etc. This gigantic solar based building has 210 m^2 of photovoltaic (three different kinds of PV modules are being used, which could generate 35 KWH per day. The building integrated PV (BIPV) technology which capable of day lighting, power generation, energy saving and environment protecting. It achieves the perfect combination with architecture and ends the hanging installation history of conventional PV components.[36] The 4980 m^2 of solar thermo system, which generate 22395 mill joules, can provide heat for daily water demand, swimming pool and also solar-powered air conditioner. The 75,000 m^2 (800,000-square-feet) floor area saves more than 80 percent energy, compared with a conventionally lighted and heated building of the same size. This represents an annual saving of 2,640 tons coal or 6,600,000 KWH of electricity, with an annual pollution reduction of 8,672 tons of CO_2.[37] The top 3 advantage of the building is less pollution, "endless" energy resource and reduce the waste of electricity during transportation as the solar energy could be converted to electricity through special equipment just on the same spot of the building.

Huang's idea of using renewable energy in a large scale actually came after his daughter was born, in the early 1990s. He said he "felt guilty" for how we are using energy such as oil and coal right now, and then leading him to worry about that the daughters of his daughter will have no energy resource and their lifestyle have to go back to the ancient

[36] http://www.chinasolarvalley.net/Article/ShowArticle.asp?ArticleID=13

[37] http://wenku.baidu.com/view/bac2ff340b4c2e3f572763da.html

time. "Renewable energy doesn't mean people have to be uncomfortable" is the reason why he chose to build the solar valley with luxury architect such as Douglas-Pavilion (figure 2.1.2-4&5) a Zero-emission architecture that Mr.Huang collaborated with an American architect ---- "the father of solar-based architecture" Douglas A. Wilke, whose idea was thought to be impractical until he met Mr. Huang at the UN conference and now under the support from Mr. Huang, the old architect has realized his dream. By making use of solar energy to the largest extent, the solar thermal system and the photovoltaic (PV) system of this building can save over 40 tons of standard coal and reduce the emission of carbon dioxide by over 100 tons annually. In the aspect of solar thermal technologies, solar energy provides hot water to the entire building; the chimney on the roof is also related to solar energy. In spring and fall, part of the heat generated by the solar energy collector can be used to heat the air and form indoor air convection so as to ventilate and cool the room; in winter, the heat stored in the special "energy storage room" under the villa which is for storing the surplus solar energy in spring, summer and fall can be used for solar heating. Multiple technologies such as solar air conditioning and refrigeration and solar floor heating and ceiling radiation technology (hidden in the ceiling without affecting the appearance while having double functions of heating and refrigeration) are adopted in the heating and refrigeration system. In the aspect of solar photovoltaic (PV) technologies, PV grid-connected system is adopted for power supply. In addition, it is possible to make the best of sunlight for natural heating by the use of the passive solar house technology.[38]

He realized that clean energy would work only if there is profit motive: "If it can't make money, this experiment will be a big failure." Indeed, government will not let a green policy go through if there is just a little profit or even no profit. In 2009, Dezhou municipal authorities spent more than $10 million just to install solar lighting along miles of road. Fortunately, many companies was impressed by this huge project, including Goldman Sachs, which, along with Beijing- based CDH Investments, has invested $100 million in Huang's company. I hope that the government could be more supportive for such project. Like Dezhou Construction Committee is doing its bit: It requires that all new buildings be equipped with solar water heaters of the type made by Huang's company. More than 80 percent of buildings in the city have them by the time of 2010.

We should thank Mr.Huang for his great courage to visualize what has been in a lot of people's dream. I cannot even imagine how much effort he put into this project. His

[38] http://www.chinasolarvalley.net/Article/ShowArticle.asp?ArticleID=102

creation --- the solar valley sets a brilliant example for everybody else who plan to develop solar based life environment.

Continued Calculation for Solar Valley

For electricity retail price, I used the data in 2011 and calculated the whole year average for residential, commercial, industrial and transportation use (see Figure 2.2.2-3[39] below). From the last column, I got the average price of electricity in 2011 in the US equals to 9.86 cents per kilowatt-hour. The "Sun-Moon" Mansion is DeZhou solar valley can achieve a annual saving worth of 6,600,000 KWH of electricity, which equals to 6,600,000 * 9.86 / 100 = **$650,760**. We know that the investment on the whole solar valley worth **$208,791,700** and this "Sun-Moon" Mansion is just one of the 7 largest buildings in the valley. It is said that the whole valley could save 2 billion kilowatt-hour, so the total saving would be 2,000,000,000 * 9.86 / 100 = **$197,200,000.** Besides, the valley gains its profit by different departments such as hotel and large-scale communication center. If the valley could by promote to more people I think that it could balances its cost within 2 year. I sincerely hope that the Solar Valley not become just a huge experiment on our planet.

Figure 2.1.2-3

Period	Residential	Commercial	Industrial	Transportation	All Sectors
2011					
January	10.87	9.78	6.53	10.29	9.48
February	11.06	9.99	6.63	10.55	9.56
March	11.52	9.93	6.53	10.24	9.55
April	11.67	9.96	6.53	9.97	9.54
May	11.93	10.19	6.68	10.70	9.78
June	11.97	10.66	7.14	11.01	10.26
July	12.09	10.67	7.31	11.21	10.47
August	12.09	10.72	7.40	10.82	10.49
September	12.17	10.59	7.15	10.80	10.29
October	12.08	10.25	6.77	10.25	9.83
November	11.78	9.98	6.53	9.93	9.58
December	11.40	9.77	6.51	9.79	9.53

[39] http://www.eia.gov/electricity/data.cfm

Figure 2.1.2-6

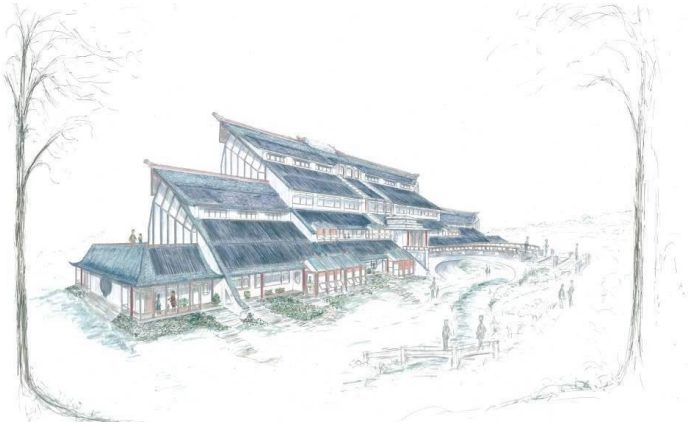


Figure 2.1.2-4[40]

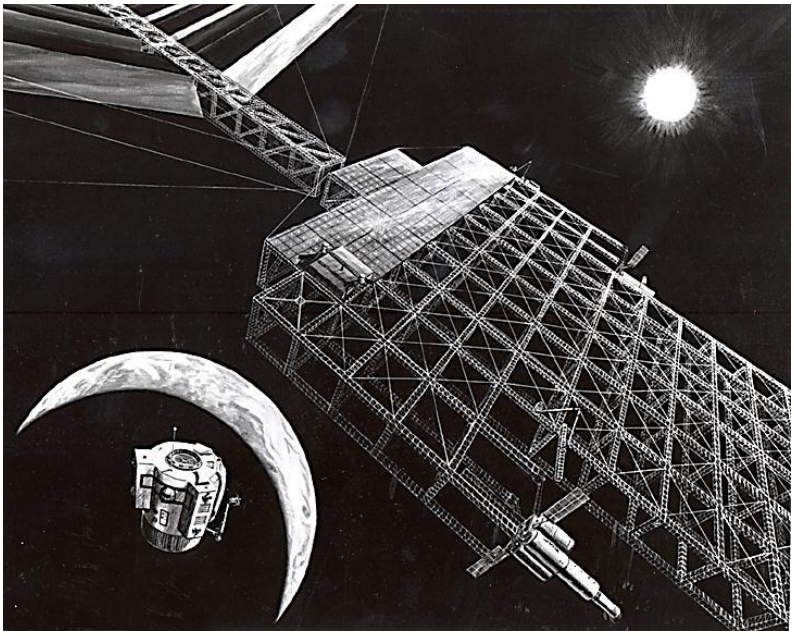
Figure 2.1.2-5

[40] Figure 2.1.2 – 1,2,4,5,6 All from http://www.chinasolarcity.com.cn/

2.1.3Space Solar Power Satellite

Development

The concept of space solar power satellite has been around for a long time. It was first mentioned in a science fiction short story "Reason" written by Isaac Asimov in 1941. And this concept was first described seriously in 1968 by Peter Glaser, in 1973, Peter Glaser also patent his method of transmitting power over long distant wirelessly by microwave using a very large antenna, now is known as rectenna (a special type of antenna that is used to convert microwave energy into direct current electricity). In late 1970's, NASA engineers make a conceptual design of the satellite; this is what it looks like:

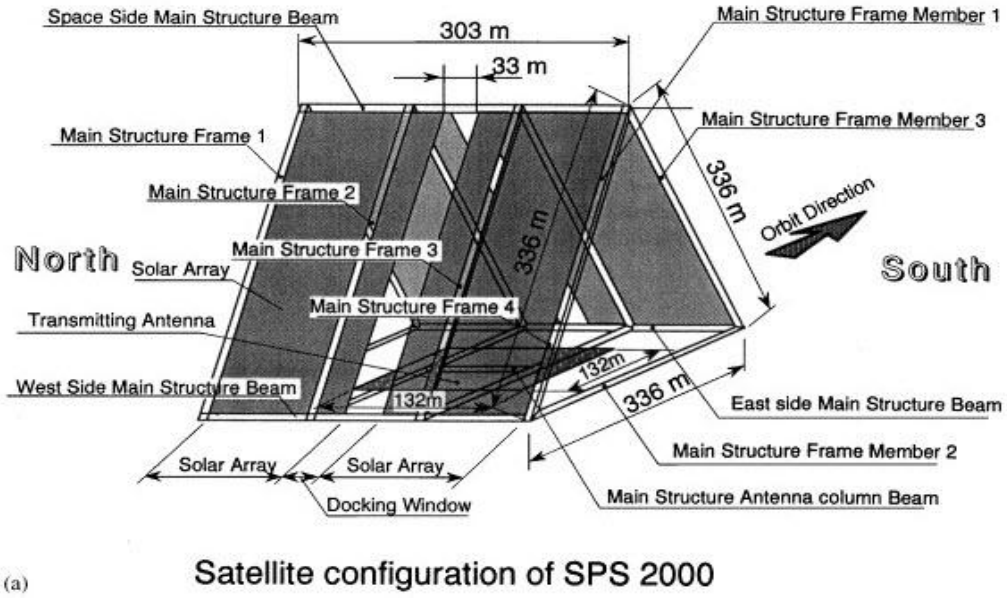


NASA, Image # 76-HC-632, 06/08/1976

As we can see, the shape of the satellite is irregular; it is difficult to stable in outer space. Base on the technologies at that time, the government did not have enough confident to make a decision about whether to proceed with this development. Furthermore, the energy price at that time is not as high as the price right now, and the emission problem was not as severe, therefore, the government didn't put in large effort into the development of this project.

A decade later in Japan, a group of engineers came up with a total different design of this Space Solar Power Satellite, which is called the SPS 2000. According to the

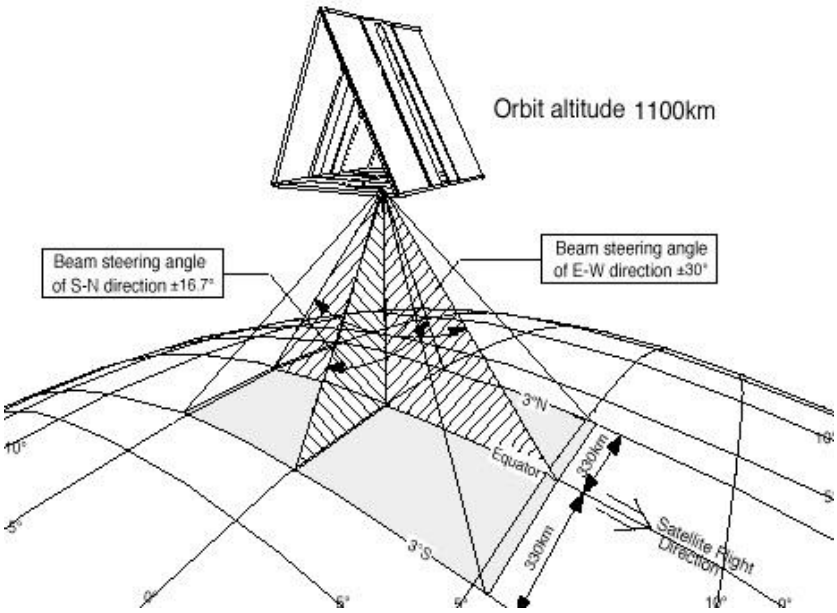
requirement of this satellite[41], it will operate in Low Earth Orbit around the equator; therefore it will be able to provide electricity for multiple locations around the equator. Also, the microwave beam to earth is not concentrated into a small area; instead it is spread out, so each ground station will require large surface area to receive this microwave and converts it into electricity. Here is the design of the system and how it will be operate.



SPS 2000 configuration and operation [42]

[41] http://www.spacefuture.com/archive/conceptual_study_of_a_solar_power_satellite_sps_2000.shtml

[42] Patrick Collins, SPS — time for a pilot plant, Space Policy, Volume 16, Issue 2, 15 May 2000, Pages 99-106, ISSN 0265-9646, 10.1016/S0265-9646(00)00010-2.



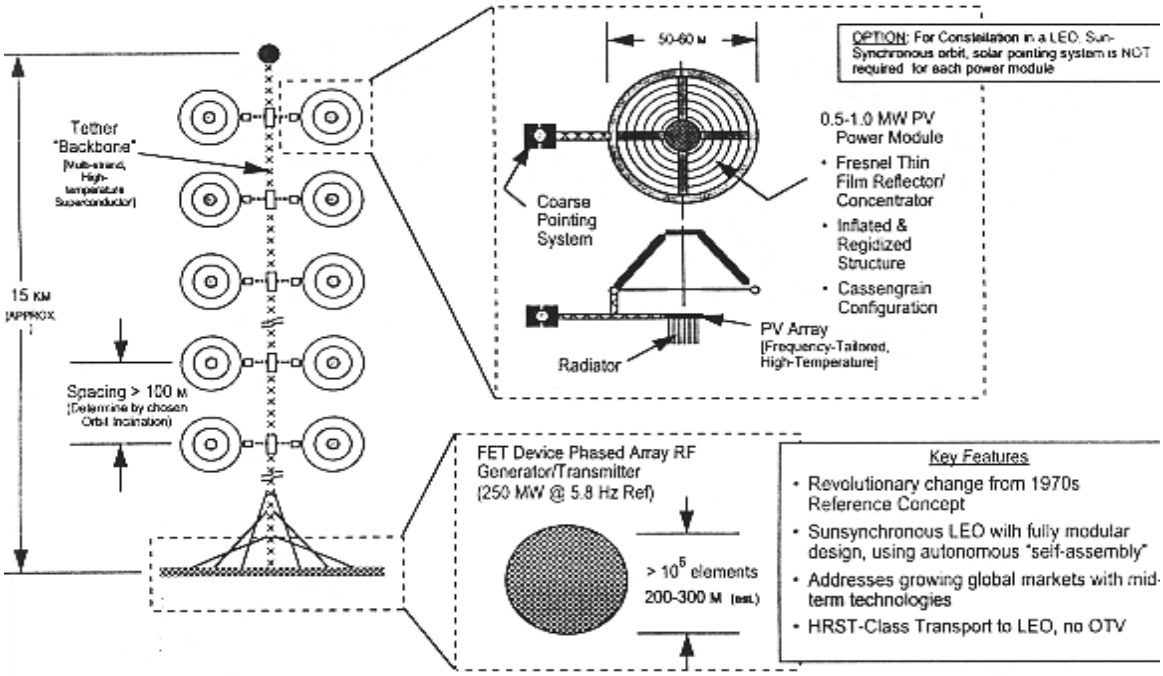
SPS2000 operation [41]

There are several problems I see in this system. First, putting the satellite on LEO is not a good option comparing to putting it on GEO, for 5 reasons:

1. In LEO, the satellite require frequent maintenance and attitude control, we will also cost energy.
2. In LEO, multiple ground stations are required, but only one of them is operating at a given time, so it is not efficient in terms of energy density (Energy obtained/Earth surface require).
3. In LEO, for each station "the satellite will deliver power for about 200 seconds as it passes overhead once during each orbit of approximately 100 minutes" [41](Quo from the system specification). So it will be necessary to store the energy received by the rectenna and delivery it continuously in a much lower power.
4. The Operational time for satellite in LEO is not 24/7, a large portion of time the satellite is blocked from the sun, therefore it will not be able to delivery and energy during those periods.
5. The interference area is large for satellite in LEO comparing to satellite in GEO. For satellite in GEO, the satellite is always on top of a specific point on earth, therefore the signal/wave transmitted by the satellite would only interrupt a single point on earth. However, for satellite in LEO, the signal/wave transmitted by the satellite would move across the equator, therefore it will interfere with the signal on the entire equator area.

The new update of this project vanished just before the year 2000. I believe that this project was canceled because of the advances of our technologies, which makes sending a large scale satellite into GEO possible. Because all the advantages of geostationary satellite could provide, our research now is focus on this area.

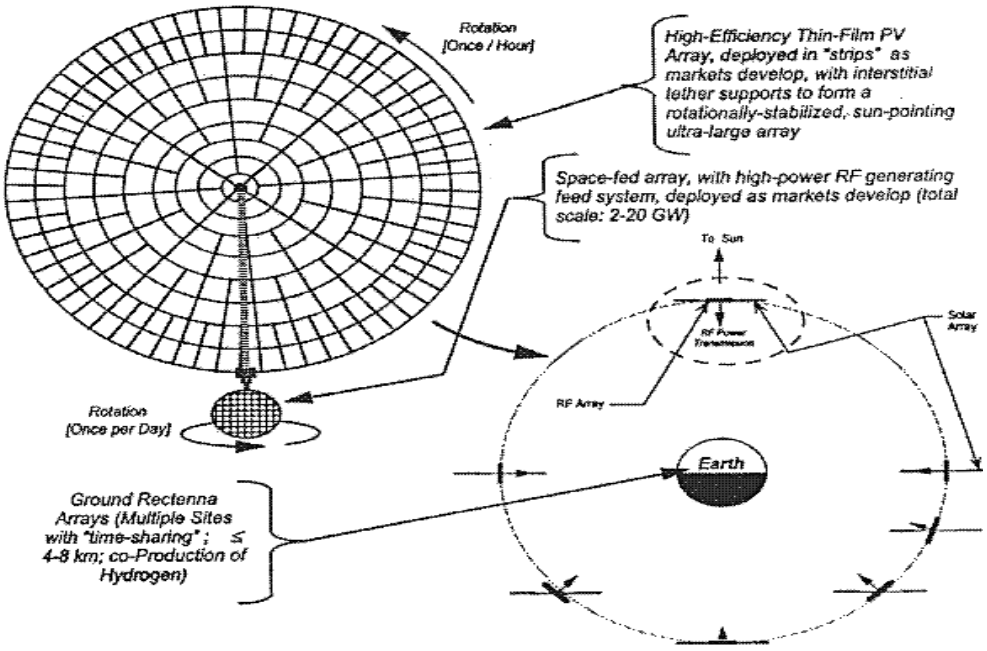
During 1995-1997, NASA conducted a "Fresh Look" study on the Space Solar power Satellite again; several new concepts were discussed in the report. One of them is the "Sun Towel" concept. The "Sun Towel" will be assembled in LEO, and then it will be transported into an elliptic Medium Earth orbit (2000 – 35800km above earth surface). The "Sun Towel" contained multiple circular solar panels, described as leaves. All the power received by these panels will be transport to the "root"; the transmitting panel that is always pointed toward the earth.



The "Sun Tower" SPS Concept [43]

Another concept is the "Solar Disk" concept, it is a single, large-scale GEO-based, RF-transmitting (Radio Frequency) space solar power systems. The satellite contains a large sun-pointing disc and a smaller earth pointing transmitter. Each satellite can provided 5 Giga-watts of energy to earth.

[43] A Fresh Look at Space Solar Power: New Architectures, Concepts, and Technologies. John C. Mankins. International Astronautical Federation IAF-97-R.2.03.



Depiction of a 5 GW "SolarDisc" SPS System Concept [42]

However, all of these are merely concepts, which never have a chance to be tested in real experiment since our funding on the SPS is not sufficient; in 1999, NASA initiates only a 15 million/year program on SPS technologies. [44] On the other hand, in recent year Japan is actually the leading country of the SSPS program. In 2009, Mitsubishi Electric Corp. and IHI Corp. and other companies joined a 2 trillion yen ($21 billion) project in developing the technology for the 1-gigawatt solar station, fitted with four square kilometers of solar panels. Hopefully this satellite would be running in three decades. According to the documentation, one giga-watt is enough to supply about 294,000 average Tokyo homes.

This technology is still under development in Japan, so not much information about this project could be found. But base on the interview with the researcher of this project, Yasuyuki Fukumuro, we know that this will be a geostationary spacecraft which will be able to deliver 1 giga-watts of power, and it will be about 4 square-kilometers in scale. They haven't decided which method of power transmitting technique to use yet, Laser beam or microwave, further experiment is required for this decision to be made. According to JAXA (Japan Aerospace Exploration Agency),

[44] G.L. Kulcinski, "Solar Energy Resources – Orbiting Solar Power Satellites", Nov 21, 2001. National Research Council.

the smaller scale demonstration model is planned to be launched by 2015. And this project is aiming for practical use in 2030s. [45]

Requirement*:*

There are certain requirements that these Space Solar Power Satellites have to meet in order for them to be useful in real scenario.

1. The power provided by these satellites must be compatible with current power plants, including amount and duration.
2. The cost of the power provided must be reasonable, this including the launch cost of the satellite, assembly cost, maintenance cost, etc.
3. The satellite must be easy to maintain and can resist damage cause by other space particles and radiation.
4. The energy transmitting method must be human and environmental friendly.

To satisfy requirement 1, the satellite must be large in scale and operate in geostationary orbit. The SPS 2000 model was failed in this aspect. It was design to operate in the Lower earth orbit, which cannot deliver power to a single location continuously. This is probably the reason why this project was terminated. In theory, the later designs of the SPS are capable of providing more than 1 giga-watts of energy continuously; therefore they are more desirable for government and investors.

However, there is a trade-off between requirement 1 and requirement 2, for large satellites that operate in GEO, they are capable of providing more power, but their launching cost and maintenance cost is significantly higher than small satellite that operate in LEO or MEO, and they will also require much more sophisticated equipment and launching techniques. For example, the Japanese is working on a SPS that is 4 square-kilometers in size. A satellite this large will require special technique to assemble in space. However, there are two approaches to accomplish this, each with its advantages and disadvantages. First approach is to take several launches. First we could transport all the parts of the satellite in LEO (Lower Earth Orbit), and then assemble the satellite by humans, finally perform a Hohmann transfer to send the entire satellite into GEO (The reason for a Hohmann transfer is because of its low cost). This approach is simple and does not require very sophisticated robotic technology. However, once the satellite reach GEO, the maintenance will become difficult since we cannot rely on human to perform these

[45] Yasuyuki Fukumuro, “Practical Application of Space-Based Solar Power Generation”, Japan Aerospace Exploration Agency.

tasks. Furthermore, in the orbital transfer procedure, a satellite this large will likely to be damaged by other space particles. Another approach is transport the subsystem into the final orbit, and then performs the assembly in GEO. This approach will rely heavily on robotic technology, therefore if some small errors occur, we will risk retrieving the entire satellite and launch it again. Comparing to the first approach, the second approach require more advanced technologies, but it also make the launch more convenience and make the spacecraft easier to maintain. If we compare the cost of each one, the first approach will cost less than the second one in short term. But it will make the launching time longer (because Hohmann transfer is slow). On the other hand the second approach might be expensive, but it will save us some time and reduce the risk of the satellite being damaged during the transportation process.

To satisfy requirement 3, we must first advance our robotic technologies and material science technology, but base on what I know, our current technologies already allow us to achieve these goals.

Requirement 4 is the most important one, but it is also the most difficult to satisfy. We will not know what the actual consequence will be unless we experiment it, but the risk of this experiment is too high. For now we still don't know for sure that what kind of consequences will be caused for long term exposure to weak microwave. But one thing we know for sure is that expose to strong microwave will be deadly (Imagine our microwave oven). So in the design of the ground base station, we will need a large earth surface area as the rectenna in order to spread out the 1 giga-watts microwave.

Actually we could do a simple calculation to see what this means. A typical consumer microwave oven consumes 1100 W of electricity in producing 700 W of microwave power. Let's assume all the microwave coming down is turned into electricity (which is far not true, to produce 1 giga-watts of electricity will require several giga-watts of microwaves). So the base area of the microwave oven is about 1/4 square-meter. So an average microwave oven will have a power density of $2800 W/m^2$. If we imagine the whole rectenna is a huge microwave oven, it will still require its surface area equals:

$$\frac{1 * 10^9\ watts}{2800\ watts/m^2} = 357143 M^2 = 0.357 km^2$$

An American football count is about 0.0053 km^2, so the area of the rectenna will be as large as 67 football count combine.

Obvious this is not realistic; we cannot have a huge microwave oven hanging around in the middle of the earth. The adverse effects to animals have been reported at 40-300 W/m^2. [44] Modified the equation and calculate the area require for 40W/m^2 power density, we have:

$$\frac{1 * 10^9\ watts}{40\ watts/m^2} = 25000000m^2 = 25km^2$$

Therefore the area of the rectanna will be at least 25 km^2 big. The city of Worcester is about 100 km^2, so this rectenna will be at least the size of 1/4 of the city of Worcester, MA. This is assuming the efficiency of the conversion is 100%, in real life the size will be 3-4 times larger. Furthermore, the outside perimeter of this rectenna is not habitable. So the perfect location for this rectenna will be on top of the ocean. But this means that we will face the transportation power loss problem again.

Recent NASA Development, the SPS-ALPHA (Solar Power Satellite via Arbitrarily Large PHased Array)

SPS-ALPHA is a method to collect solar energy using a satellite in geostationary orbit (35,786 kilometers above earth surface, ~ 5.6 times of Earth's radius). This satellite will convert the solar energy into microwave and transmit them to earth. SPS-ALPHA uses a large array of individually controlled thin-film mirrors, outfitted on the curved surface of the satellite. These movable mirrors intercept and redirect incoming sunlight toward photovoltaic cells affixed to the backside of the solar power satellite's large array. Then the energy collected from the sun is converted to microwaves which will be transmitted to the on-earth power plant. According to John Mankins, the leader of this project, "If successful, this project would make possible the construction of huge platforms from tens of thousands of small elements that can deliver remotely and affordably tens to thousands of megawatts using wireless power transmission to markets on Earth, as well as missions in space." [46]

[46] David, Leonard, Proposed Satellite Would Beam Solar Power to Earth. SPACE.com's Space Insider Columnist, 06 April 2012.

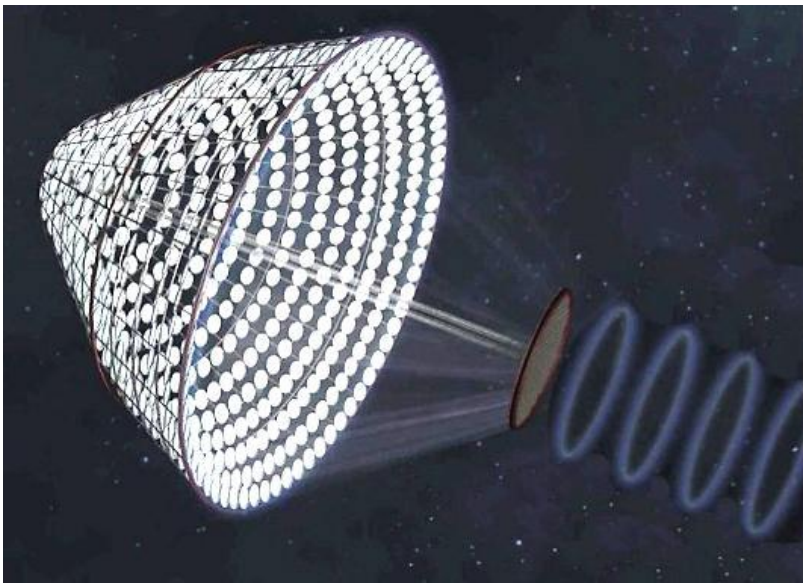


Image from NASA: www.nasa.gov/images/content/590465main_mankins_full.jpg

This satellite is operating in geostationary orbit, so let us first take a closer look at this orbit. As its name suggest, the satellite in this orbit is "stationary," which means that it is always on top of a specific location on earth. This orbit has three restrictions:

1. The centripetal force acted on the satellite must be equal the gravitational force
2. The angular velocity of the satellite must be equal to the earth spin rate
3. The orbit of the satellite is on the same plane as the earth's equator

Constrained by this three restrictions, this orbit will require a specific altitude, which we will calculate using the information that we know.

$$First, the\ gravitational\ force\ F_g\ subjected\ by\ the\ satellite\ can\ be\ calculated\ by$$

$$F_g = \frac{GM_e m_s}{R^2} \qquad where\ R = distance\ between\ earth\ center\ and\ satellite$$

$$and\ equals\ to: \sum F = ma_c\ ,\ \ where\ a_c \equiv Centripetal\ acceleration\ ,\ \ a_c = \frac{v^2}{R} = \omega^2 R$$

$$\sum F = m_s \omega^2 R = F_g \qquad \therefore \frac{GM_e}{R^2} = \omega^2 R = \left(\frac{2\pi}{T}\right)^2 R$$

$$Where\ T = Time\ for\ the\ earth\ to\ spin\ a\ complete\ rotation \quad \therefore \mathrm{T} = 86400\ \text{seconds}$$

with const variables we know: $\mathrm{G} = 6.667 * 10^{-11} \frac{\mathrm{Nm}^2}{\mathrm{kg}^2}$, $M_e = 5.9736 * 10^{24}\ kg$

$$solve\ for\ R\ and\ substitute\ in\ values\ :\ R = \left(\frac{GM_eT^2}{4\pi^2}\right)^{\frac{1}{3}} = 4.223 * 10^7 m$$

$$Altitude = R - R_e = 4.223 * 10^7 m - 6371000 m = \mathbf{35,800}\boldsymbol{km}$$

$$\therefore We\ know\ that\ the\ Geostationary\ orbit\ must\ have\ the\ altitude\ of\ 35{,}800km$$

So what will be the advantage of putting the satellite on 35800km altitude? One advantage is that this satellite will always on top of the same spot on earth, therefore the attitude of the satellite will not require significant adjustment in order to point to the right location. Another more important advantage is it could significantly increases the satellite's operational time since the satellite is always exposed to the sun. So what is the percentage of operational time comparing to the on earth PV-plane collectors (Maximum 50% operational times)? Let's do a simple calculation.

For satellite in geostationary orbit, eclipse season occurs twice a year when the sun is close to the earth's equinoxes (*Equinoxes means when the center of the Sun being in the same plane as the Earth's equator*). The spring eclipse season runs from approximately 26 February until 12 or 13 April (~47 days). The fall eclipse season runs from approximately 30 or 31 August until 15 October (~47 days). The eclipse starts slowly. As the Sun travels from one of the Tropics to the equator, the satellite is blocked for a minute or two, at first. Gradually the eclipse increases until the Sun reaches fall or spring equinox and the satellite, and solar panels, are blocked for 72 minutes. As the Sun continues to travel to the other Tropic, the eclipse time becomes smaller and smaller until the solar panels are again exposed to the Sun 24x7.[47] So assuming the rate of change of the time which the satellite is blocked is constant during those times, and the numbers of days for the sun to approach the equinoxes is equal to the numbers of day the sun is moving away from the equinoxes (both 23.5 days), which both are very reasonable assumptions.

The rate of change of the time which the satellite is blocked can be calculated by:

$$\frac{dT}{dt} = \frac{72\ min}{23.5\ days} = 3.06383 \frac{min}{days} \qquad where: T\ is\ in\ minutes\ and\ t\ is\ in\ days$$

So the times the satellite is blocked can be calculated by the integral:

[47] http://www.intelsat.com/resources/tech-talk/eclipse-seasons.asp

$$\int_0^{23.5} (3.06383)(t)dt = \frac{3.06383}{2}\ (23.5)^2 - 0 = 846\ mins$$

There are 4 equal portions of time which the satellite is blocked in one year, so the total times the satellite is blocked can be calculated by:

$$846\ minutes * 4 = 3384\ \ minutes$$

This is the total times the satellite is blocked from the sun in exactly one year, and there is 525600 minutes in one year. So the percentage of time that the satellite is not operating is

$$\frac{3384}{525600} = \mathbf{0.6438}\% \ \therefore the\ operational\ time\ is\ more\ than\ \mathbf{99.35}\%$$

From this result we know that the satellite on Geostationary orbit can operate nearly 100% of the times, which eliminate the operational time disadvantage of solar power.

So far this idea sounds wonderful, but we have not yet consider its impact on the earth. The earth can be considered as an equilibrium system with an average temperature that is suitable for creatures on earth. When the flow of incoming solar energy is balanced by an equal flow of heat to space, Earth is in radiative equilibrium, and global temperature is relatively stable. Anything that increases or decreases the amount of incoming or outgoing energy disturbs Earth's radiative equilibrium; global temperatures must rise or fall in response. If the SPS-Alpha project is successful, tens to thousands of megawatts of extra energy will be receiving by the earth for each satellite that is launched. This might have an impact on the energy balance of the earth itself, and the earth average temperature will rise in response to this additional energy.

To calculate how much the additional energy will affect the global average temperature, first we need to know how the temperature changes with the received energy. Temperature doesn't infinitely rise, however, because atoms and molecules on Earth are not just absorbing sunlight, they are also radiating thermal infrared energy (heat). The amount of heat a surface radiates is proportional to the fourth power of its temperature.[48] The amount of heat radiated from the atmosphere to the surface should be equivalent to 100 percent of the incoming solar energy. The Earth's surface responds to the extra energy by raising its temperature.

So let's put everything we know together and do an approximate calculation on how much this additional energy will change our average temperature. On average, 89

[48] http://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php

petawatts of solar energy will be absorbed by land and oceans, which will keep the surface at an average temperature of 14 °C (287 °K).[49] And we know that the amount of heat a surface radiates is proportional to the fourth power of its temperature, so we can assume approximately that:

$$\frac{dE}{dt} = K(T_{Absolute})^4 \quad where\ K\ is\ a\ constance\ and\ T\ is\ the\ Temperature\ in\ Degree\ Kelvin$$

$$Solve\ for\ K\ using\ information\ we\ know ==> K = \frac{89 * 10^{15} watts}{(287\ °K)^4} = 1.31178 * 10^7$$

$$Back\ to\ our\ Equation: \frac{dE}{dt} = 1.31178 * 10^7 * (T_{Absolute})^4$$

$$if\ \frac{dE}{dt}\ increase\ by\ 1 gigawatts, assuming\ is\ the\ power\ that\ could\ generated\ by\ 1\ satellite$$

$$we\ have\ 89 * 10^{15} watts + 10^9\ watts = 1.31178 * 10^7 * (T_{Absolute})^4$$

$$Solve\ for\ T_{Abs}\ and\ compare\ it\ with\ the\ original\ value, it\ increase\ by\ \mathbf{8 * 10^{-7}\ °K}$$

This means that for a single satellite that is launched, the average earth surface temperature will rise by $8*10^{-7}$ degree. So this change is significantly small, to get a better understanding, let assume the world's energy consumption (15 terawatts, $15*10^{12}$ watts) will be produced by these satellite:

$$89 * 10^{15} watts + 15 * 10^{12}\ watts = 1.31178 * 10^7 * (T_{Absolute})^4$$

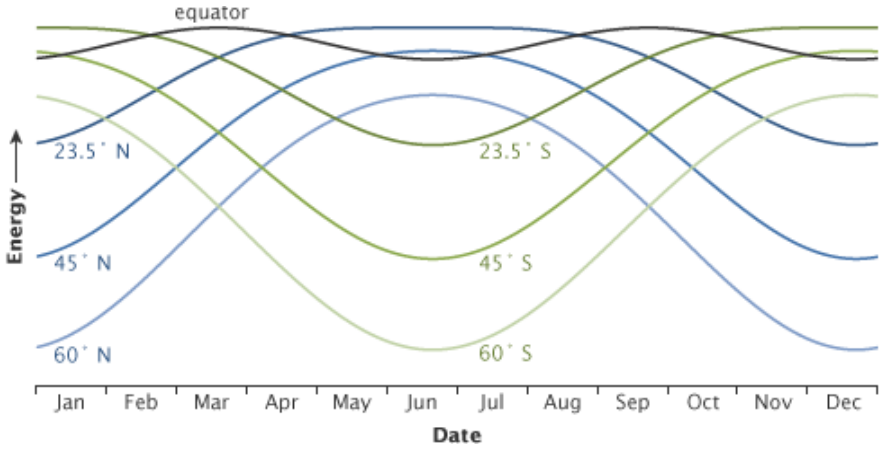
$$Solve\ for\ T, and\ compare\ it\ with\ the\ original\ 287\ °K, we\ see\ that\ it\ increase\ by\ \mathbf{0.0121\ °K}$$

This is assuming 100% efficiency, if the satellites operate in 1/3 efficiency, the temperature increase will be **0.0363** degree, if we also take into account of greenhouse effect (which means that not all energy is directly radiated back to space, some of them will be trapped inside the atmosphere), we will expect this number to be larger. However, this still seems to be a small change even if we replace the entire world's energy consumption with these satellites.

Still, this small change of average temperature can also affect our system, and their consequence will be different depends on where we decided to beam this additional energy to.

[49] Somerville, Richard. "Historical Overview of Climate Change Science" (PDF). Intergovernmental Panel on Climate Change.

First of all, we need to understand how the earth works. The heat received by earth from the sun is not uniform everywhere, the net heating imbalance between the equator and poles drives an atmospheric and oceanic circulation that climate scientists describe as a “heat engine.” The climate is an engine that uses heat energy to keep the atmosphere and ocean moving.



Energy received varies with latitude and times [48]

According to the plot above, we can see that the average energy received from the sun is larger in regions near the equator, and then decrease as latitude increase. This suggests that in area near the equator and tropics, there will be a net energy surplus because the amount of energy absorbed is larger than the amount of energy radiated. If we decided to beam the additional energy to this region, it will only make this problem worse. On the other hand, in area near the poles, there will be an annual energy deficit during winter season because the energy radiated to space is larger than the solar energy received from the sun. Therefore beaming this additional energy to the near-poles regions might sounds like a good idea.

But as I said previously, the earth is a “heat engine” that operations on heat difference between regions, it is “design” this way so that we will experience seasons change, moving winds and ocean current. If we artificially increase the heat (or energy, temperature) in a region where it supposes to be cold, then our climate will be changed and serious consequences will occurs (such as natural disasters). So after all, I think that the risk of this project is high, and I believe that we should not challenge the environment.

However, the above prediction assumes that we can maintain a constant concentration of greenhouse gas in our atmosphere. In reality, there might be a counter effect where as we beam more energy to the earth, the temperature of the earth will become lower. To understand this, first we need to know how the greenhouse gas in our atmosphere

works. As the earth receiving energy from the sun, it also emits the same amount of energy back in order to maintain an energy balance. If without the greenhouse gas in the atmosphere, the amount of energy transmits by sun could keep the earth in an average temperature of -27 degree Celsius. The purpose of the greenhouse gas is to trap heat inside the atmosphere, if the concentration is too high, too much heat will be trapped and the average temperature of the earth will rise, this is the problem we are facing today. But if we completely replace our fossil fuel usage with this SSPS technique, the earth's greenhouse gas will completely disappear someday, and the average temperature will drop to near -27 degree Celsius. Therefore, the difficult part of using clean energy is for us to find the balance and maintain it. We could reduce the amount of fossil energy usage, but we cannot completely replace it.

Another possible design for SSPS

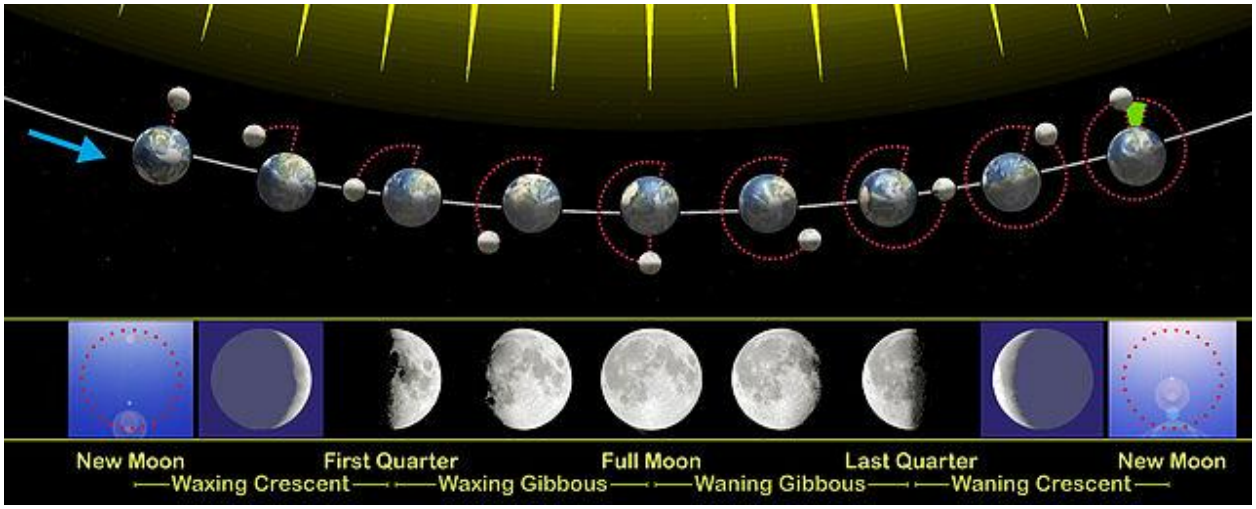
For decades we are designing large scaled satellites to put into space for solar power generation, but most of us forget about our natural satellites, the Moon. The moon is actually a perfect "satellite" for space solar power generation since it is stable, and has a predictable orbit. More importantly, the angular velocity of the moon orbiting around the earth is equal to its own spin rate, which means that one side of the moon will always points toward the earth, no matter which position the moon is in.

On average, the Moon is at a distance of about 385,000 km from the center of the Earth, which corresponds to about 60 Earth radii, with a mean orbital velocity of 1,023 m/s ($2.65714*10^{-6}$ rad/sec).[50] It will take the moon 27.36 days to return back to its original position with respect to earth; this is called the sidereal months.

$$\frac{2\pi}{2.65714 * 10^{-6} rad/sec} = 2.36464 * 10^6 s = 27.36\ days \quad (Sidereal\ month)$$

However, because the Moon's appearance depends on the position of the Moon with respect to the Sun as seen from the Earth, we will usually describe the period of the moon using Synodic month, which we take into account of the angular velocity of the earth orbiting around the sun. Therefore the average length of the synodic month is 29.53days.

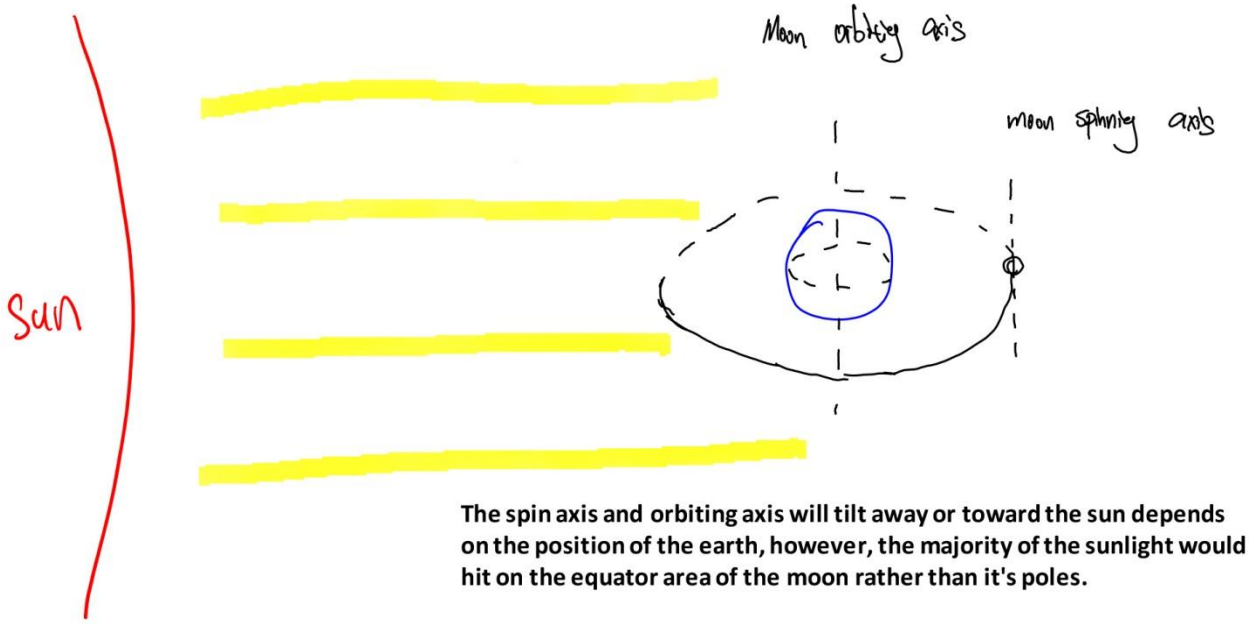
[50] "Earth's Moon: Facts & Figures". Solar System Exploration. NASA. Retrieved 2011-12-09



Moon Phase: From Wikipedia.org

The advantage of using the moon to collect solar power is that we don't need to control its orbit it's orientation since one side of the moon is always pointing to the earth. So my idea is we could build a central power station on that side of the surface, and then transmit all the solar power generated by the moon to this central station. This station can locate the stations on earth using laser beam, and them convert the solar energy generated into microwave and transmit them to the earth station, using the same technique as a regular space solar power satellite.

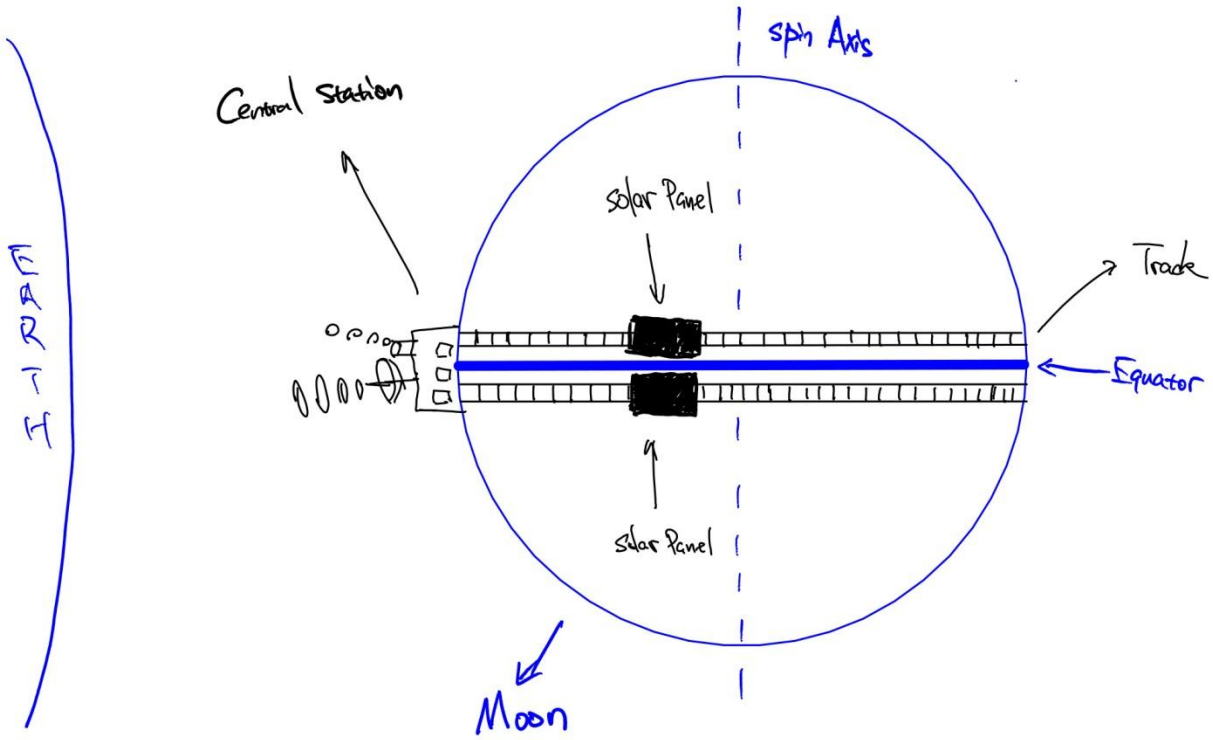
There's another problem, we should we place the solar panels so that they could generate the most power? To solve this problem, first we need to know how the moon is exposed to the sun.



The spin axis and orbiting axis will tilt away or toward the sun depends on the position of the earth, however, the majority of the sunlight would hit on the equator area of the moon rather than it's poles.

We know that the majority of the sunlight will hit on the equator of the moon, but if we put the solar panel in a specific location around the equator, the panels will have maximum power output when the sun is directly on top of it, but half of time it will not expose to the sun at all, therefore we still facing the operational time problem of solar power. If we put a large amount of solar panels around the equator of the moon, the cost would be too high, and it would not be efficient since half of the panel will not be working at a given time.

For this problem, one solution I come up with is we could build multiple tracks around (near) the equator region of the moon. There will be one large solar panel on each track, so that they could move around the equator. All of the tracks will be connected to the central station; therefore the energy collected by this solar panel can be transfer to the central station via these tracks. The solar panels will move to the location where they will always directly under the sun for maximum power output. Below is a figure to show what this would look like.



Solar Panel track on Moon's equator

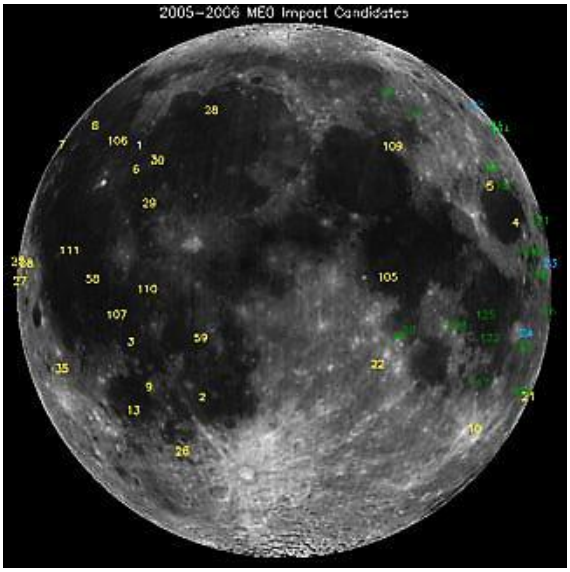
Unfortunately, there will be several problems and difficulties regarding this idea. First is the communication delay. Signal sent to the Moon will take 1.26 seconds to reach the moon, and another 1.26 seconds for it to travel back. Therefore error will exist in the aiming process.

There will also be a transmitting problem in this idea since the moon is too far away from the earth, if we transmit the microwave directly from moon to earth, the wave will spread out and we will not be able to collect it efficiently. To deal with this idea, we could use several stages transmission. We could have several satellites that orbiting between the earth and the moon, and we could transmit the wave through these satellites one by one.

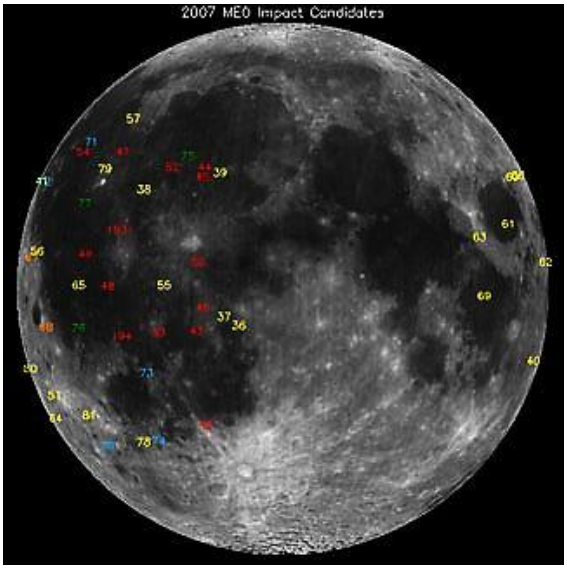
Another problem, or maybe the major problem that limits this idea, is the lunar impacts. On average, 33 metric tons (73,000 lbs.) of meteoroids hit Earth every day, the vast majority of which harmlessly ablates ("burns up") high in the atmosphere, never making it to the ground. The moon, however, has no atmosphere, so meteoroids have nothing to stop them from striking the surface. The slowest of these rocks travels at 20 km/sec (45,000 mph); the fastest travels at over 72 km/sec (160,000 mph). At such speeds even

a small meteoroid has incredible energy -- one with a mass of only 5 kg (10 lbs.) can excavate a crater over 9 meters (30 ft.) across, hurling 75 metric tons (165,000 lbs.) of lunar soil and rock on ballistic trajectories above the lunar surface. Current meteoroid models indicate that the moon is struck by a meteoroid with a mass greater than 1 kg (2 lbs.) over 260 times per year.[51] Therefore we need to carefully pick the central station so that it will not get hit by the asteroids; also we will need to predict the impact sites to protect our solar panels from these impacts. Furthermore, it will require humans or sophisticated robots on the Moon to perform maintenance of the tracks.

So where should we pick the location for the central station? Below is a series of impact locations candidates from the pass. [52]



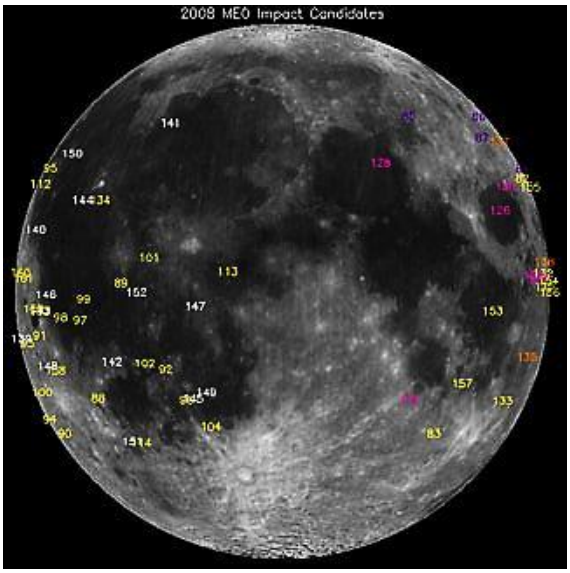
2005-2006 Impact candidates

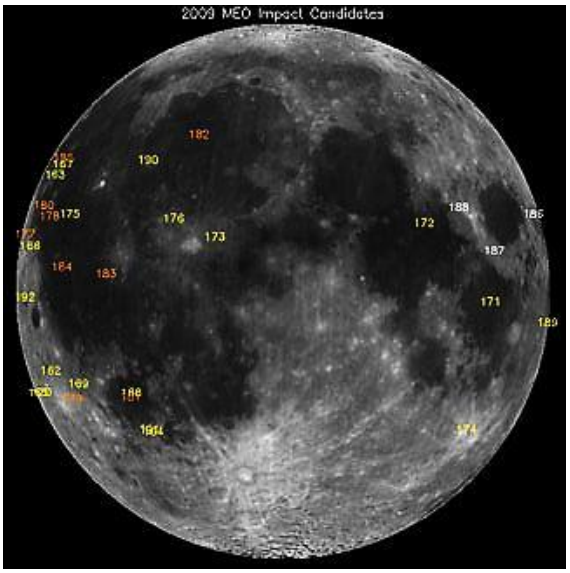


2007 Impact candidates

[51] "Lunar Impact Monitoring", NASA, Marshall Spae Flight Center.

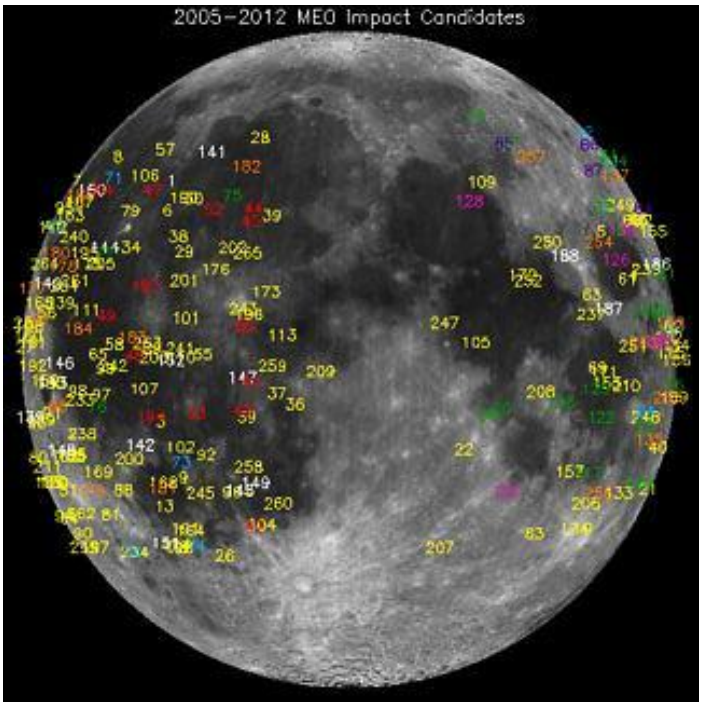
[52] "Lunar Impacts", NASA, Marshall Space Flight Center.





2008 impacts candidates 2009 Impacts candidates

As we can see, the majorities of the impact locations are on the side of the Moon, there are no impacts that happen in the center region. Therefore, the center region of the moon is a good fit for the central power station.

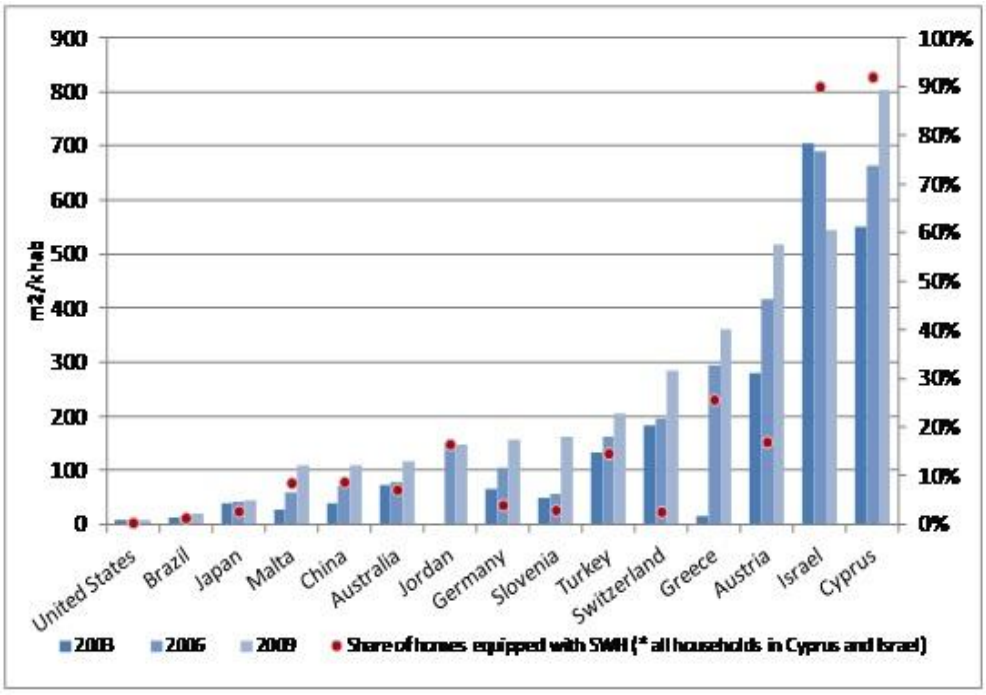


2005 – 2012 Impact Candidates

2.2 Solar thermal

2.2.1 Solar Water Heater

Solar water heating system perfectly represents a kind of mature renewable energy technology that has been well established for many years. It has been widely used in many countries such as Cyprus, Israel, Greece, Turkey, Australia, China and Japan. The following diagram shows the installed capacity of solar water heaters per thousand



Source: Global Energy Data - Enerdata, from EurObserv'ER and the International Energy Agency

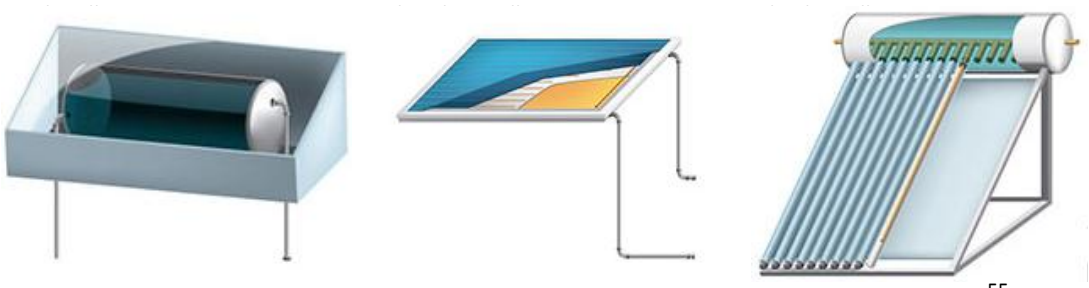
inhabitants and share of homes* equipped.

As you can see from the diagram, Cyprus is the world leader in terms of capacity per capita. Actually, by the time of 2005, 4.5% of the annual energy demand of Cyprus is provided from solar energy. This energy is used mainly in the domestic sector (93.5%) for hot water production. Additionally, 80% of the hotel apartments and 44% of the hotels are equipped with central solar water heating systems. [53] What makes a solar water heater a good investment? Let's first look at how it works.

[53] SOLAR WATER HEATERS IN CYPRUS MANUFACTURING, PERFORMANCE AND APPLICATIONS ,2005, by Soteris Kalogirou

Typically, a solar water heater contains two crucial parts: water storage tank and solar collectors. Three collector types are: batch collector, flat-plate collector and evacuated tube collector. The last one is the most efficient collector among the three. Each tube functions as a thermos in principle: a glass or a metal tube that containing the water or heat transfer fluid is surrounded by a larger glass tube. The space between them is a vacuum, so very little heat is lost from the fluid. [54]This kind of tube can work in winter --- in temperature as low as -40F. Also, it is easy for maintenance since every single tube could be replaced individually. However, at the same time the collector costs twice as

Figure1



the flat-plate collector. (See figure 1 for image of the three types of collector)[55]

There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which don't. Active solar water heating system has two circulating type: direct and indirect, with pumps circulating water or non-freezing heat-transfer fluid correspondingly (See figure 2 for image of active solar water heater). Passive solar water heating systems are typically less expensive than active systems, but they're usually not as efficient. However, passive systems can be more reliable and may last longer.[56] [3]

In Massachusetts, the average amount of solar resource is about 400 watt hour/feet^2 /day. According to the National Renewal Energy Laboratory, with such solar resource, 100,000 square feet of solar panel surface area could generate enough electricity for about 1040 houses (figure 4). With such amount of solar resource, why doesn't every family install the solar water heater? I guess one reason is that people though that money spend on installing such a water heater, plus the cost of the heater itself, is far more than what on the normal pump heater. But is that true in the long run? The

[54] http://www.energystar.gov/index.cfm?c=solar_wheat.pr_how_it_works
[55] http://www.energystar.gov/index.cfm?c=solar_wheat.pr_how_it_works
[56] http://energy.gov/energysaver/articles/solar-water-heaters

following table gives some idea of the cost and payback period to recover the costs in several countries. It does not take into account annual maintenance costs, annual tax rebates and installation costs. However, the table does give an indication of the total cost and the order of magnitude of the payback period. The table assumes an energy savings of 200 kW.h per month (about 6.57 kW.h/day) due to SWH. [57][4]

Costs and payback periods for residential SWH systems with savings of 200 kW.h/month (using 2010 data) Source: http://en.wikipedia.org/wiki/Solar_water_heating

Country	Currency	System cost	Subsidy(%)	Effective cost	Electricity cost/kW.h	Electricity savings/month	Payback period(y)
Brazil	Real	2500[5]	0	2500	0.25	50	4.2
South Africa	ZA Rand	14000	15[6]	11900	0.9	180	5.5
Australia	Aus.$	5000[7]	40[8]	3000	0.18[9]	36	6.9
Belgium	Euro	4000[10]	50[11]	2000	0.1[12]	20	8.3
USA	US$	5000[13]	30[14]	3500	$0.1158[15]	$23.16	12.6
UK	UK Pound	4800[16]	0	4800	0.11[17]	22	18.2

Some people believe that the main constraint in the adoption of solar water heaters is purely economic. With its high initial investment costs and lengthy return on investment period, the adoption rates are closely linked to promotion policies and regulations. Tax credit and direct subsidies are an efficient way to promote solar water heaters. In Greece, tax reductions contributed in raising the capacity per thousand of inhabitants from 20 m² in 2005 to 360 m² in 2009. In Spain, subsidies and mandatory SWH on new buildings raised the capacity per thousand of inhabitants from 13 m2 in 2005 to 47 m² in 2010. The table below shows us the promotion policies for solar water heating in some European countries. (Note: 1k toe = 1000 toe = [1/86]*10^12 Wh, toe = Tons of Oil Equivalent)

[57] Del Chiaro, Bernadette and Telleen-Lawton, Timothy. "Solar Water Heating (How California Can Reduce Its Dependence on Natural Gas)" (PDF). Environment California Research and Policy Center. Retrieved 29 September 2007.

Promotion policies for solar water heating in Europe (selected countries)

Country	Type of measures	Target	Expected CO_2 emission reduction $(ktCO2)^2$
Austria	Rebates Subsidies	169 ktoe by 2020	1,000
Cyprus	Subsidies	90 ktoe by 2020	1,000
France	Tax credit Investment grants	927 ktoe by 2020 4 million homes equipped with SWH by 2020	3,100
Germany	Preferential loans Subsidies	1,245 ktoe by 2020	4,400
Greece	Tax reductions Minimum solar contribution to the hot water supply	355 ktoe by 2020 60% of hot water needs from solar	1,100
Italy	Tax credit Subsidies	1,586 ktoe by 2020	5,000
Portugal	Subsidies Tax reductions Preferential Loans Mandatory SWH system on new buildings	160 ktoe by 2020 + 100,000 m^2/year until 2020 1 m2/occupant in new buildings	510
Spain	Minimum solar contribution to the hot water supply	644 ktoe by 2020 10 million m^2 by 2020	2,300
Source	ENERDATA, from National Renewable Energy Action Plans, International Energy Agency and REN21		

Outside of Europe, China and India are implementing ambitious solar thermal policies, setting targets of 300 million m² by 2020 and 20 million m² by 2022, respectively. Subsidies are currently the main lever to promote solar water heating, but other incentives are under consideration. Some towns like Kunming (YunNan) and DeZhou (ShanDong) in China have set targets to accelerate the development of solar water heating (50% of buildings with solar hot water by 2010), while Shenzhen mandated SWH in all new residential buildings. India is planning to offer preferential loans and to make solar water heaters mandatory on new buildings.

In the USA, where the market is still underdeveloped, SWH systems benefit from a 30% federal tax credit, while some States have also implemented credits and rebates. I hope that USA will come up with more promotion policy that could really leading a trend of using this kind of cost effective and environmental friendly water heater. It definitely would bring a huge benefit in the long run.

Figure 2

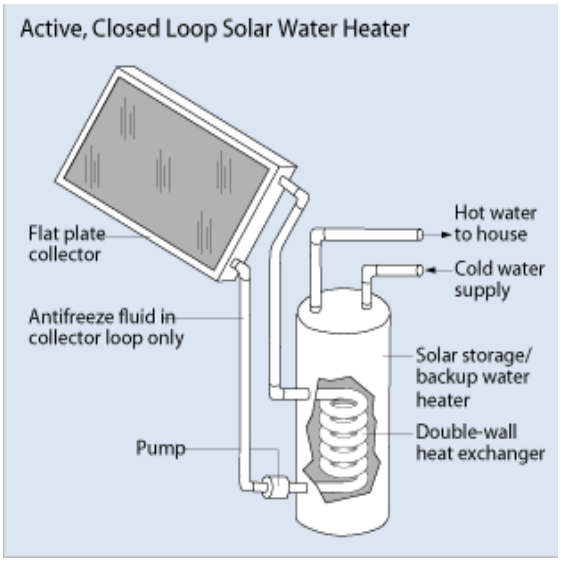
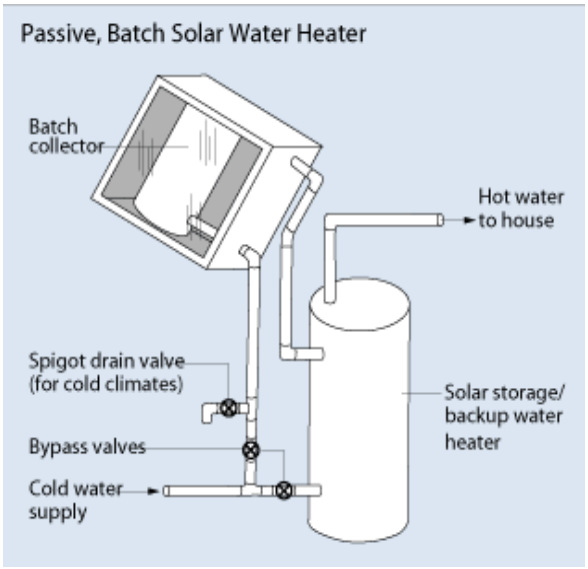


Figure 3



Source: http://energy.gov/energysaver/articles/solar-water-heaters

2.3 Jet Stream

Jet streams are fast flowing, narrow air currents found in the atmospheres. The main jet streams are located near the tropopause, the transition between the troposphere (where temperature decreases with altitude) and the stratosphere (where temperature increases with altitude). [58] Two jet streams exist in each hemisphere: the "polar jet stream", found over the mid-latitudes at altitudes of 7-12 km, and the weaker "sub-tropical jet stream", found near ± 30º at greater altitudes (10-16 km).Despite seasonal shifts, the jet streams are relatively persistent features of the mid-latitudes in both hemispheres. The total wind energy in the jet streams is roughly 100 times the global energy demand.[59] Could we harness the wind energy within jet stream and convert it to a form of energy that could be used in our daily life?

Some scientists doubt about it. In one of the major scientific articles about jet stream power, Miller, Gans and Kleidon claim that the jet streams can generate the total power of only 7.5 TW and along with catastrophic climate impact. They used a simple thought experiment of geostrophic flow to demonstrate why high wind velocities of the jet streams are not associated with a high potential for renewable energy generation. However, I personally think that there should be some way to harness the energy from jet stream because the wind is always there. If there something could "catch" the wind, or "feel" the force from the wind, we will finally harness the energy. This reminds me of the kites flying in the sky. What if we use a huge kite and fly it in the high altitude so that it could "catch" the jet stream? Actually, people begun to make rigorous technical analysis of kites for generating electricity since about 1980. Till now, there are 10 different companies around the world doing research more building prototypes of kites that could generate electricity [60]. Among all these companies, I amazingly found out that a group people in Italy are flying a big kite right now and they actually achieved something.

2.3.1 Kite Gen

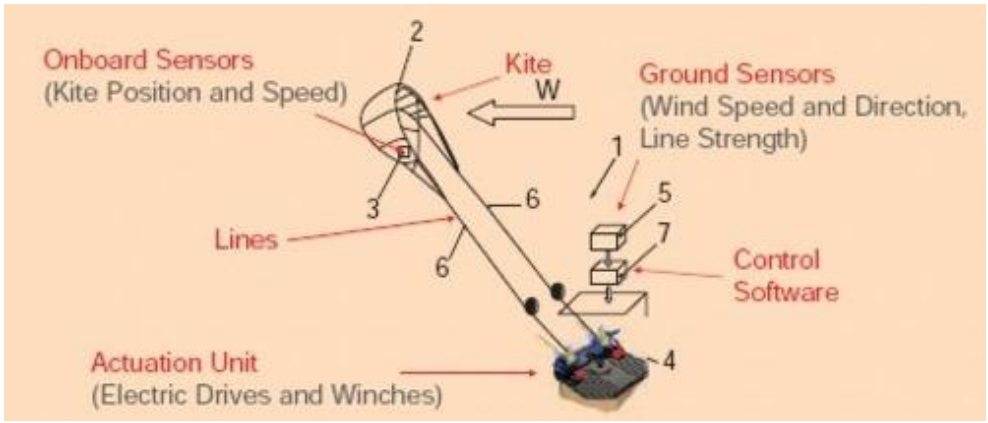
People from a Turin-based startup called Kite Gen Research and, as their name implies, they are trying to generate electricity by flying big kites high above the sky. The design contains airfoils as kites that measure about 50 square meters (about 538 feet) and ground-based generator connected with each other by two lines made by a

[58] United States Department of Energy (26 June 2002). "Ask a Scientist". Retrieved at May, 5th 2008.
[59] Roberts, B.W.; Shepard, D.H.; Caldeira, K.; Cannon, M.E.; Eccles, D.G.; Grenier, A.J.; Freidin, J.F. Harnessing high-altitude wind power. *IEEE Trans. Energy Convers.* **2007**, *22*, 136-144.
[60] Robert Creighton, Kite, IEEE Spectrum, Decemer 2012

polyethylene material (shown in figure 2.3.1-1). According to Kite Gen's president and founder Massimo Ippolito, since higher altitude winds blow more constantly than those at ground level, the winds he's targeting are available for 6,000 hours a year. The Kite Gen transfers energy mechanically via its unraveling strings (shown in figure 2.3.1-2). Two strings reel out from spinning drums attached to alternators – Kite Gen calls the units "STEMS". Once the wind pulls out the full length of the strings, one of the strings tugs on one end of the kite, pulling it back down for about 20 seconds, and then releasing it back to the wind for about two minutes, in a yo-yo motion. [61] Each STEM has 8 alternators, combining for capacity 3.2 megawatts, which is enough for a small utility scale generation.

Figure 2.3.1- 1

Figure2.3.1- 2
Source:http://krisdedecker.typepad.com/photos/uncategorized/2008/08/05/kitegen_kite_wind_energy_3.jpg



[61] http://www.science20.com/mark_halper/kite_energy_leveraging_jet_stream_renewable_power-93059

Some other people are even inspired by Kite Gen. They come up with an idea of using a cluster of kites tethered to a central rotor that is fluttered in the air to a distance of over a mile. When the powerful winds hit the kites, the twirl sets the rotor in motion. A radar system is there to take care that the kites don't come in way of the aircrafts or the birds.[62] By controlling the position of the kites in the air, the turbine could keep spinning (see figure 2.3.1-3 & 4).

Figure 2.3.1-3, Source: http://www.sciencedirect.com/science/article/pii/S0360544208002569

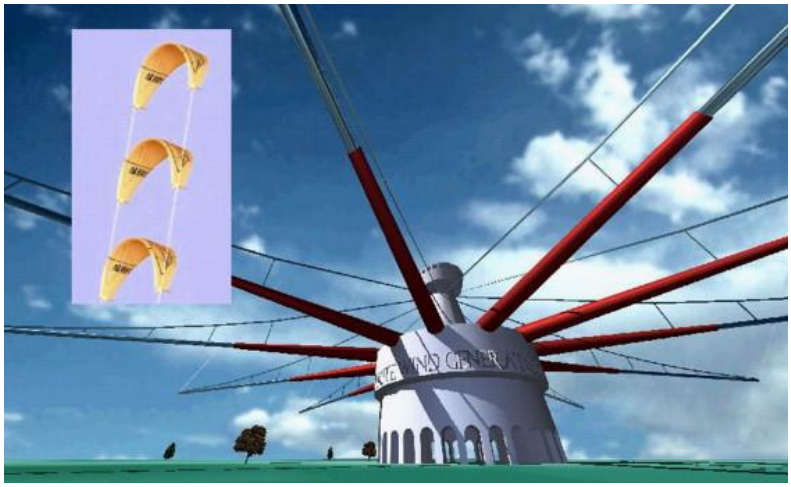
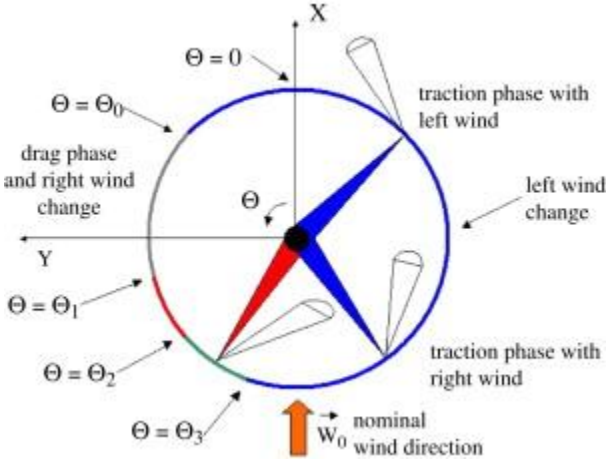


Figure 2.3.1-4, source: http://www.sciencedirect.com/science/article/pii/S0360544208002569

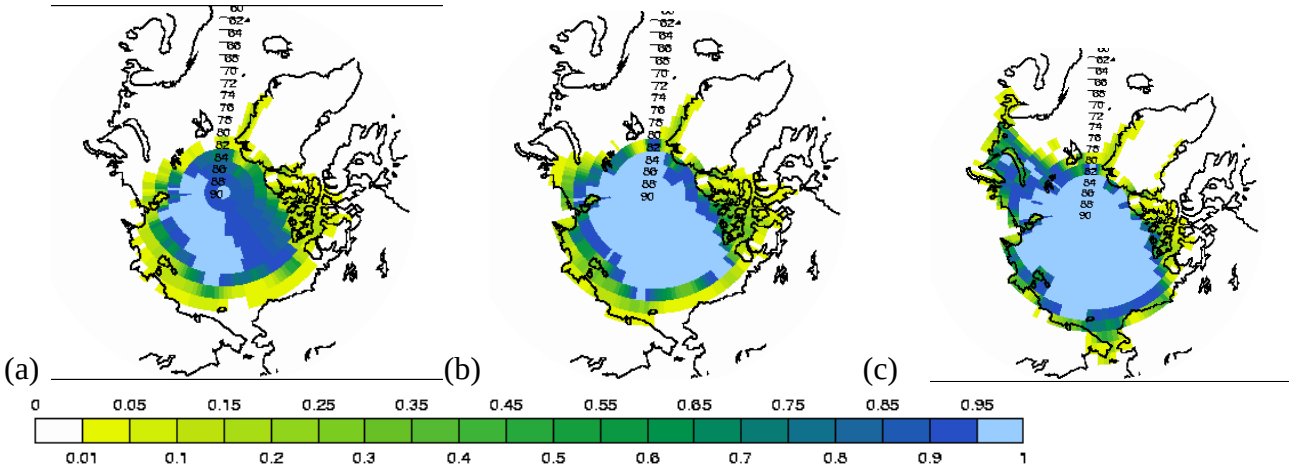


However, the impact on climate does exist. Archer & Caldeira designed a worst case scenario in which high-altitude devices were laid out uniformly throughout the atmosphere at densities varying between 1 and 10,000 m^2 of turbine area per km^3 of atmosphere (lower limit represents roughly the device density needed to supply the

[62] http://www.sciencedirect.com/science/article/pii/S0360544208002569

world's electricity demand). As a result, the earth's surface would cool down, and sea ice cover increased (see figure 2.3.1-5).[63]

Figure 2.3.1- 5 Source: Archer, C. L. and Caldeira, K. Global assessment of high-altitude wind power, IEEE T. Energy Conver., 2, 307–319, 2009.
Fraction of surface area covered by sea ice near the North Pole from climate simulations with increasing density of high-altitude devices throughout the atmosphere: (a) 1 m2/km3, (b) 100 m2/km3, and (c) 10,000 m2/km3.

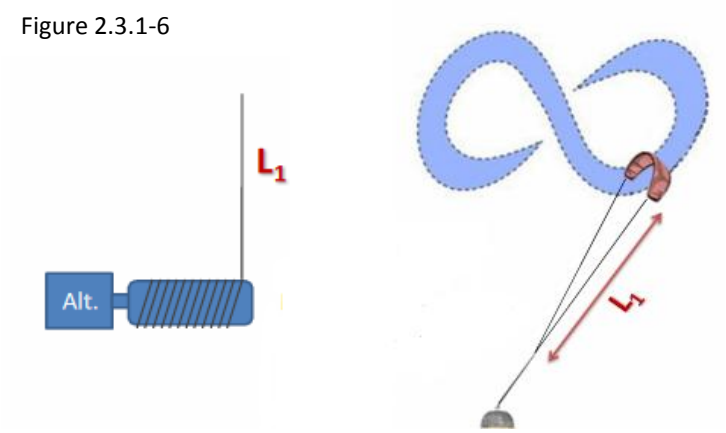


How KiteGen Works

Let's look at how KiteGen operates. The origins of the KiteGen idea is the functioning called the "Yo-Yo" cycle. Traditional wind turbines are subject to a structural limit and so they will hardly reach a great height with higher and steadier wind. Given that in a traditional wind turbine 80% of the power is generated by the external part of the bladed (20% of its whole length), the idea behind the KiteGen concept is that of taking just the most productive section of the blade up in the air, controlling it through a pair of "ropes" in the same way as acrobatic kites. In the meantime, set the generator also on the ground (inside the structure that controls the kite). As original turbines, KiteGen produces electric energy through alternators. Inside the KiteGen Stem (the part on the ground) each cable is wound around a drum directly connected at the rotor of an alternator, which also function as electric motors to control the tension on the ropes and therefore the flight of the kite. During the flight, wind pressure creates a strong tension on the cables and causes the rotation of the drums, generating electricity (see Figure 2.3.1-6 below).

[63] Archer, C. L. and Caldeira, K. Global assessment of high-altitude wind power, IEEE T. Energy Conver., 2, 307–319, 2009.

Figure 2.3.1-6



Source: www.kitegen.com/en/2012/07/24/interactive-presentations-functioning/

In the "Stem" configuration the wing pull the cables that, through a pulley system, activate the alternators on ground, which in turn produce electricity. When the production phase ended and cables are entirely unwound (shown in Figure 2.3.1-7 below), the wing is guided to a position where it loses its wind resistance (the slideslip maneuver shown in Figure 2.3.1-8) and the cables are wound in to restore the initial conditions. Energy consumption of the winding phase is a minor fraction of the energy generated during the unwinding phase.[64] This whole production cycle is called "Yo-Yo".

Figure 2.3.1-7

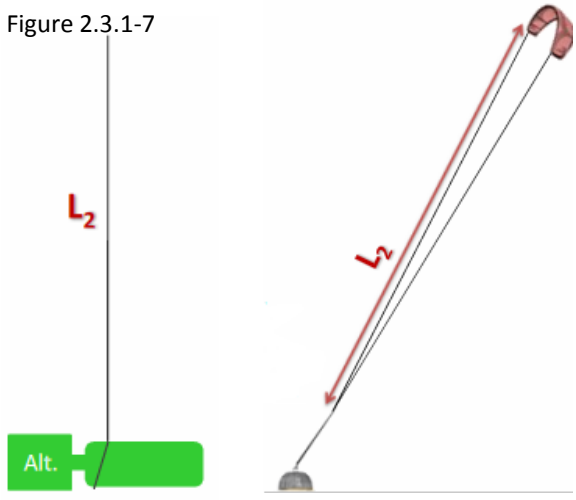


Figure 2.3.1-8

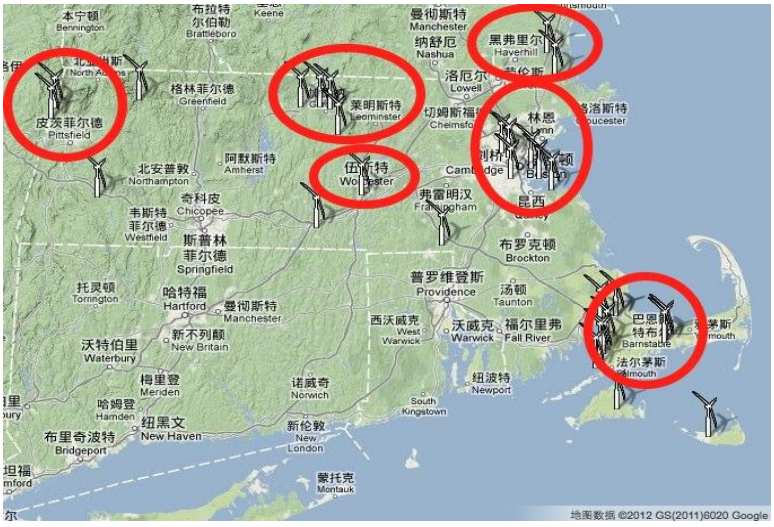
Source: www.kitegen.com/en/2012/07/24/interactive-presentations-functioning/

64 http://www.kitegen.com/en/products/stem/

2.3.2Future Scenario

The kite would reach the height of 2000 meters to "meet with" the steady wind. It can generate 1000 million watt per megawatt hour, which means that the net amount of electricity that the machines generates equals to 1000 – 1 = 999 million watt (999 megawatt) each hour[65]. The cost of electricity generated by KiteGen is 20 euro (almost $26) per megawatt hour, as the average price of electricity in European country is 80 euro. Also, the cost of the whole utility is 360 thousand euro (about $46771) plus limited space[66]. Let's do a simple calculation. In 2010, the electricity usage of Massachusetts is 602,178-megawatt hour, and the average retail price is 14.26 cents per kWh ($142.6 per megawatt hour). Suppose the US government purchase and use KiteGen to generate electricity in Massachusetts, it could save the whole state 602,178 * (142.6 - 26), equals to more than **$70,000,000** a year. Since transporting electricity will cause great loss, we would like to set several "KiteGen site" in the state. Figure 2.3.1-9 below shows the locations of wind farms in Massachusetts. If we pick the 6 major ones to build the new wind farm with 9 KiteGen Stem which covers a square area of 2.5 hectare[67], it would cost $46771 * 6 * 9 = **$2,525,634** to build them ---- not even close to the saving that made by KiteGen in just one year! Although there are more aspects to concern about, such as the cost of re-built, cost of training and hiring professionals for KiteGen, maintenance and so on… I believe the advantages far outweigh the disadvantages in this case.

Figure 2.3.1-9



Source : http://www.masscec.com/index.cfm/cdid/12451

[65] http://wenku.baidu.com/view/2aa145976bec0975f465e2e3.html
[66] http://www.kitegen.com/en/2012/09/21/kitegen-and-alcoa-updates/
[67] http://www.kitegen.com/en/technology/faq/

2.3.3Environmental Concern

Besides the profit that KiteGen could bring to people, I think of the environmental issue, which people are more worried about. First of all, will this big kite killing birds in the sky? Several studies suggest that compare to other anthropic causes (power lines, pesticides, cars, buildings with windows, etc.), overall bird deaths due to wind turbines is not significant at all. Specific and detailed analysis will have to be conducted for the Kite Gen power plants, but the "higher operative height of the power kites appears to be a positive factor", with the consideration of that the speed of the lines' movement decreases as they get closer to the steering units at ground level. [68]

It seems that the noise is not a problem either. On KiteGen's website, it says, "The ground systems can be compared to a low speed railway with good soundproofing (50 dB at 200 m distance)". Also notice that we could almost ignore the noise produced by the aerial part.

Personally I believe KiteGen is a very environmental friendly electricity generator; not to mention in a global scale, wind power generation methods produce "zero" CO_2, or other greenhouse gases.

[68] http://www.kitegen.com/en/technology/environmental-concern/

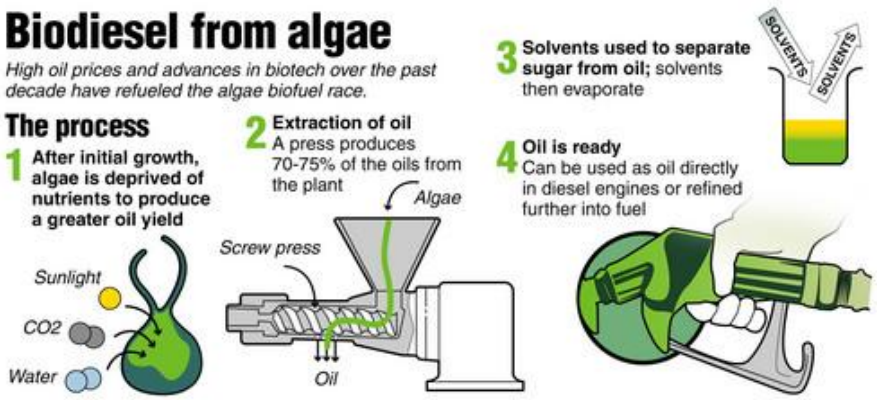
2.4 Bio Fuel

2.4.1 Algae as Biofuel

Biofuel is a good alternative energy for coal, oil and natural gas. Among all kinds of biofuel that we already drew attention to, algae is said to be “one of the most promising feedstock” for biofuels. [69] (Also see Figure 2.4.1-1 for oil yield information) Algae are organisms commonly found in aquatic environments. The large multicellular macro algae show up in ponds and in the ocean. They can grow to more than 100 feet in length. Microalgae are tiny unicellular organisms that grow as suspensions in water; they are measurable in micrometers. They are frequently found in bogs, marshes, and swamps.

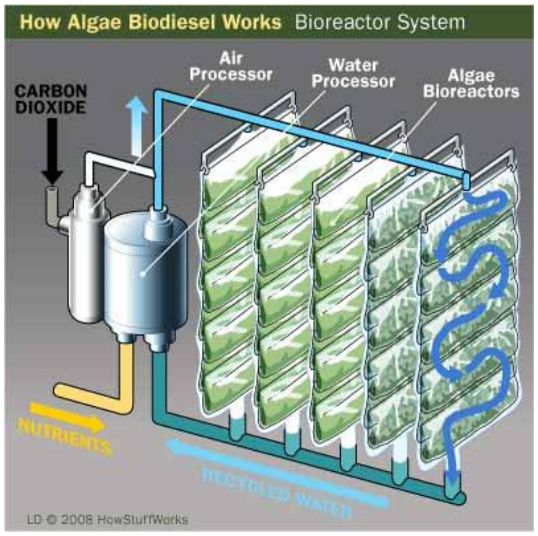
All algae require sunlight, water, nutrients, and carbon dioxide to grow. Through the process of photosynthesis, algae convert the carbon dioxide into glucose (a sugar). The glucose is then broken down into fatty acids, which under normal conditions, are used to produce membranes for new algal cells. If, however, the algae are starved of nutrients, the fatty acids produce fat molecules (oil). Most algae do not produce much oil unless they are physiologically stressed, which is to say deprived of one or more of their basic requirements for growth.[70] In the process of extracting energy from the sun, algae "can double their size in a day, making them among the most efficient organisms at converting light energy into biomass".[71] Oil is then extracted from the algae, creating a product "almost chemically indistinguishable from light, sweet crude oil, except that it is green in color".[72] The following figure shows the process of how to get biodiesel from algae:

Figure 2.4.1-1 Source: oilgea.com, MCT Photo Service



[69] *An Outlook on Microalgal Biofuels*, by Rene H. Wijffels and Maria J. Barbosa, *Science*, 2010, Vol329
[70] http://www.education.com/science-fair/article/producing-algal-oil/
[71] Nowak, Rachel. Bring on the Second Generation of Biofuels. *New Scientist* February 2, 2008.
[72] Hiserodt, Ed. Algae May Be an Energy Answer. *The New American* August 18, 2008.

The algae can grow in open pond where is the most natural place that they can gain energy from the sun. However, the open-air also brings bacteria and bad weather that can kill-off the algae. People then found a way to grow them in closed system known as a photobioreactor. By using the method called “vertical growth/closed loop production” (shown in figure 2.4.1-2), people can produce algae faster and more efficiently than open pond growth. As shown in figure, the algae are placed in clear plastic bags where they can be exposed to sunlight in both sides while gaining water and CO_2 from the system.



Source: How Algae Biodiesel Works: A Bioreactor System LD © 2008 HowStuffWorks.com

The lipid, or oily part of the algae biomass can then be extracted and converted into biodiesel through a process similar to that used for any other vegetable oil, or converted in a refinery into "drop-in" replacements for petroleum-based fuels. The algae's carbohydrate content can be fermented into bioethanol and biobutanol. One great use of algae oil is as jet fuel. Rising jet fuel prices are putting severe pressure on airline companies,[73] creating an incentive for algal jet fuel research. The International Air Transport Association, for example, supports research, development and deployment of algal fuels. IATA's goal is for its members to be using 10% alternative fuels by 2017.[74]

Virgin Galactic was the first airline to fly with biofuel when its Boeing 747-400 flew from London to Amsterdam on Feb 28, 2008, carrying in one of its four fuel tanks 20 per cent of biofuel. In November 2011, United Continental flew an aircraft between Houston and

[73] More airlines fold as fuel prices soar: IATA. News.asiaone.com. Retrieved on 15 April 2012.
[74] Alternative Fuels. Iata.org. Retrieved on 15 April 2012.

Chicago on a fuel mix of 60 per cent jet fuel and 40 per cent algae-based biofuel. Alaska Airlines has also started operating flights using a mix of 80 per cent conventional jet fuel and 20 per cent biofuel derived from used cooking oil or fast-food restaurant discards.[75]

The problem is biofuels are currently too expensive and too scarce for them to be successful commercially. Supercritical extraction of algae oil requires high-pressure equipment that is both expensive and energy intensive. To overcome this obstacle, governments needed to foster research into new energy sources and refining processes. One new technology we already know is Enzymatic extraction. It uses enzymes to degrade the cell walls with water acting as the solvent; this makes fractionation of the oil much easier. In 2006 it cost $3,000 to produce a gallon of algae oil, the price fell to $250 per gallon in 2007, now in 2012, the price hits $26 per gallon.

Besides the costs of extracting, Algae oil also has advantage of friendly to environment. There is no need for fresh water to cultivate algae. It can be grown using either marine water or wastewater. One more good news is that algae need CO_2 for their growth. For capturing CO_2, algae are fed with industrial emissions after the removal of sulfur dioxide. Algae utilize the CO_2, which are dissolved in the water (bicarbonates) as a source of carbon and grow. To grow 1 T of algae about 1.8 T of CO_2 is required. (Becker, 1994)

Crop	Oil Yield Gallons/acre
Corn	18
Cotton	35
Soybean	48
Mustard seed	61
Sunflower	102
Rapeseed/Canola	127
Jatropha	202
Oil palm	635
Algae (10 g/m^2/day at 15% TAG)	1,200
Algae (50 g/m^2/day at 50% TAG)	10,000

(http://www.greenchipstocks.com/articles/investing-algae-biofuel/253)

[75] http://algaebiodiesel.com/iata-pushes-for-greater-biofuel-use-by-aircraft

Composition of algae oil

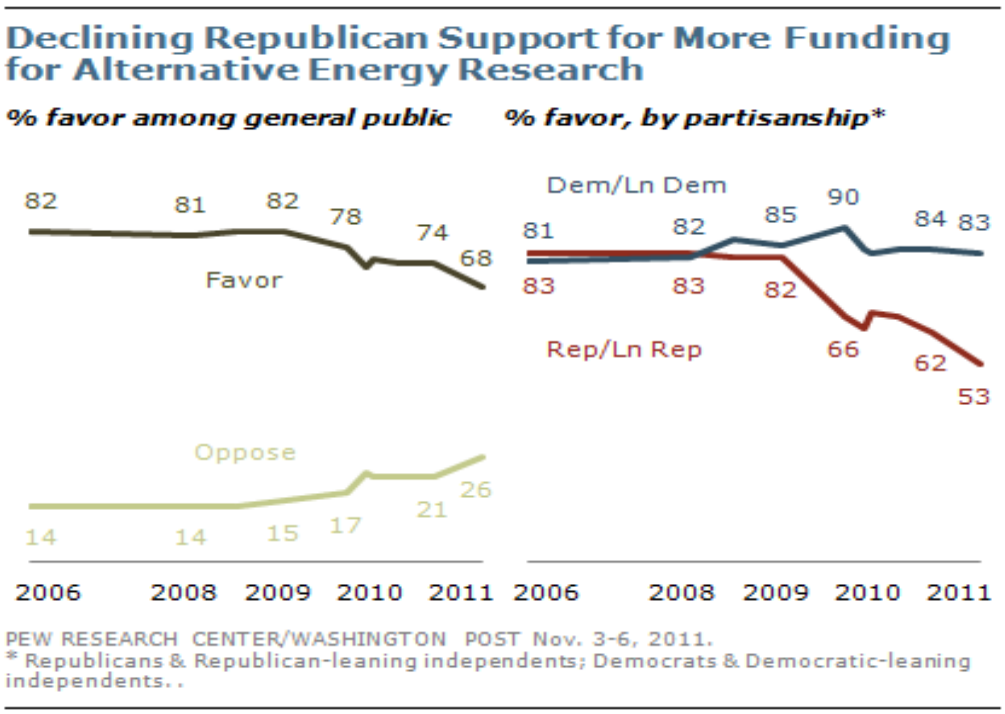
component	**composition**
Lipids	45-55%
Neutral lipids	58.5% of the lipid mass
Phospholipids	22.9% of the lipid mass
Galactolipids	10.9% of the lipid mass
Isoprenoid hydrocarbons (including β-carotene)	7.0% of the lipid mass
Aliphatic hydrocarbons (straight chain and methyl-branched C17 and C19 hydrocarbons)	5.2% of the lipid mass
Fatty acids:	
Palmitic	20.6%
Linolenic	12.5%
Linoleic	10.7%
Palmitoleic	7.8%

Reference: NREL, ASP

Chapter3. Fossil and Renewable Comparison

Considering the fossil energy is running out, why is the renewable energy source was not widely used in our society? There might be two reasons involved. The first reason is our technologies are not sophisticated enough to use renewable energy source effectively. Second, the general public might not want to switch to renewable energy because of all the advantages that fossil energy can provide.

In the history of energy, people switched from burning wood for energy, to burning coal, oil and gas. The reason for this change is because this fossil fuel can provide more energy and more efficient, also they are more suitable for modern machinery. People don't want to switch to renewable energy because they are not willing to abandon the efficiency and convenience of fossil fuel, and they don't want to invest large amount of money to develop other form of energy that are less efficient. According to the report by Pew research center, the amount of people that support the development of alternative energy has decrease for 82% to 68% from 2006 to 2011.



So, what are the pros and cons of both fossil energy and renewable energy? To consider this question, we need to consider their effectiveness, economic, and environmental impact simultaneously.

Consider their effectiveness; I think that we could all agree that fossil energy is more efficient and more convenient comparing to renewable energy since we have spent more than a century to develop machineries that are specifically designed for fossil energy. In order to replace fossil energy with renewable energy, we have to consider redesigning most of the modern machineries such as internal combustion engines and turbines. Replacing all the fossil energy with renewable sounds impractical, how about we consider replacing half of the fossil energy with renewable source? Recent estimate suggest that replacing half of the coal, oil and gas consumed today would require 6 terawatts of renewable source, but renewable today can only produce just 0.5 terawatt. So, one simple solution comes up; we have to increase the total production of renewable energy.

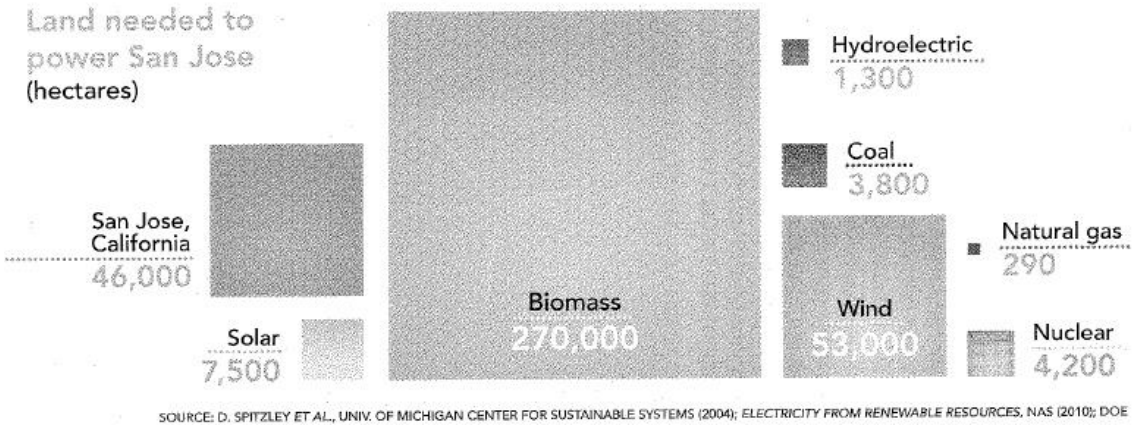
Unfortunately increasing the production of renewable energy is not that easy. Renewable energy is not very efficient comparing to fossil energy because they are too spread out; collecting them would require large earth surface. The "Power density" *(which is defined by the amount of energy produced per square meter if the earth surface)* of Coal mine or oil field yields 20 to 200 times more power per square meter of earth surface than solar facilities, 200 to 100 times more than wind farm, and 100 to 1000 times more than biomass plant. [76]

Power Source	Power Density (W/m2)	
	Low	High
Natural Gas	200	2000
Coal	100	1000
Solar (PV)	4	9
Solar (CSP)	4	10
Wind	0.5	1.5
Biomass	0.5	0.6

Power density comparison chart by Vaclav Smil, May 14 2010

Below is an image to visualize it. From the image we could see that the area require powering the entire San Jose, California by wind or biomass is even larger than the area of the city itself. From this we could see that why replacing all the fossil energy with renewable energy is impractical base on the current technology: we simply don't have enough land.

[76] Smil, Vaclav. *Power Density Primer: Understanding the Spatial Dimension of the Unfolding Transition to Renewable Electricity Generation.* May 2010



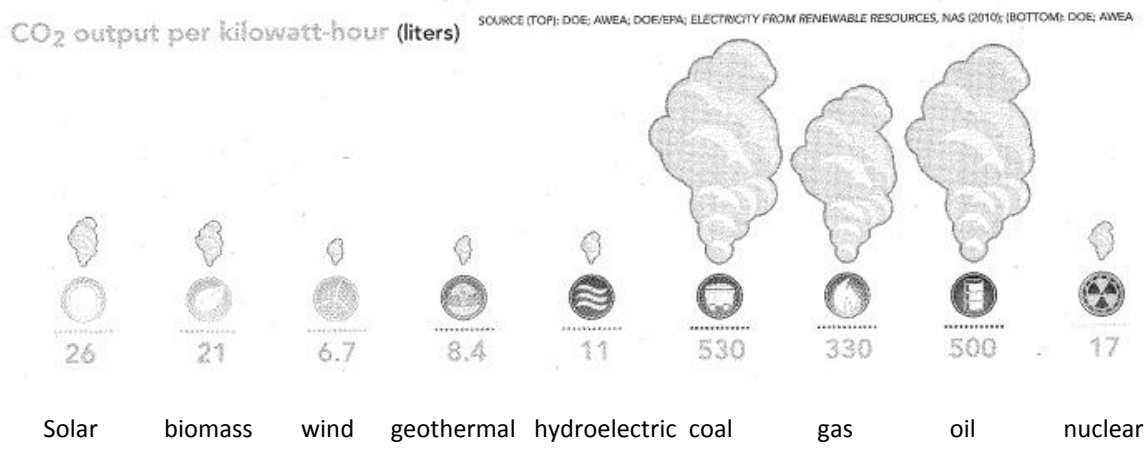
If land is our only problem, how about we put the wind turbines to someplace far away, such as the surface of the ocean? In fact, the WPI Aerospace Engineering department has been working on this kind of wind turbine as an MQP for several years, but the major problem for this is they are difficult to stabilize in deeper region because it requires long and strong cables that could reach the bottom of the ocean. Also the energy generated is difficult to transmit to the mainland because the energy loss is huge considering the distant that the electricity has to travel. This brings up another problem for renewable energy; the energy generated by renewable source is difficult to store and transport. Unlike the fossil energy such as coal and oil, they are dense and "nicely" pack, that's why they can be stored easily. On the other hand, energy like wind and sunlight are impossible to store, their intensity is only depend on the geographic location. Unfortunately, many of the windiest and sunniest places are uninhabited. Also, the renewable sources are not operating 24/7, for solar power, the Sun is guaranteed to be unavailable half of the times, so storing the excessive energy while the renewable power plant is operating is essential. The only way to store the renewable energy is in the form of electricity, but the battery for storing electricity is expensive and not very effective, that is why the price of the renewable energy is much higher than the price of fossil energy.

In the economic perspective, renewable energy also could not compete against fossil energy. First, in order to use renewable energy effectively, large amount of money must be put into the development, whereas our fossil fuel system has been continuously perfected over the years. Secondly, the cost of the power generated by renewable source is significantly higher than fossil fuel. According to IEA (International Energy agency) statistics, the average cost for coal and gas to produce electricity is US$65/MWh and US$70/MWh, the cost for solar photovoltaic is from US$226 to US$2031/MWh and the cost for on-shore wind-generated electricity is from US$50-US$165/MWh.It seems that the cost for wind generation is not so much higher than coal, but in fact the

production of electricity is not stable, and this electricity must be transported to a more populated area, which will increase the cost of generation. Therefore, the large cost difference might be the main reason why the general public does not support the development of renewable energy.

So what can we do to reduce the price of renewable energy so that it could be accepted widely? First, our technologies must be improved in order to use renewable more effectively, one way to do that is to convince the government and private companies to invest more money into the development of renewable source, but this might take a long time. Another way that could be done sooner is to provide electricity that was generated by wind power to on-shore residents instead of electricity that was generated by fossil energy source. But this way would just be beneficial to a small amount of people; it would not improve the situation significantly.

The environmental perspective is where renewable energy shows its advantage. Study suggests that Coal-fired electric power generation emits around 2,000 pounds of carbon dioxide for every megawatt hour generated. Using renewable source can greatly reduce the harmful gas emission, reduce the greenhouse effect, and improve health of human and other animal.



But there are also some negative environmental impacts causes by renewable power generation. One is the noise produced by wind turbine. People that live near the wind turbine will constantly complain about this situation. If we try to slow down the turbine to reduce the noise, the power generated by the wind turbine will decrease. Another negative impact is wind turbines will kills hundreds of birds or bats per day, which might cause the imbalance of the environment. Third, wind turbine will cause signal/radar interference, which might affect the safety of air travel.

To sum up, both fossil and renewable energy have their advantage and disadvantage. Fossil fuel is the main reason for our global warming, but renewable fuel is too expensive and too land consuming. In general, fossil energy might be more appealing than renewable energy in short term. However, someday the fossil energy will eventually dry out and people will be forced to use other kind of available energy source regardless. On the other hand, renewable energy at first seems unattractive comparing to fossil energy, but its advantage will continue to show as our technologies improve. Furthermore, human will be forced to use renewable energy sooner or later, why not start early and do as little harm to the environment as possible.

Chapter4. Solutions for current energy crisis

There are three major energy problems we are facing right now. The first one is the increasing energy demand; according to the table below, since 1990s, the world energy consumption has increased by 40%, and statistic suggests that the demand will continue to increase in the next few decades. The second problem is how we are going to satisfy this increasing demand, while our fossil energy resources are running out. The final problem is the environmental impact on producing this energy.

Regional energy use (kWh/capita & TWh) and growth 1990–2008 (%)[8][9]									
	kWh/capita			Population (million)			Energy use (1,000 TWh)		
	1990	2008	Growth	1990	2008	Growth	1990	2008	Growth
USA	89,021	87,216	−2%	250	305	22%	22.3	26.6	20%
EU-27	40,240	40,821	1%	473	499	5%	19.0	20.4	7%
Middle East	19,422	34,774	79%	132	199	51%	2.6	6.9	170%
China	8,839	18,608	111%	1,141	1,333	17%	10.1	24.8	146%
Latin America	11,281	14,421	28%	355	462	30%	4.0	6.7	66%
Africa	7,094	7,792	10%	634	984	55%	4.5	7.7	70%
India	4,419	6,280	42%	850	1,140	34%	3.8	7.2	91%
Others*	25,217	23,871	nd	1,430	1,766	23%	36.1	42.2	17%
The World	19,422	21,283	10%	5,265	6,688	27%	102.3	142.3	39%

Source: IEA/OECD, Population OECD/World Bank

We need to take multiple perspectives into account when considering the solution for these challenges. For economic perspective, we cannot just raise the energy price to reduce the usage; this will introduce serious economic issue. Also, we need to consider our social pattern, we cannot shift people's social pattern radically in order to meet the energy requirement. Moreover, we need to consider the environmental impact; we cannot just increase the energy production significantly to meet the current energy demand. Therefore solving our energy problem isn't just about producing more power or using less, is about getting the most out of what we already have.

One of the most effective solutions to solve our three major problems simultaneously is to increase the efficiency of energy usage, production and transmission. We could start with the small things that might be neglected by most of the people. Increase efficiency of small things such as light bulbs could have a very big impact. According to the light bulb comparison below, LED will be the most efficient bulb, and cost the least in long term. Comparing the efficiency of LED and CFL with Incandescent, both LED and CFL's power consumptions are much lower than Incandescent. So if we replace all the Incandescent light bulbs with LED or CFL, the electricity consumption will reduce greatly.

	LED	CFL	Incandescent
Light bulb projected lifespan	50,000 hours	10,000 hours	1,200 hours
Watts per bulb (equiv. 60 watts)	10	14	60
Cost per bulb	$35.95	$3.95	$1.25
KWh of electricity used over 50,000 hours	300/500	700	3000
Cost of electricity (@ 0.10per KWh)	$50	$70	$300
Bulbs needed for 50k hours of use	1	5	42
Equivalent 50k hours bulb expense	$35.95	$19.75	$52.50
Total cost for 50k hours	$85.75	$89.75	$352.50

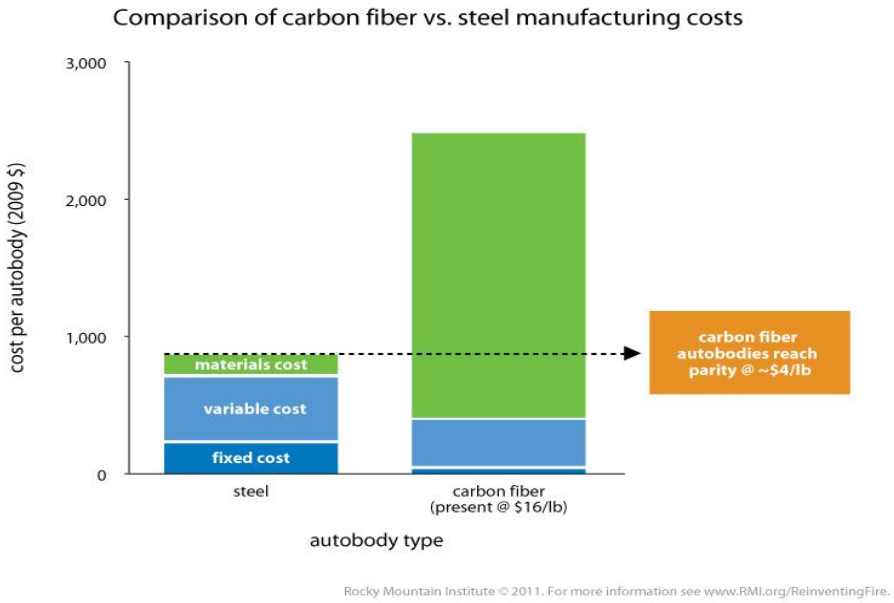
(Source: http://eartheasy.com/live_led_bulbs_comparison.html)

Construct more efficient buildings is another way for saving energy. An efficient building has reflective roofing which makes a better use of daylight. The building has high-performance windows and extra insulation in walls, ceilings, and floors, so it reduces air leakage through the building envelope. Today, a zero energy home can be built for as little as $165 sq/ft and some green buildings have yielded $53 to $71 per square foot back one investment.

Most family in America has more than one car, and people always concern about the oil price. Some stores (such as Pricechopper near WPI) give customers oil discount on money spending in store to attract more business. Actually the drivers themselves can save much more than the discount if they know some “tips” of fuel efficiency. One of the most obvious involves ensuring proper inflation of one's tires. In fact, automobile manufacturers are exploring electronic remote monitoring of tire pressure as one method to ensure fuel efficiency. Keeping tires properly inflated may lower gas mileage by 0.3 percent for every 1 psi drop in pressure of all four tires. Another method is to drive sensibly to limit frequent and intense stopping and starting, the most fuel-intensive driving activities. Excess weight on a car and excessive idling will also cause a waste of oil. Some cars have cruise control, and it can reduce the usage of oil on highway. A little saving of each person can accumulate into a huge contribution to the entire society. If the driver license test adds some fuel efficiency question in the future, drivers may have a better sense of saving energy.

Nowadays three forth of the oil consumption goes into transportations, if we could find a way to increase the efficiency of mobile transportations, we could significantly reduce oil consumption. Today the typical mobile vehicle on the street was made of steel, which is heavy and inefficient. In general, two third of the energy it take to move a typical car is cause by its weight. Therefore, reducing the weight of vehicles could

dramatically reduce oil consumption. One inspiration we got from the Dr. Lovins was using ultralight and ultra-strong material such as carbon fiber composite to manufacture mobile vehicles. Using this material not only significantly reduce the weight of vehicle, but also increase safety since it can absorb up to 12 times as much crash energy per pound as steel does. Using carbon fiber to manufacture car allow it to operate in lower power, therefore reduce the size of engine (which also reduce weight) and make electric propulsion for mobile vehicle possible, which reduce the consumption of oil even more.



One disadvantage of using carbon fiber composites to manufacture vehicles is the material cost is much higher than steel. Above is the comparison of the price between steel and carbon fiber. As we can see, the total price for a complete auto body using carbon fiber is about 2.5 times as the price for using steel.

Here comes another question, how are we going to make everyone abandon his/her cars for these new efficient mobile vehicles? One of the strategies is to let people know that how much money they could save in the future. Recent estimate suggests that hybrid vehicles will use 50% less fuel than traditional vehicle. If you planning on driving this car for the next few years, the money saved on gas is huge. Also, burning less fuel means less carbon dioxide emission, which can reduce the Greenhouse Effect. The next strategy is to let the manufacturer allow customers to exchange their less efficient vehicle for a more efficient one with some additional fee depending on the condition of the vehicles. This would make people switching to more efficient hybrid vehicle, and the manufacturer can refurbish the old vehicle and improve their functionality, and release this improved vehicle into the market again.

Only increasing the car efficiency is not enough. According to the Futurist Magazine, The Texas Transportation Institute has found that in the United States alone 2.3 billion gallons of gas is wasted each year in traffic jams. This bring out another issue, in order to increase the transportation efficiency, we have to find a way to minimize the amount of traffic jams. The solutions that were proposed by the Futurist magazine involving driver robots and teleportation seem unrealistic for current technologies, but there are some other solutions that could improve the situation. First solution is to upgrade the traffic lights. The typical U.S. traffic signaling system is 30 to 40 years old. And the result of this inflexible signaling traffic is a lot of needless idling and the lack of easy adaptability in most cases to either sudden events like traffic accidents or even daily events like traffic congestion in a certain direction at a particular time. We could engineer a new kind of traffic light that could dynamically change the time period of each color base on the current traffic condition, so that it could control the cars come from different direction based on current traffic condition.

However, poorly designed traffic lights are not the main reason for traffic jams on highway. In order to reduce the amount of traffic jams on highway, we need to use another approach. Based on our observation, it is the bottleneck region near the highway exit or entrance that slows traffic down. If we could locate these regions and improve them, we will significantly reduce the traffic jams on the highway.

Another appropriate solution involves reducing the amount of vehicles on the road. We suggest lower the public transportation fee to encourage people using public transportation instead of driving their own vehicles. Moreover, we could introduce a new tax on using the toll road, and use this additional tax on the development of renewable energy technologies. Both these method could reduce the amount of vehicles on the road and improve the traffic condition.

Increasing power generation efficiency is another way of “getting more out of what we already have.” Nowadays 45% of the total electricity in the US is generated by coal, so increase the efficiency of coal-firing power plant can reduce the energy demand problem. Also, increasing efficiency means burning less coal, which will also reduce the amount of carbon dioxide emission, alleviate the Greenhouse Effect. Recent studies suggest that the coal-firing power planes in the US is operating in about 33% efficiency, which means that two thirds of the energy we use into power generation was lost into the atmosphere mainly by heat transfer. If we could find a way to capture this lost energy and use them into something useful, we could significantly increase the total efficiency.

The efficiency of the power plant is defined by:

$$\eta = \frac{\text{Power our of the cycle } (\dot{W}_{cycle})}{\text{rate of chemical energy into the cycle}}$$

$$Where\ \dot{W}_{cycle} = \ Total\ power\ generated - \ power\ used\ by\ equipment$$

Therefore in order to increase efficiency, we could either increase the power out of the cycle or decrease the chemical energy into the cycle (which means burning less coal). The chemical energy used in the cycle is mainly adding heat to the air or steam so that they could have sufficient momentum to move the heavy turbine. One ways to reduce this chemical energy required is to raise the flow temperature before the combustion process. The technique to do this is called regeneration, which means that using the exhaust heat to preheat the flow before it enters the combustion chamber so that less energy is require in the combustion process. Implementing this technique in power plant could bring up the efficiency by up to 10%, which is a very good number.

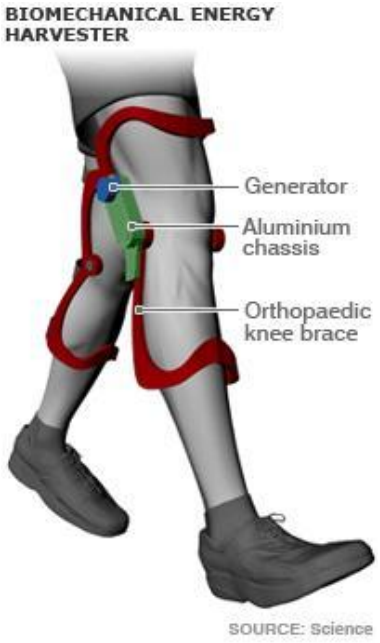
Another way to increase efficiency is to increase the power out of the cycle, but since the amount of power generated is hard to change, the easier way to do this is by reducing the power used by equipment. A process call intercooling can make this happen. Intercooling means that reducing the flow temperature before it enters the second compressor; therefore reduce the work needed to compress the flow into a desirable pressure ratio.

But the major disadvantage of these methods is it requires replacing the power plants' equipment or at least upgrade them, which is a huge cost. However, since many of the US power plants are very aged and inefficient, it might be a good opportunity to consider these options.

On the other hand, it will be misleadingly simple if we answer the question "How we'll fuel our future?" using this two-sided debate: We either have to produce more energy or use less. This answer is lack of consideration since it ignores a basic thermodynamic truth: you can never make use of 100 percent of the energy you consume. Something is always lost in the conversion from fuel to the actual work. While that may sound like bad news, it also introduces a third way to address future energy needs. For example, when you walking down the street, the energy fuels you come from the sun and are stored by photosynthesis in the form of chemical bonds [77]. "It turns out that food has about 100 times as much energy per unit mass as lithium batteries," says Max Donelan,

[77] Popular Mechanics, December 2011, We're throwing away energy... By Alex Hutchinson

head of the Locomotion Laboratory at Simon Fraser University in Vancouver, British Columbia. This means a person can store, in average, as much energy as a 1-ton battery can. But we lost much of it when converting those chemical bonds into muscle contractions. The remainder is used to accelerate and decelerate limbs --- and that deceleration can be scavenged to generate power much like the regenerative braking in hybrid cars: Donelan has developed a lightweight (three-and-a-half pound) knee brace that can generates 12 watts of power from the simple act of walking for one minute, and 12 watts of power is enough to give a cell phone 30 minutes of talk time.



Source: http://medgagget.com/2008/02/knee_brace_generates_electricity.html
http://www.eurekalert.org/pub_releases/science/2008-02/donelan-02-08-08.html

But that energy comes with a price. Donelan said that the knee brace alone, without all the energy scavenging technology, would cost at least $1000; so don't expect to pick one up at Wal-Mart for charging your cell phone anytime soon. Still, market of such a product exists. The initial market would be the off-grid power users such as backwoods hikers and the military. The later is undoubtedly a better potential market, as long as the government would like to have such an investment. Soldiers can pack 30 pounds of batteries for a 24-hour mission [78]. All those batteries add up to an equally astonishing $57,000 per soldier per year in battery costs. Imagine a marching band in practice; since the brace takes no extra effort from the person using it, it's definitely a way of killing

[78] Knee brace Harvests 'negative work' Feb 8, 2008 http://physicsworld.com/cws/article/news/2008/feb/08/knee---brace---harvests---negative---work

two birds at once. We could even put it into prisons for prisoners doing exercise every day. Maybe one day in the future, there will be a kind of community service called "walking/running for electricity".

Other than using our "knee power", there are other ways of turn what we're throwing way into energy that we could use. Everyone must have noticed the heat released by our laptops when it's been running for hours. Although we install little fans for cooling them down, for data center and supercomputers the inefficiencies that warm our laptops become huge problem. Why use more energy for "blowing away" energy that could have been used? The Department of Energy's Oak Ridge National Laboratory brought us a new pyroelectric device that can solve the problem. Pyroelectric material can be repeatedly heated and cooled for generating usable electrical power. Comparing to devices we have, using pyroelectric generators for generating electricity has many advantage including potentially lower operating temperatures, less bulky equipment, and fewer moving parts. [79]

If one considers these as "iceberg above sea level" of all the power we are throwing away, we can move our attention to power transmission. The outmoded, inefficient copper wiring is both our power infrastructure's backbone and a major source of waste. During transmission, we losses squander about 7 percent of the electricity, and traffic jams on the grid waste billions of dollars a year.[80] With superconducting wire, we could conduct 100 times the current across supercooled lines as much on copper cables with virtually no loss. The only problem is the technology has not ready yet. In the meantime, this reflects that we're trying too hard on finding new technology or new energy source to "fill-up" the consumption. What have been neglected is that more and more energy was wasted through our daily routine, and we do have ways to make the most of what we have now.

[79] Kouchachvili, L; Ikura, M (2007). "Pyroelectric conversion—Effects of P(VDF–TrFE) preconditioning on power conversion". Journal Of Electrostatics 65: 182.doi:10.1016/j.elstat.2006.07.014
[80] Popular Mechanics, December 2011, We're throwing away energy... By Alex Hutchinson

Chapter5. The future of energy

5.1 Introduction

Energy is a worldwide issue which can never be ignored. Do we have enough energy? What energy are we going to use in 50 years? I think the energy in the future will have the following aspects.

Diversity

World energy structure has undergone the fire wood, coal and oil. Now natural gas has a trend to become the main energy. At the same time, water power, nuclear energy, wind energy, and solar energy are also more widely used. Sustainable development, environmental protection, and cost of energy determine the global energy diversification. In some areas, gas stations have replaced the trend of coal-fired power stations, and Natural gas consumption will steadily increase. In the future, new energy and renewable energy will be valued at the same time developing conventional energy. According to the 2010 EU renewable energy development plan, wind power needs to achieve 40 million kilowatt and water power needs to reach 105 million kilowatt. At the beginning of 2003, the British government announced the energy white paper which states that the proportion of renewable energy power generation of British power from the current 3% to 10% by 2010, and to reach 20% by 2020.

Clean

With the new energy technology and more strict environmental standards, the development of future energy will be further to the direction of cleanness. Not only the process of energy production has to be clean, but also energy industry should continue to produce more and better clean energy. The proportion of clean energy consumption among total energy consumption will gradually increase. In the world energy consumption structure, the proportion of coal will decrease from the current 26.47% to 21.72% in 2025, and natural gas from the current 23.94% to 28.40% in 2025, the proportion of oil will remain at 37.60% ~ 37.90% level. At the same time, "dirty" energy such as coal and traditional energy (fire wood, straw, waste utilization) will be developed to be clean. Clean coal technology (such as coal liquefaction technology, coal gasification technology), biogas technology, biological diesel technology will catch a breakthrough and be widely used. Some countries, such as France, Austria, Belgium, and the Netherlands have shut down all domestic coal mines and to develop nuclear power. They believe that nuclear power is more efficient and clean, which can solve the problem of greenhouse gas emissions.

High Efficiency

The efficiency of world energy processing and consumption has huge difference in different countries. The energy efficiency potential is tremendous. As the new technologies are developing, the efficiency of future energy will improve, and the energy intensity will gradually reduce. For example, in 1997 dollars constant plan, the world's energy intensity was 0.3541 tons/thousand dollars in 1990, which had been reduced to 0.3121 tons/us dollars in 2001, and 0.2759 tons/thousand dollars in 2010. The estimation is 0.2375 tons/thousand dollars in 2025.

Globalization

According to the world energy resources distribution and the imbalance of the demand distribution, countries and regions are getting more and more difficult to rely on their own resources to meet the domestic demand. They need to rely on resources supplied by other countries or regions. World trade is getting wilder and bigger, and the volume of trade is increasing as well. With oil trade as an example, the world petroleum trade was 1.22 billion tons in 1985 which increased to 2.12 tons in 2000 and 2.18 tons in 2002. The average annual growth rate of petroleum trade is about 3.46% which is more than the rate of world oil consumption (1.82%). In the foreseeable future, the world oil net imports will gradually increase. The process of globalization for the world energy supply and consumption will speed up, and the world's major energy producers and energy consumers will actively join the market in the process of globalization.

Marketization

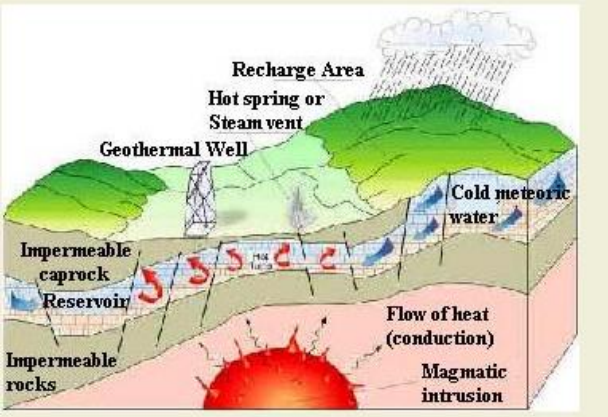
With the development of world economy, market is the best way to reach the goal of optimization and allocation of the international energy resources. Governments around the world will reduce the behavior that intervenes directly in energy utilization, and the government will serve more for energy market. Governments should perfect their energy laws and regulations to provide better energy market environment. At present, countries with rich energy resources are constantly improve its national energy investment policy and administrative measures.

5.2 Alternate Energy Sources for the Future

5.2.1 Geothermal Energy

What is geothermal energy?

Geothermal energy is the hidden energy in the interior of the earth, and it emits almost no greenhouse gases ("Geothermal", 2012). The enthusiastic cycling water tube and the magma can cause heat energy to the table when they violate to the earth's crust. At some other places, the steam brings the heat energy to the surface. Permeable and porous rocks trapped the rising hot water and stream under a layer of impermeable rock, and it can create a geothermal reservoir which stores the heat energy. A geothermal reservoir can reach temperatures of 370 Celsius degrees which is a powerful source of energy.



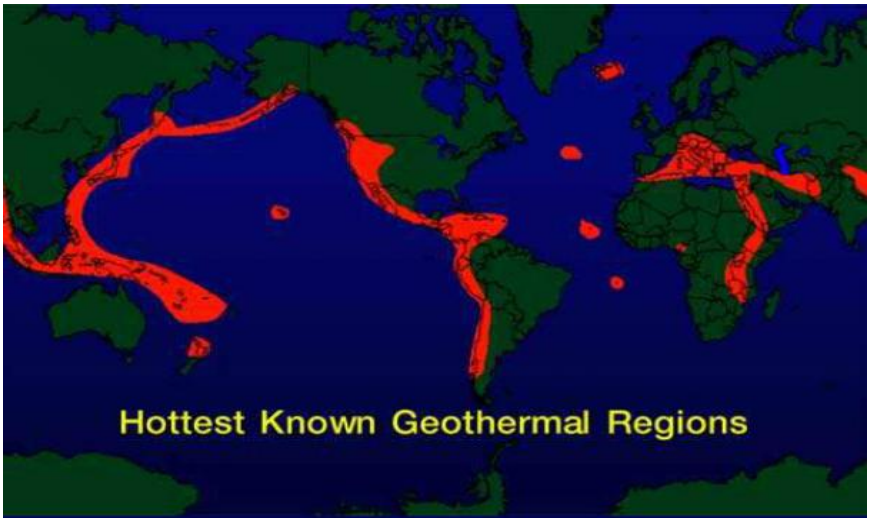
(Picture source: http://www.renewables-in-school.eu/worksgeothermal.html#1-1)

As I introduce geothermal energy to others, people may want to ask why they should know about geothermal energy and what benefits they can gain from geothermal energy. Nowadays we cannot avoid using fossil fuels, but they are damaging people's living qualities at the same time. Geothermal energy is a clean renewable energy, and the earth contains a large number of them. Thus, making use of geothermal energy is necessary for us and it can become one of the ways to solve energy problems.

Exploration & Drilling

As we know, geothermal energy exists under the ground. If I want to invest money to a geothermal project, where can I find the energy and how deep should I drill? Some visible features of geothermal energy are volcanoes, hot springs, geysers and fumaroles. Researchers cannot see most geothermal energy since usually it is deep underground.

Many areas have available geothermal resources, especially countries along main plate boundaries where earthquakes occur frequently ("geothermal energy", 2012). Five areas -- Circum-Pacific geothermal belt, Mediterranean Himalayas to tropical, The Pacific tropical, Red Sea-Aden Bay-East African Rift geothermal belt, and other geothermal belt, distributes the geothermal energy resources.

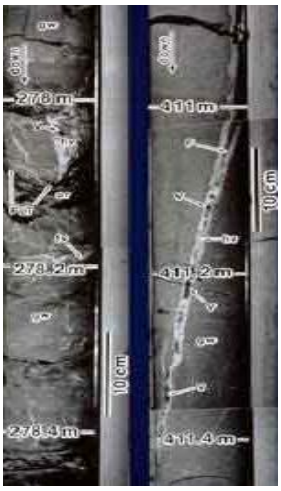


(Picture source: http://geothermal.marin.org/geopresentation/sld015.htm)

As long as I find the geothermal areas, I will wonder which spot I can start my project. Can I set my driller anywhere in the 'hot' areas? In order to reduce the risk for finding profitable geothermal energy, as the 'investor', I need to explore and investigate to find the perfect place to start drilling. Exploration often starts from the analysis of satellite images. Other conventional methods used for geothermal exploration are

- volcano systematic studies -- geologists explore volcanic regions to find the most promising areas for geothermal energy;
- geologic and structural mapping – geologists examined the rocks in the test area, and created geologic maps, which showed rock type and ages in different colors;
- geochemical surveys – researchers collect data from electrical, magnetic, chemical and seismic;
- geophysical surveys – geologists and drillers study the obtained data to determine whether to recommend drilling.
- hole drilling – the investigators drill a small-diameter hole with a truck-mounted rig about 200 to 4000 feet deep to determine the temperatures and underground rock types.

Now, drilling is the only way to discover if a geothermal reservoir is suitable for commercial use. First, investigators drill a "temperature gradient hole". They bring up rock fragments and long cores of rock from the hole and then measure the temperature at a depth. Geologists examine the cored rock marked with depth markers.



(Picture source: http://geothermal.marin.org/GEOpresentation/sld029.htm)

Within 15km under the earth's surface, geothermal temperature increase 2 Celsius degrees by every 100m. From 15km to 25km, the temperature increases 1.5 Celsius degrees by every 100m. This temperature effect will strengthen the drilling of a larger well. Production-sized wells require large drill rigs and can cost as much as a million dollars or more to drill.

(Picture source: http://www.gradient.com/)

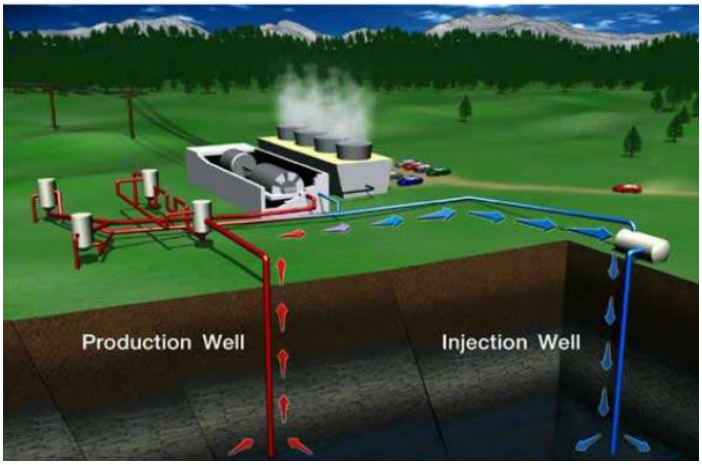
Geothermal wells can be drilled over 3km deep, and the drilling continues 24 hours per day. If investigators discover a reservoir, they begin to test characteristics of the well and the reservoir by flowing the well. If the well is good enough, engineers will build a wellhead, with valves and control equipment onto the top of the well casing (Nemzer).

(Picture source: http://www.sciencedirect.com/science/article/pii/S0375650508000886)

Generation of Electricity

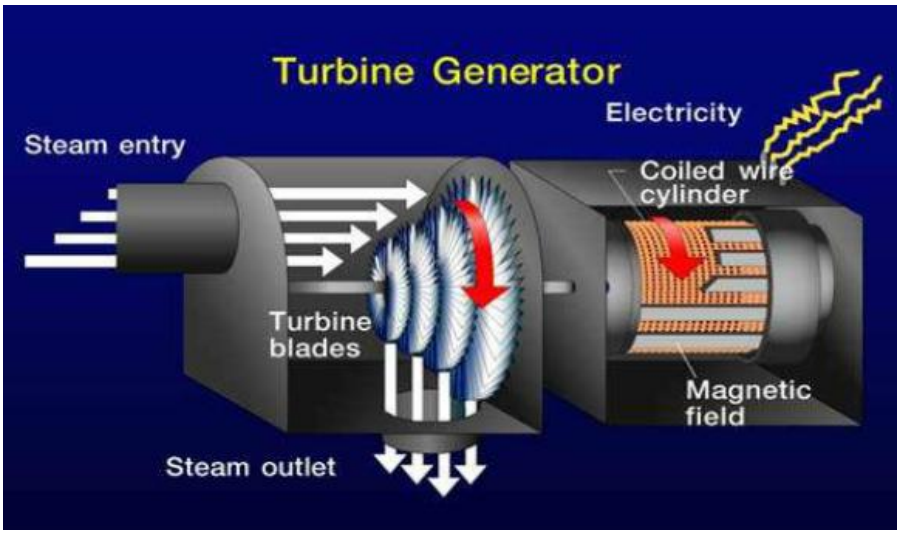
After I find the right spot of geothermal energy, what should I do next and how can I make use of the energy? Geothermal power generation make use of the carrier of the heat of the high temperature and high pressure steam to push engine power. Generally speaking, the high temperature geothermal can be directly used to steam power generation, and the medium temperature geothermal can be used by hot water flash or heated by low boiling point working medium to produce steam power. According to the data from the 1996's World Renewable Energy Meeting, the installed capacity of electricity generated by geothermal energy could be 6543MW. Today, more than 20 countries make use of geothermal energy to generate electricity.

Natural steam from the production wells power the turbine generator. The steam is condensed by evaporation in the cooling tower and pumped down an injection well to sustain production.



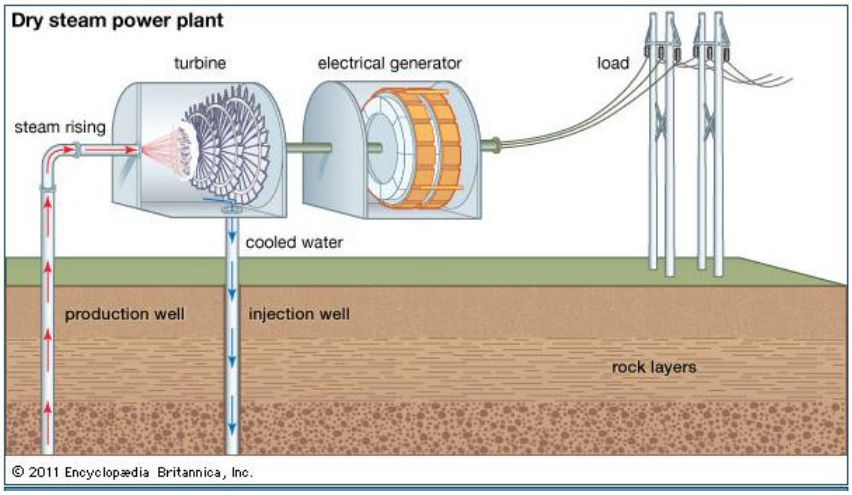
(Picture source: http://geothermal.marin.org)

Like all steam turbine generators, the force of steam is used to spin the turbine blades which spin the generator, producing electricity. But with geothermal energy, no fuels are burned.



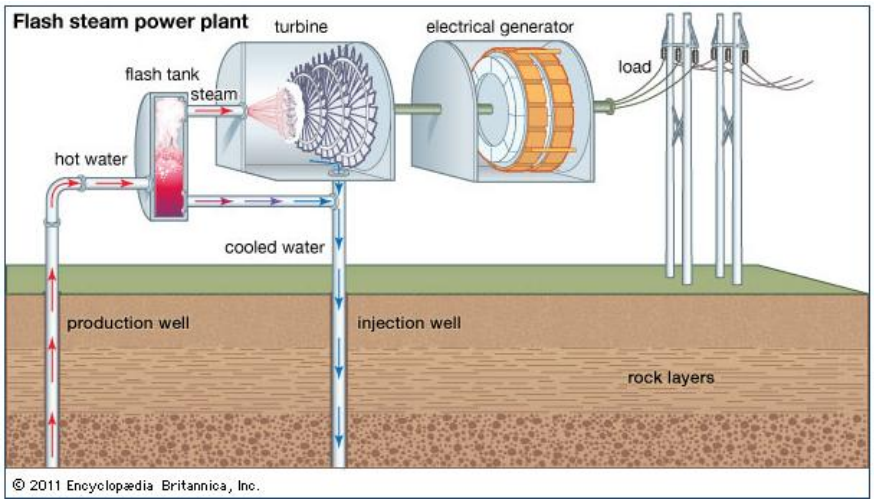
(Picture source: http://geothermal.marin.org)

There are different types of geothermal reservoirs and power plants. The three main power plants are dry steam, flash steam, and binary cycle ("geothermal energy", 2012). In dry steam power plants, the steam (no water) shoots up the wells and is passed through a rock catcher and then directly into the turbine that drives an electrical generator. Dry steam fields are rare. The first dry steam power plant was built in Larderello Geothermal Field in Italy, which was also the first geothermal power plant (Lund, 2004). The first geothermal power plants in the U.S. were built in 1962 at The Geysers dry steam field, in northern California. It is still the largest producing geothermal field in the world, and The Geysers is the only dry steam field in the United States.



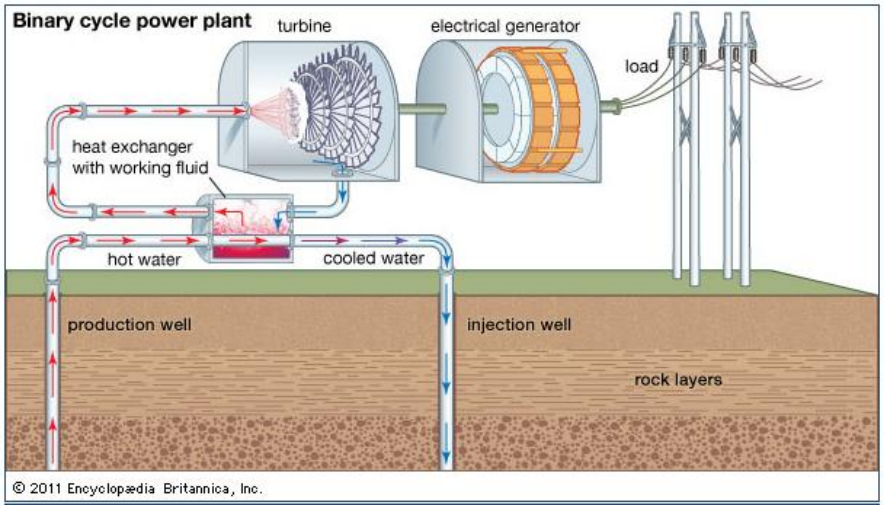
(Picture source: http://www.britannica.com.ezproxy.wpi.edu/EBchecked/topic/230403/geothermal-energy)

Flash steam power plants use hot water reservoirs. In flash steam power plants, as hot water is released from the pressure of the deep reservoir in a flash tank, where the sudden decrease in pressure causes the liquid water to flash into steam ("geothermal energy", 2012). Flash technology was invented in New Zealand for power plants at Wairakei (has "wet steam" source), the volcanic region of North Island of New Zealand (Lund, 2004). In flash plants, both the unused geothermal water and condensed steam are injected back into the periphery of the reservoir to sustain the life of the reservoir.



(Picture source: http://www.britannica.com.ezproxy.wpi.edu/EBchecked/topic/230403/geothermal-energy)

In a binary cycle power plant, the heat from geothermal water is used to vaporize a "working fluid (such as oil or other hydrocarbons)" in separate adjacent pipes and the vapor powers the turbine generator. In the heat exchanger, heat is transferred from the geothermal water to the working fluid. The geothermal water is never exposed to the air and it is recondensed and piped back to the heat exchanger. Electrical power usually requires water heated above 175 Celsius degrees, but binary technology allows the use of lower temperature (85-90 Celsius degrees) reservoirs, thus increasing the number of reservoirs that can be used.



(Picture source: http://www.britannica.com.ezproxy.wpi.edu/EBchecked/topic/230403/geothermal-energy)

Usages of geothermal energy

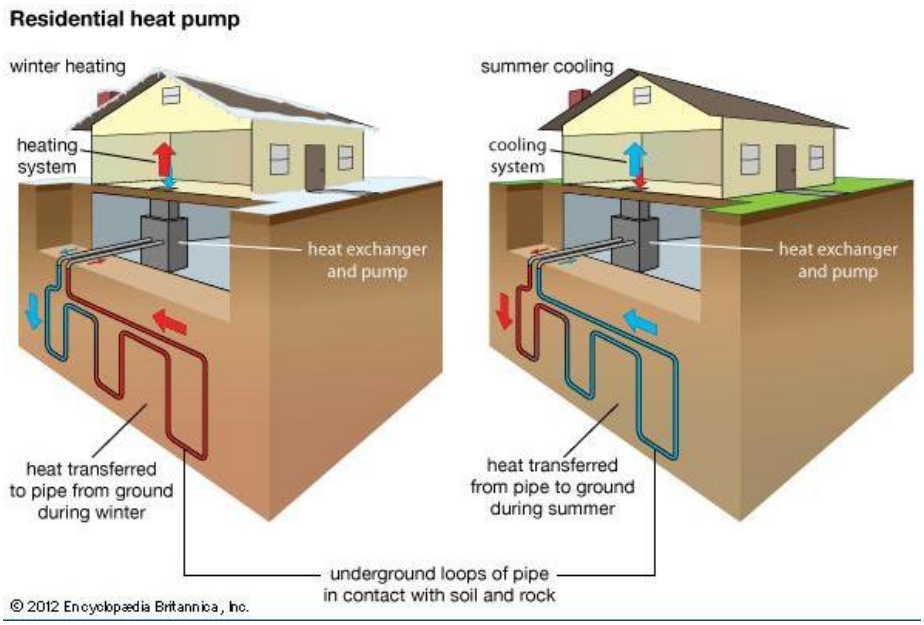
As asked before, what can we use geothermal energy for and what benefits can we gain from geothermal energy? Geothermal energy has variant usages with low price and emissions, but geothermal energy requires specific regions and a high cost at the beginning. In addition, some geothermal energy field may have poison air. Geothermal energy has different usages with different temperatures. The following table shows the variant usages of geothermal energy.

level		temperature	main usages
high		t>=150	electricity, dry
median		90<=t<150	dry, electricity, industrial, refrigeration
low	hot water	60<=t<90	heating, technological process
	median hot	40<=t<60	medical treatment, showering, greenhouse
	warm	25<=t<40	agricultural irrigation, cultivation, soil heating

(Collect data from: http://www.chevron.com/deliveringenergy/geothermal/?utm_campaign=Tier_1)

(Temperature in Celsius degrees)

Over 40 countries uses geothermal water supply over 11,000 thermal megawatts directly.



(Picture source: http://www.britannica.com.ezproxy.wpi.edu/EBchecked/topic/230403/geothermal-energy)

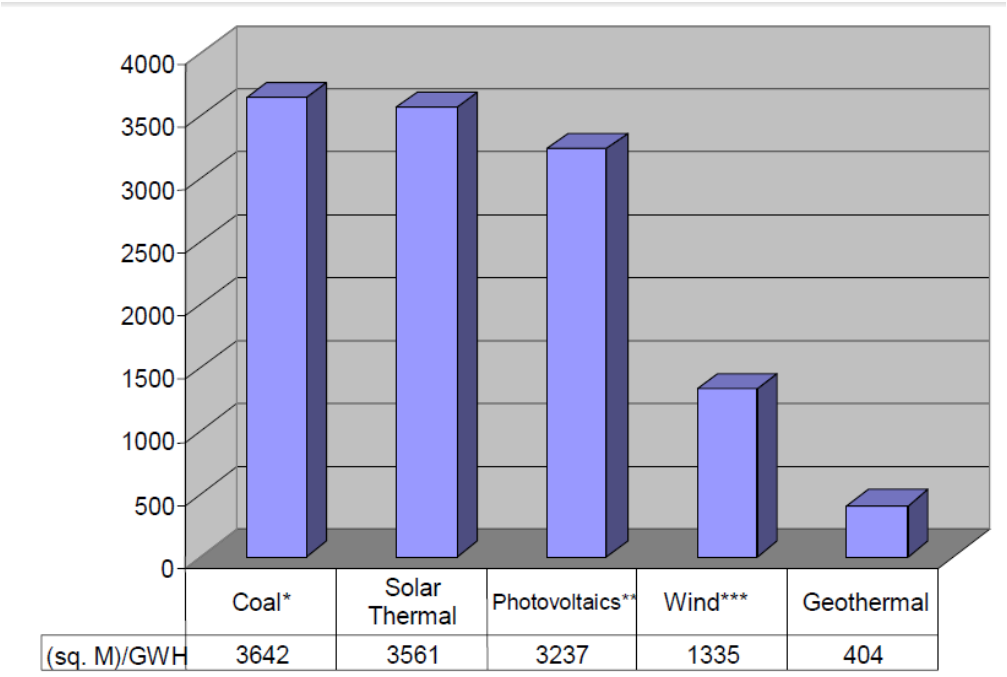
Is Geothermal Energy Renewable?

As I mentioned at the beginning, geothermal energy is a renewable energy, but you may ask why it is renewable and will it diminish in the future. Geothermal energy is literally heat from the Earth, and the Earth's heat is essentially limitless. The center of the Earth has been very hot for some 3.9 billion years and will continue to be hot for at least that far into the future. At the Earth's core, 4,000 miles deep, temperatures can reach upwards of 5000 Celsius degrees. In addition, the underground water or steam used to convert heat energy into power will never diminish if managed properly, because precipitation will continue to recharge geothermal reservoirs. Geothermal resources can be considered renewable on timescales of technological systems and do not need geological times for regeneration as fossil fuel reserves do. The National Energy Policy Act of 1992 and the Pacific Northwest Electric Power Planning and Conservation Act of 1980 both define geothermal energy as a renewable resource (Kagel, 2007).

Geothermal Energy and the Environment

The environmental effects of geothermal energy and power generation involve the changes in land use associated with exploration and plant construction, noise and sight pollution, the discharge of water and gases, the production of foul odours, and soil subsidence ("geothermal energy", 2012). Most of these effects have been minimized with current technology. Normal geothermal power plant operation produces little noise which

is not considered an issue of concern according to common sound level standards. Geothermal plants use 5 gallons of freshwater per megawatt hour and binary power plants use no fresh water. Compared to geothermal plants, natural gas facilities use more than 70 times water per megawatt hour. Geothermal fluids used for electricity are injected back into geothermal reservoirs, which reduce surface water pollution and increases geothermal reservoir resilience. Geothermal power plants can be designed to use less land than fossil fired plants, and can be located on multiple-use lands that incorporate farming, skiing, and hunting. A geothermal facility uses 404 square meters of land per gigawatt hour, while a coal facility uses 3632 square meters per gigawatt hour.



(Picture source: http://www.geo-energy.org/)

Geothermal power plants have no smoky emissions. They emit water vapor, and those white plumes you see at geothermal power plants are steam. According to the characteristics of geothermal energy, geothermal power plants are clean and are operating successfully in sensitive environments. Geothermal power plants have been built in the middle of crops, forested recreation areas, fragile deserts and in tropical forests.

Emission	Nitrogen oxide (NOx)	Sulfur Dioxide (SO_2)*	Particulate Matter (PM)	Carbon Dioxide (CO_2)
Sample Impacts	lung irritation, coughing, smog formation, water quality deterioration	wheezing, chest tightness, respiratory illness, ecosystem damage	asthma, bronchitis, cancer, atmospheric deposition, visibility impairment	global warming produced by carbon dioxide increases sea level, flood risk, glacial melting
Geothermal emissions (lb/MWh)	0	0 - 0.35	0	0 – 88.8
Coal emissions (lb/MWh)	4.31	10.39	2.23	2191
Emissions Offset by Geothermal Use (per yr)	32 thousand tons	78 thousand tons	17 thousand tons	16 million tons

(Data from: http://www.geo-energy.org/)

Geothermal Energy Costs

I talked about the benefits of geothermal energy to customers and environment before, so what are the benefits of geothermal energy to investors? In order to find out the benefits, we have to find out the costs. Geothermal power plants are characterized by high capital investment for exploration, drilling wells, and plant installation, but low cost for operation and maintenance. This character determines that investors can gain profit from geothermal project in the long term. Therefore, companies doing long term investment are more likely to invest geothermal projects[81]. I consider the following factors will influence the cost of a geothermal power plant. These factors include:

- size of the plant
- power plant technology
- knowledge of the resource
- temperature of the resource
- chemistry of the geothermal water
- resource depth and permeability
- environmental policies
- tax incentives
- markets
- financing options and cost

[81] "GEOTHERMAL Basics." *Geo-energy*. Geothermal Energy Association, n.d. Web. 15 Dec. 2012. <http://geo-energy.org/Basics.aspx>.

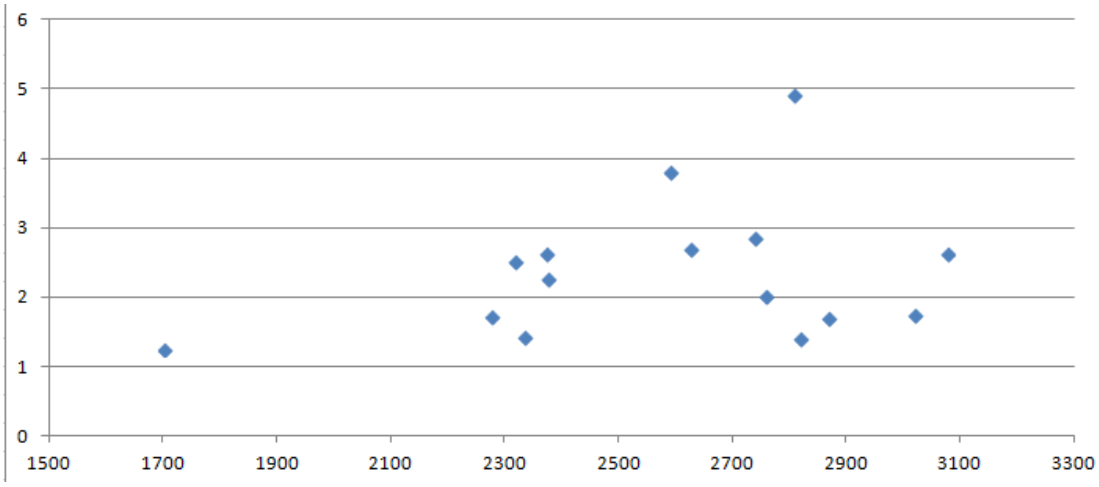
- time delay

In general, geothermal plants are affected by the cost of steel, other metals and labor, which are universal to the power industry. However, drilling costs may vary as well.

Actual geothermal well drilling and completion costs in year 2003 US $.

Well	Meters	Feet	Year Drilled	Cost Year 2003(m$)
Non-US	3077	10096	1996	2.64
Non-US	3021	9912	1996	1.75
Non-US	2869	9414	1996	1.7
Non-US	2819	9249	1997	1.4
Non-US	2807	9210	1996	4.91
Non-US	2760	9055	1997	2.02
Non-US	2739	8986	1997	2.85
US	2627	8618	1997	2.69
US	2590	8496	1991	3.82
Non-US	2377	7800	1996	2.27
Non-US	2374	7789	1997	2.64
US	2334	7658	1986	1.44
Non-US	2317	7603	1996	2.53
US	2277	7471	1985	1.73
US	1703	5588	1986	1.26

(Data from: Actual geothermal well costs from Sandia National Laboratories)



(Made graph from data above)

I put all the prices according to the depth into a graph above. I notice that the price does not follow the common sense that the deeper the more expensive. This may happen since the year drilled are different, and the drilling in different region would face different situations. Geothermal projects are site-specific, thus the costs to connect to the electric grid vary from project to project. Also, whether the project is the first in a particular area or reservoir impacts both risks and costs. The acquisition and leasing of land also varies, because to fully explore a geothermal resource, a developer is required to lease the rights to 2,000 acres or more. Challenges to leasing and permitting vary from project to project; especially on federal lands ("GEOTHERMAL Basics").

As looking at the cost of geothermal energy, I want to find out how much money can a geothermal power plant make? Can it gain a profit? Is it economically competitive with other energy sources? A geothermal power plant can cost as low as $3400 per kilowatt installed. According to the report from international investment bank Credit Suisse, geothermal power costs 3.6 cents per kilowatt-hour, versus 5.5 cents per kilowatt-hour for coal.

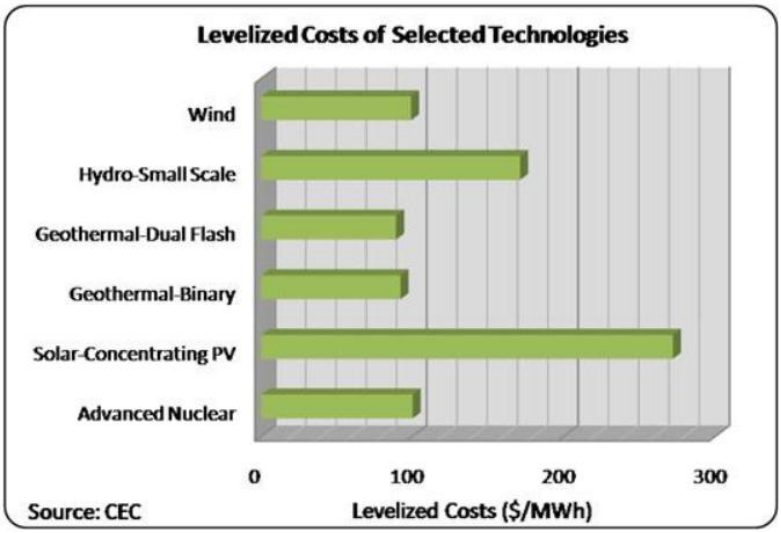
LCOE SCENARIO ANALYSIS	HIGH CASE	BASE CASE	LOW CASE	MIN.	DIFF.
Solar PV (Crystalline)	$201	$153	$119	$119	$82
Solar PV (Thin Film)	$180	$140	$110	$110	$71
Fuel Cell DG	$117	$90	$72	$72	$46
Solar Thermal	$126	$90	$69	$69	$57
Coal	$66	$55	$46	$46	$19
Natural Gas (CCGT)	$64	$52	$40	$40	$25
Nuclear	$64	$62	$35	$35	$29
Wind	$61	$43	$29	$29	$32
Geothermal	$59	$36	$22	$22	$38
Efficiency	$30	$15	$0	$0	$30

Source: Credit Suisse

dollars per watt-hour

(Picture source: http://www.scientificamerican.com/article.cfm?id=can-geothermal-power-compete-with-coal-on-price)

The Credit Suisse's analysis relied on the "levelized cost of energy," or the total cost to produce a given unit of energy.



(Picture source: http://geo-energy.org/)

From the data above, a 270MW geothermal power plant (Coso in California) which generates energy 2381 GWh/yr costs 270,000*3400=918 million dollars at the beginning,

and 0.036*2381*10^6=85.716 million dollars each year. The average electricity price in United States is 0.13 dollars per KWh in 2011 and 0.128 dollars KWh in 2012. If the geothermal energy was sold at the price of 0.128 dollars per KWh. This geothermal power plant makes a revenue as 0.128*2381*10^6=304.768 million dollars. Thus, this power plant makes profit as 304.768-85.716=219.068 million dollars each year regardless of the tax. This power plant will become economically beneficial after 4.2 years. Geothermal power plant has a low maintenance fee, so it will be economically competitive in the long term. If we only look at the profit, geothermal power plant can be a better choice than coal mine or natural gas station. However, most companies still like coal or natural gas better than geothermal energy today. It will be more difficult to persuade an investor with a higher up-front cost. As a result, companies are more likely to spend money on things with lower front-end costs, which are cheap to build but relatively expensive to operate because of the cost of the fuel needed to run them. Another reason that coal and natural gas are more popular than geothermal energy is because they can be deployed anywhere, whereas only 13 U.S. states have identified geothermal resources[82].

[82] "geothermal energy." *Encyclopædia Britannica. Encyclopædia Britannica Online Academic Edition*.

Encyclopædia Britannica Inc., 2012. Web. 15 Dec. 2012.

<http://www.britannica.com.ezproxy.wpi.edu/EBchecked/topic/230403/geothermal-energy>.

World Geothermal Congress 2005 in Turkey

Installed (gross) Geothermal Power Worldwide (2004)			
Country	Installed (MW)	Est. Energy (GWh/yr)	percentage to domestic total energy
Argentina	/	not operating	0
Greece	/	not operating	0
U.S.	2395	16000	2
Philippines	1931	8630	40
Mexico	953	6282	50
Indonesia	807	6085	15
Italy	790	5300	45
New Zealand	453	3600	64
Japan	535	3470	11
Iceland	200	1433	85
Costa Rica	162	1170	30
Kenya	127	1100	22
EI Salvador	105	550	24
Nicaragua	78	308	38
Russia	100	275	7
Guatemala	29	180	16
China	32	100	1
Papua New Guinea	30	100	12
Turkey	21	90	23
Ethiopia	7	30	34
France (Guadalupe)	4	21	6
Taiwan	3	15	9
Austria	<1	5	12.5
Australia	<1	3	8
Germany	<1	2	10
Thailand	<1	2	3
Total	8771	54793	

(Collect data from: http://www.geothermal-energy.org/331,world_geothermal_congress_-_the_history.html)

From the World Geothermal Congress, there are more than 24 countries making use of geothermal energy. There are 17 countries produce geothermal energy more than 90 GWh/yr which is more than most of Solar Power Plants. This means that geothermal energy has been noticed as an important energy source, and it will play a crucial role as one of the main renewable energy in the future. However, geothermal energy only maintains a small partial to domestic total energy in big energy countries such as China and U.S. The development of geothermal energy are still needed and the market will be big in the future.

Country	% of houses using geothermal energy for heating
Iceland	95
Poland	52
Sweden	50
Finland	49
Austria	12.5
Netherlands	3
Estonia	52
Denmark	51
Slovakia	40
Hungary	16
Germany	12
UK	1

The percentages of houses heated by the geothermal energy in various countries in Europe

(Collect data from: http://link.springer.com.ezproxy.wpi.edu/chapter/10.1007/978-94-007-1402-1_4/fulltext.html)

Geothermal energy has become a sole energy source for several countries such as Iceland. In Iceland, 15% of energy consumption comes from geothermal energy, and 95 percent houses are using geothermal energy for heating.

Country	% of Natural Capacity (MW)	% of Natural Energy (GWh/yr)
Philippines	16.2	21.5
El Salvador	15.4	20.0
Kenya	15.0	20.0
Nicaragua	17.0	17.2
Iceland	13.0	14.7
Costa Rica	7.8	10.2
New Zealand	5.1	6.1
Indonesia	3.0	5.1

(Picture source: http://geoheat.oit.edu/bulletin/bull25-3/art2.pdf)

Geothermal Energy in America

Geothermal Field in U.S.

Geothermal Field	Total Installed Capacity (MW)	Total Energy (Gwh/yr)	Unit	Operating Year	Typology
CA-The Geysers	1584	7061.7	25	1971--2007	Dry Steam
CA-Salton Sea	329	2633.7	13	1982--2000	DF/Single Flash
CA-Coso	270	2381	9	1987--1989	Double Flash
CA-Heber	212	708.1	26	1985--2009	DF/Binary
NV-Steamboat	136.3	696.2	17	1986--2008	Bin
CA-East Mesa	120	555.6	6	1987--1989	DF/Bin
NV-Dixie Valley	73.8	426.3	2	1988-2011	DF/Bin
UT-Roosvelt	37	328.4	2	1984--2007	SF/Bin
NV-Stillwater	48	313.5	4	2009	Bin
HI-Puna	43	236.5	11	1993	Bin
CA-Mammoth	40	236.4	10	1984--1990	Bin
NV-Blue Mountain	50	177.4	1	2009	Bin
NV-Beowave	18.4	129.2	2	1985--2011	DF/Bin
NV-Brady Hot Spring	27	122.5	3	1992	DF
NV-Desert Park	23	106.4	1	2006	Bin
NV-Salt Wells	24	97.8	2	2009	Bin
NV-Soda Lake	26.2	93.9	10	1987--1991	Bin
ID-Raft River	15.8	90.7	1	2008	Bin
NV-Steamboat Hills	14.4	75	1	1988	SF
UT-Thermo Hot Spring	10	59.1	50	2009	Bin
NV-San Emidio	4.8	30	4	1987	Bin
CA-Honey Lake	3.8	28.1	5	1985--1989	Bin/Hybrid
NV-Wabuska	2.4	10.8	2	1984--1987	Bin
AK-Chena Hot Springs	0.7	3.9	3	2006	Bin
NM-Lightening Dock	0.2	0.5	1	2008	Bin
WY-Naval Petroleum	0.2	0.5	1	2009	Bin
OR-Klamath Falls	0.3	0.1	1	2009	Bin
NV-Jersey Valley	15	0	1	2011	Bin
Total	3129.4	16603.4	214		

(Collect data from: http://www.geothermal-energy.org/)

From the data above, we can see that there are 214 geothermal wells in the United States, and most of them are in California. There is only one dry steam power plant. As mentioned before, dry steam geothermal source is rare. Most of the power plants in U.S. use binary technology as it does not require high temperature source. As mentioned before, if the cost of geothermal energy is 0.036 dollars per kwh and the price of electricity is 0.128 dollars per kwh, all the geothermal power plants in U.S. can make a profit as 1527.51 million dollars a year.

Future of Geothermal Energy

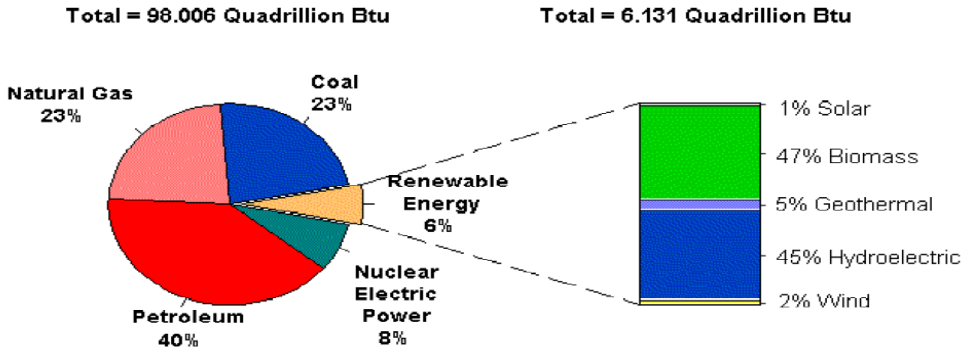
As the data stated above, and from my view, the most opportunities of geothermal energy are in China in the future. The geothermal energy type will transit from deep source to shallow source. Earth close to the ground can be a good container of solar energy. Now geothermal energy is restricted with regions. If we combine solar energy technology and geothermal energy technology, geothermal energy can be widely used. China has not developed geothermal energy as America and European countries, and China has huge land with large amount of population. Thus I predict shallow geothermal energy in China will be developed soon and widely used if Chinese geothermal group cooperate with American or European geothermal technicians.

Conclusion

Geothermal energy has no smoky emissions, and requires a less place to build the power plant than other energy sources. The cost of geothermal energy is also competitive with other energy sources. The cost of geothermal power has been declining and in many cases, is competitive with fossil fuel plants at 4 to 5 U.S. cents per kWh. Compared to other renewable energy sources, the main advantage of geothermal energy is that its base load is available 24 hours per day, 7 days per week. However, solar power and wind power are available only about one third of the time as geothermal power plant. The main disadvantage of geothermal energy is the high initial investment cost and the high risk of proving the resources. Geothermal resources in low-permeability rocks are often found, and exploration activities often drill holes that produce steam in amounts too low to be exploited economically[83].

With proper management including the injection of spent fluids, the geothermal resource can be sustained and operated for many years. Geothermal fields have been operated for over 50 years and probably can be for over 100 years.

Despite improvements in coal, natural gas, and oil power plant technology, fossil fuel continues to produce more air pollution than any other source. In light of the inevitable impact and use of energy, specifically electricity, in the United States, it is important to consider the environmental benefits of geothermal energy, especially when compared to more common energy sources such as fossil fuels. Although geothermal provides environmentally electricity to millions of Americans, it supplies only a small percentage of total domestic electricity. An expansion of geothermal energy is needed and going to happen.



Total United States Energy Use, 2003

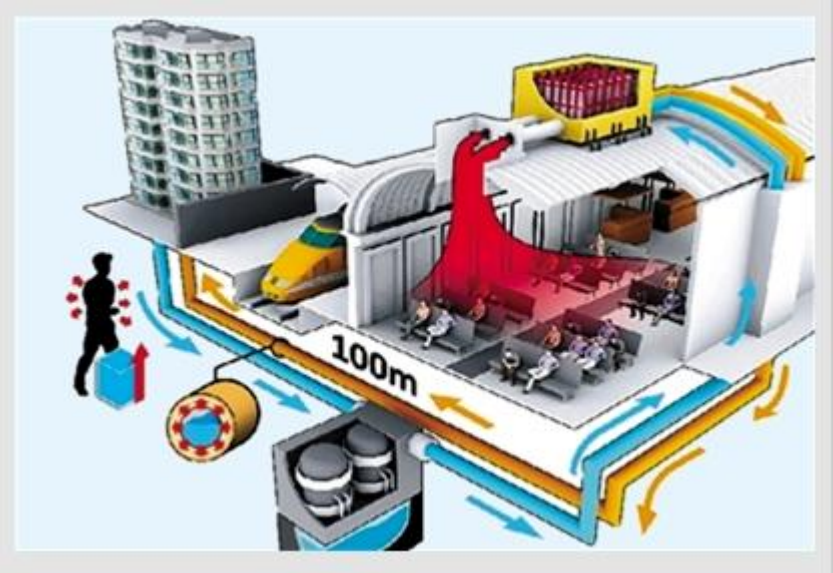
(Data source: http://www.geo-energy.org/)

[83] Nemzer, Marilyn. "Geothermal Education Office." *Geothermal Education Office*. N.p., n.d. Web. 15 Dec. 2012. <http://geothermal.marin.org/index.html>.

5.2.2 Human Body Heat Energy

Human's body heats itself every second. We wear blanket when we sleep and heavy clothes during the winter time all because we want to keep this heat. For this energy, we have infinite sources and it has no pollution at all, but we need to find a way to collect it efficiently and store it.

Central Station in Stockholm is the largest train station in Sweden. About 250,000 passengers pass through it each day. All those moving bodies generate a lot of heat which is more than the building needs. So the real estate company that owns the building is using heat exchangers to transfer Central Station's excess heat to water, which is then piped over to heat another building across the street. Apparently the innovation lowers the energy costs of the office block by 25 percent ("Body Heat Heating Building in Stockholm.")[84].



(Picture source: http://yuhongbo555888.blog.163.com/blog/static/619239812011025115481 66/)

According to the manager of Stockholm central station, it costs as low as 20,000 dollars to build the system, and the heat collector can collect 1850000 kilo calories from 250000 passengers each hour. Thus, it collects 7400 calories from 1 passenger each hour. Assume each passenger stay at the station for 20 minutes every day, so the station will collect 616667 kilo calories of energy which is 2580133 kj. Let's determine how much water this much energy can boil by using the equation:

Q=cm(t1-t0)

[84] "Body Heat Heating Building in Stockholm." *â" Nordic Energy Solutions*. N.p., n.d. Web. 15 Dec. 2012. <http://www.nordicenergysolutions.org/inspirational/body-heat-heating-building-in-stockholm>.

t1 is 100 Celsius degrees as the boil water temperature

t0 is 20 Celsius degrees as the water is stored underground which has a constant temperature about 20 Celsius degrees

2580133=4.2m*80

m=7679kg=7.679ton

This equals the energy produced by 154 cubic meters of natural gas, and the price of natural gas in Sweden is 0.8 dollars per cubic meters. Therefore, this system can save 123 dollars every day, and 45,000 dollars a year which is more than the investment. This system will be more beneficial to build in place like China and Japan since there will be 3 to 5 times passengers more than the ones in Stockholm central station.

It is obvious that human body heat cannot be a reliable energy source in the future since the amount generated is too small to the population. However, it can serve as a way to save energy and reduce pollutions. In addition, it is not expensive to build and does not require high technology. Countries with a large population like China may want to develop the technology of collecting body heat and generate more energy.

5.3 Future Social Pattern

5.3.1 Social Technologies

Sometime in the future, people's will no longer depends on fossil energy, once that day has come, what will people's daily life be?

First, transportation will change radically; people can no longer afford to use oil as the primary fuel since the oil price will be extremely high. At that time, more and more people will be using public transportation; the public transportation technologies will be more advanced. For small personal vehicle, internal combustion engine will be obsolete, solar energy propulsion will replace oil as the primary fuel for small vehicle. By that time, the surface of the vehicle will be built by solar panel, when the sun is up, the vehicle can convert the solar energy into electricity and store it. If the weather is bad and the sun is block for a few days, people can still charge their vehicle with electricity outlet. Below is some conceptual idea of how a solar power vehicle will looks like:

Conceptual Idea of Solar Power vehicle [85]

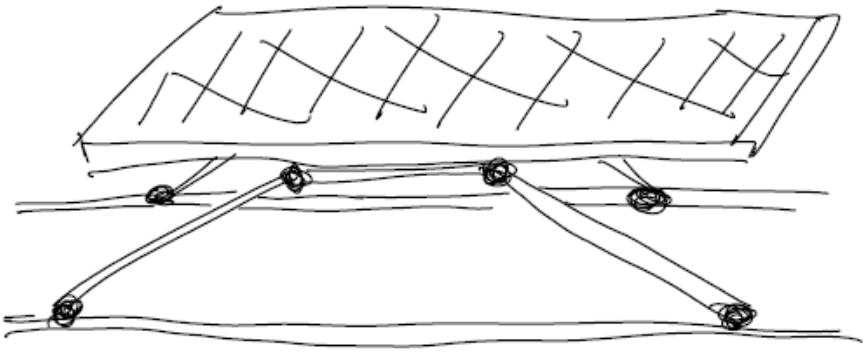
[85] Owning a Solar Power car, solarpoweredcar.us

The idea of solar propulsion vehicle will also affect a few things. First, the number of indoor parking lot will drop significantly. However, this change might not create a parking space shortage problem because the manufacture cost of the solar power vehicle will be a lot higher, therefore fewer people will be able to afford them, more and more people will be forced to use the public transportation, and fewer parking spaces is needed. Another thing is that that parking meter in the city area needs to include charging functionality since the sun light will most likely be blocked by the tall buildings in the city area.

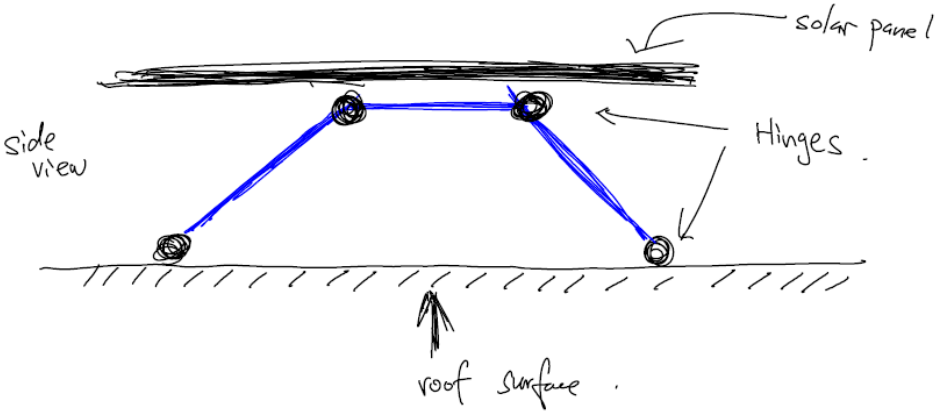
Another change will be that most of the house will produce the energy it needs using solar energy. In the future, the efficiency of solar panel will be much better than the efficiency of solar panel now. Therefore installing this high efficiency solar panel on the roof will allow the house to produce the energy it needs. During the daytime, it will capture as much energy as it can and stores the excessive energy for later usage. The design of the house roof will also affected by this energy collecting method. The design should maximize the amount of energy capture. So rather than have a sharp and point roof top, the new roof design should be flat and with a small slope (for cleaning snow and rain). The solar panel will be installed on the roof top with a mechanism that could turn the panel to different direction.

Sligo heating, roof-top solar panel
Source: http://sligoheating.com/gallery-5/rooftop-solar-panels/

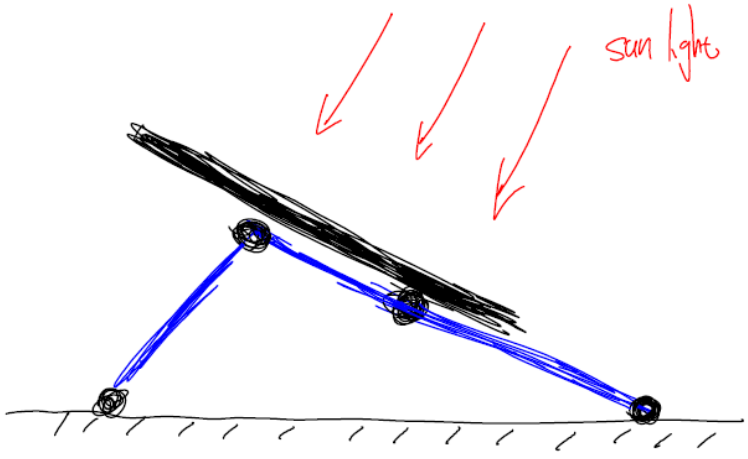
Below is a series of figures to illustration how the mechanism will work:



Full view of the mechanism



The side view when the solar panel is level



The Solar panel turns in order to face the Sun

The advantage of this design is that it can increase the efficiency of the solar panel, also it make this module more flexible; easier to assemble and disassemble. This modulation design makes the replacement process much easier once the solar panel is not functioning properly.

5.3.2 Grocery Deliver

Along with the increasing of the oil price, people have to find other way to get their daily supplies instead of driving back and forth. I believe some supermarket will finally hit the idea of "grocery deliver". Actually Amazon already has a system like that. If you are shopping goods under "Grocery & Gourmet Food" category and choose "Subscribe & Save" before you check out, you can get a small discount and the good would automatically delivered to your address at the frequency you chose. The problem with this is that people would worry about the freshness of the product such as milk, eggs and vegetable. Since Amazon delivers so many products each day and they cooperate with other delivery company, it's impossible to have eggs delivered. It is totally deferent for local grocery stores or supermarket. First of all, they are local, so the product would be fresh. Second of all, as long as they hire people to deliver tire product, even fragile goods can be delivered safe and sound (could learn something from pizza delivery, like what do they use to carry food, etc.).

However, if we look at this from a society point of view. There is not a huge amount of energy saving, it change the multiple trips from every home to the grocery store to a (possibly) a trip start from the store to 1st home and then go through all homes within a certain area. But people will be willing to pay for such kind of service as long as it worth the delivery charges.

5.3.3 Car pool

If we want so save money on oil expense, car pool is a really good way. I always wonder why people are using this way so much right now. I think it has something to do with trust between people in our modern society. If you see people on the street waiting for taxi and dive closer to them asking whether they want to take a ride, most of the people would give you a weird look and say no thank you. Back in my home, there are some people uses their private car as taxi to make money. This is definitely illegal but the ridiculous thing is that people (waiting for taxi) rather pay for this illegal service than take a free ride from a kind stranger. I figured out what they are thinking about: "In the former service, the people are doing this for money for sure; the latter, I don't know what they want, maybe they want to do something bad."

It is not hard to understand, that under this money society, people naturally believe that everything has a value but don't understand that things like car-pool, which you can get an immediate benefit, would do so much good for the whole world. I think social media should help people realize this point. Community should organize car pool "bonding" event. For example between families with kids, parents could send 3 or 4 kids all together in turn; people work close to each other could go to workplace together in one car.

For big city, some road policy could act as reinforcement. Beijing had using alternating dates allows cars on road by the odd/even number in last digit of the license plate during the time of Olympic. This cut the number of cars on road into a half. After the game, the city continues to set limit the number of cars on road: cars are grouped by the last digit the plate (1 and 6, 2 and 7, etc.) and during the workdays, each group will be banned on road for one day. This cut down the number of cars on the road into 4/5.

5.3.4 From Fiber-optic Solar Cell to Wearable Battery

In December 2012, a group of engineers, physicists, and chemists announced that they have created the first flexible, fiber-optic solar cell that can be woven into clothes.

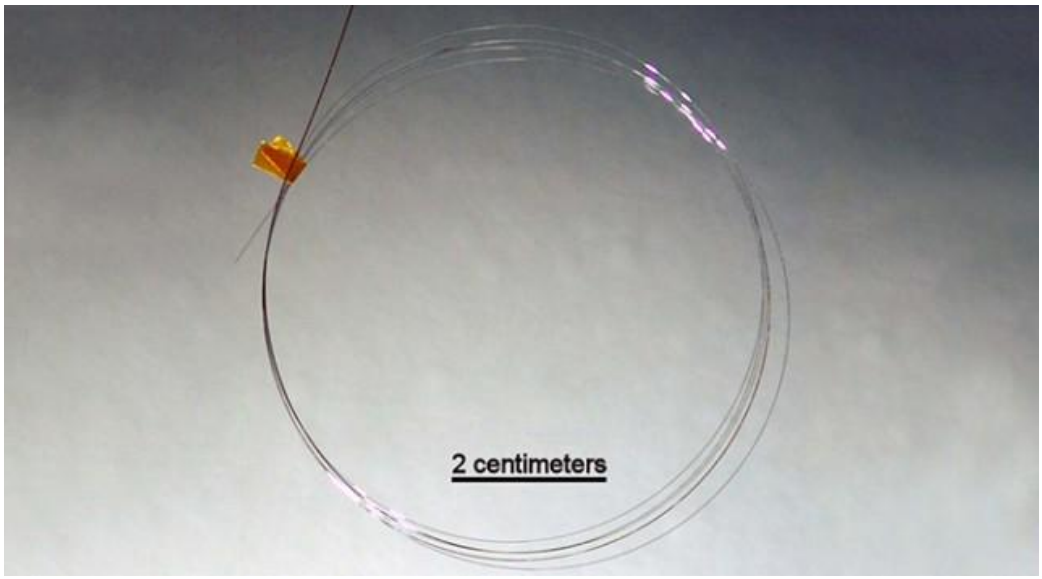


Figure 6 Source: *Rongrui He , Todd D. Day , Mahesh Krishnamurthi , Justin R. Sparks , Pier J. A. Sazio, Venkatraman Gopalan , and John V. Badding, Silicon p-i-n Juction Fibers, 2012,2*

This kind of junction-fiber is even thinner than human hair, and is soft and bendable. The most important is that they can generate solar power and produce electricity. The US military is already interested in this new product and plan to weaving the fiber into cloth for military clothes. In essence, the research team started with optical fibers made from glass — and then, using high-pressure chemical vapor deposition, injected n-, i-, and p-type silicon into the fiber, turning it into a solar cell. Functionally, these silicon-doped fiber-optic threads are identical to conventional solar cells, generating electricity from the photovoltaic effect.[86]

[86] *Extremetech, The first flexible, fiber-optic solar cell that can be woven into clothes, http://www.extremetech.com/computing/142755-the-first-flexible-fiber-optic-solar-cell-that-can-be-woven-into-clothes*

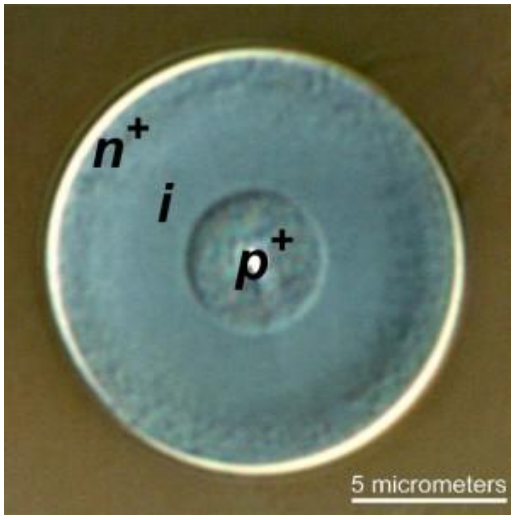


Figure 7[87]

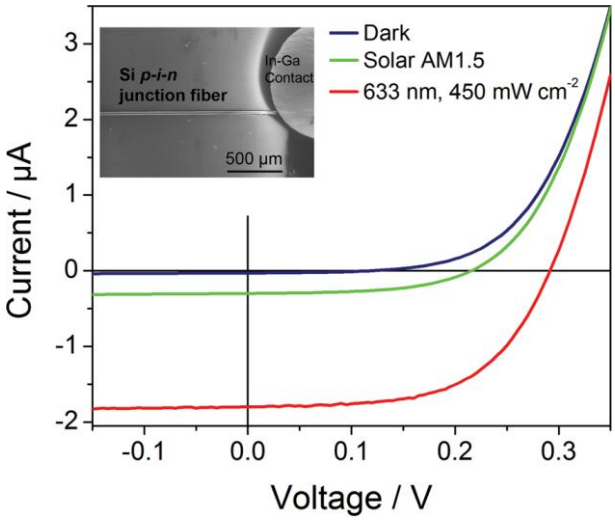


Figure 8[88]
Simulated AM 1.5 illumination is used to evaluate the solarcell performance, while a 633 nm laser demonstrates the photodetection capability.

The difference between this kind of fiber and solar panel is that the panel is limited in the 2D format while the fiber can generate solar power from a 3D cross-section and retain the flexibility.

The research group from Penn State University already made “meters-long fiber”, the lead researcher John Badding says their next goal is to produce over 10 meters fiber and by then the only problem is how to weaving the thread into a fabric. If the fiber can hold everyday garment stresses, we will be able to charge our mobile phone or other small electronic devices using our clothes or hats.

There are two other intriguing properties of the fiber that could be investigated. First, since they have a 3D cross-section, they can absorb sunlight from any direction — unlike their conventional, 2D siblings that “lose much of their efficiency when the sun sinks below a certain angle”. Further, according to Pier Sazio, another member of the research team, they used the same silicon injection method to embed photo detectors inside the fiber.[89] Sazio doesn’t explain about what this might lead to, but we can still looking forward to a wearable computer with built-in solar charging and high-speed networking.

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87 4 *Rongrui He , Todd D. Day , Mahesh Krishnamurthi , Justin R. Sparks , Pier J. A. Sazio, Venkatraman Gopalan , and John V. Badding, Silicon p-i-n Juction Fibers, 2012,2*

89 *Extremetech, The first flexible, fiber-optic solar cell that can be woven into clothes, http://www.extremetech.com/computing/142755-the-first-flexible-fiber-optic-solar-cell-that-can-be-woven-into-clothes*

5.3.5 Self Sufficient Ideas

Green has been introduced as a future life color. We are looking forward to a ‘clean’ life pattern. As some people predict, solar, biomass, hydrogen and geothermal energy will replace fossil fuel as our main source of energy in the future life. If that happens, what our life will be?

We will live in a building using clean energies.

(Source: http://www.arkema-inc.com/index.cfm/flash/msds.cfm?pag=573&SUB_ID=420)

We no longer depend on the air conditioning refrigerant. Instead, we use the solar energy air conditioning. We are no longer use ordinary water heater for heating. A ground source heat pump system is going to replace them. Besides we can decorate many efficient solar collector in the roof of our house and distribute opt thermal curtain wall around the house.

5.3.6 Green Gym

The most advantage place to collect energy may be gym in the future. People hold the purpose of heat consumption in the gym sweat, and a large number of energy drops on fitness equipment. Now researchers have cooperated with the gym. They install energy conversion on some easy-collecting instrument and collect them.

If you’re in good shape, you can generate about 100 watts on a stationary bike.

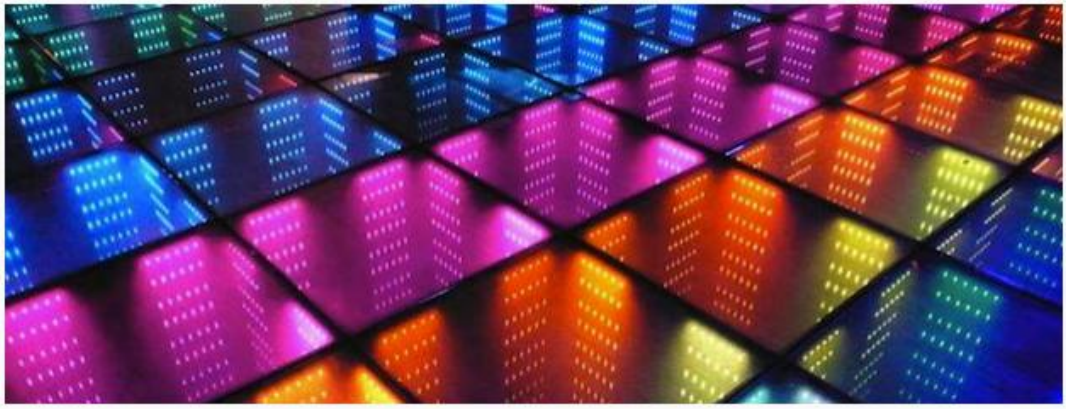
(Source: http://visual.ly/green-machines)

According to the Green Company's information, 20 people using the fitness equipment to exercise 1 hour at the same time can produce 3 kW power. If these fitness equipments run 4 hours every day, they can produce more than 300 kilowatts of energy every month, which can be used for lighting half a year for an ordinary family. Exercising people can produce one-month electricity for 72 families during a year in a 'green' gym. Now, only the exercise bike can be used as an electricity generator. More types of gym electricity generator will be developed in the future as most people will use gym. This energy collector can also be used outdoor.

(Source: http://www.improntaecologica.it/read.asp?Titolo=La+nuova+frontiera+per+la+palestra+del+futuro%3A+autoalimentarsi+col+sudore+degli+atleti&Chiave=958#)

5.3.7 Dance Clubs

Not only gym can generate electricity, but also dance clubs. If we make use of the floors in a dance club, we can generate electricity while people dance on them. The dance club in the future will use elastic floor to collect people's mechanical energy - potential energy, and then use the floor to transform into kinetic energy and then into electrical energy. It's like we are to play on the seesaw, the only difference is that the other side of the seesaw is not a person, but a electrical energy generator.



(Source: http://acornmontessori.com/sustainable-energy-floor.htm)

5.4 Predictions

5.4.1 Prediction #1

What will the future of energy look like? Besides those unpredictable issues like war, which will definitely consume huge amount of energy, to answer this question we must first look at how population would change in the next few decades. In the first three bar charts provided in the BP 2013 Energy Outlook 2030 the leftmost (colored green) one shows that in the period of 1990 of 2030, the population had and will have a steady growth, which is a good news considering energy consumption. But when we look at the GDP growth in the orange-and-red bar chart and compare the bar chart shown in the second image, the GDP is growing faster --- about 2% faster than the energy growth in the 2010-2030 periods. Higher population and higher GDP represent more energy consumption, in the global level. Then let's take a look at the share of world primary energy (image 5.2.1-3). As you can see, oil and coal are both decreasing after 2010. Notice that although gas has been slightly increasing since 1965, we can see a trend that it will hit a certain point and start to decrease in a few decades. Because the gas price has got a substantial increasing since approximately the year 2010. We must begin to move our "attention" to other energy resource.

In my opinion, nuclear power could be a good choice. Actually, country like France is already relying on this kind of cheap, clean and also renewable energy resource. France derives over 75% of its electricity from nuclear energy, and this is due to a long-standing policy based on energy security. **Also, about 17% of France's electricity is from recycled nuclear fuel.** It means that, government is one of the important rings in the whole "energy chain". I would suggest other government start to introduce and promote nuclear energy to people who are not quite familiar with it. People should realize that we are not guaranteed a bright future without looking at other energy resource. Indeed we could keep discovering new energy, but why not take what we already found out and try to fully develop it?

Surely we could not abandon electricity as a kind of energy in a short period of time since all the electronic devices that everyone relies on is powered only by electronic. Also we already built so many facilities for generating and transporting electricity, which we certainly don't want to get rid of so quick. However, we could find substitution of oil, to a certain extent. The first thing come to my mind is the maglev train, which is powered by electricity. Though changing the entire highway road to some kind of magnet track seems unreasonable, we could still change just one lane to run maglev

train for public transportation. Since the maglev train almost does not have fraction, except for the one that brings by the air, it barely has no noise. So if we built the track near residential area, it won't be annoying. Or we could build the "old-school" style maglev train --- what we have right now --- and have the track above our head so the space is not a problem. In the meantime, we should develop public transportation, for example have a maglev bus that is faster, cheaper and the most important, uses less energy (per capita) than private car.

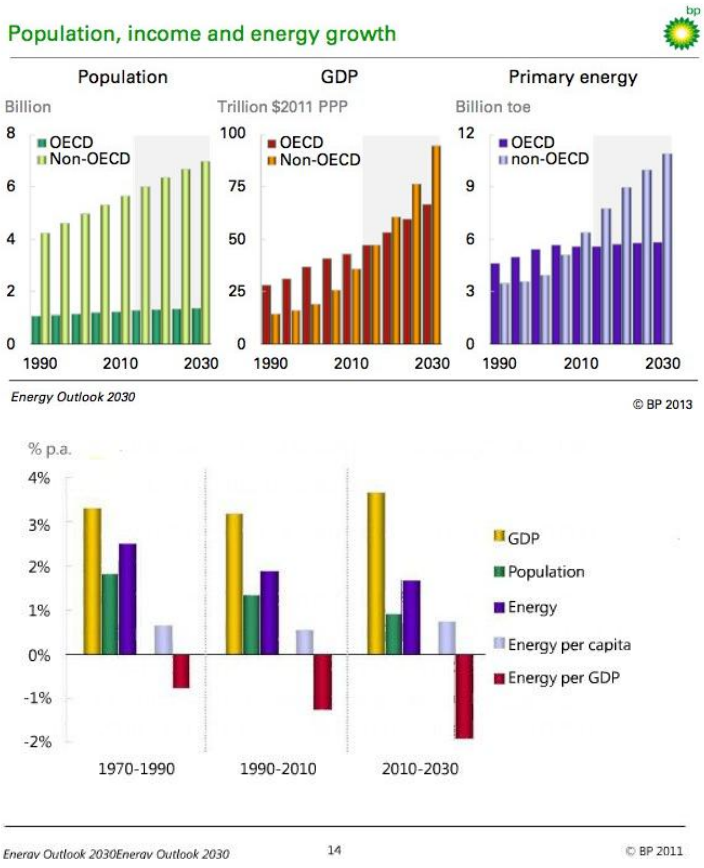
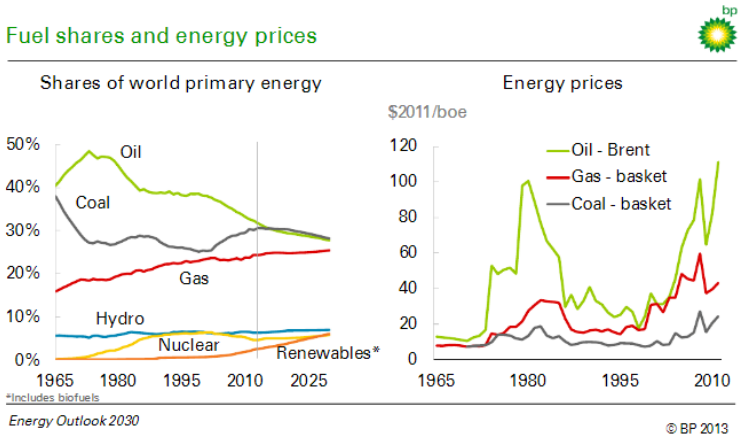


Figure 5.2.1-3



5.4.2Prediction #2

In terms of the future energy consumption, there is just a simple math problem for us to solve. The reserves of fossil fuel such as oil, coal and gas will only decrease in the future, therefore the price of these fossil fuels will go up as they get harder and harder to recover. On the other hand, more and more renewable energy we will be able to collect as our technologies advances. Therefore, the price of fossil fuels will catch up with the price of renewable energy someday in the future. Once this day has come, the economic issue of these two major energy sources will not be important. What matter are their environmental impact and sustainability.

For my prediction, I will neglect the economic issue between these two kinds of energy source since I believe that once the price of fossil energies and the price of renewable energies have become relative similar, they will stay in this way for a for a long time. The reason is that if the two energy sources can easily replace each other, their price will be similar.

If economy of not an issue any more, our objective is to look for a safer and more sustainable way to produce our energy so that our civilization can last as long as possible, we will begin to eliminate any danger that would threaten our existence. For this reason, I predict that some dangerous energy source such as nuclear energy will gradually disappear from the market based on what we have learned in the historical disaster related to nuclear power plant.

The Chernobyl disaster is one of the most well-known nuclear power plant disaster, it is one of only two classified as a level 7 event on the International Nuclear Event Scale. The major consequence of a nuclear disaster is nuclear contamination, which will affect the health of living things and plants for centuries. Living creatures being exposed to

excessive amount of radiation will increase the likelihood of developing cancer and mutation. On farms in Narodychi Raion of Ukraine, for instance, in the first four years of the disaster nearly 350 animals were born with gross deformities such as missing or extra limbs, missing eyes, heads or ribs, or deformed skulls; in comparison, only three abnormal births had been registered in the five years prior. [90] Therefore, location that is exposed to excessive amount of radiation will not be habitable for decades.

The abandoned city of Pripyat and Chernobyl (Image by Jason Minshull)

In March 11, 2011, there was a series of equipment failures, nuclear meltdowns, and releases of radioactive materials at the Fukushima I Nuclear Power Plant, following the Tōhoku earthquake and tsunami. This is the other level 7 event on the International Nuclear Event Scale. 80 days after the disaster, on May 30, 2011, Germany formally announced plan to abandon nuclear energy completely within 11 years, event thought 22.4% of the national supply of electricity was provided by nuclear power plants in 2010. Germany is not alone in this act, Japan and Switzerland also changing their planning for the future power plant. In May 2011, the Swiss government decided to abandon plans to build new nuclear reactors. The last reactor in Switzerland will be allowed to operate until 2034.

[90] "Malformations in a chornobyl-impacted region". ncbi.nlm.nih.gov. 18 March 2011. Retrieved 20 August 2011

Sustainability will be our primary goal for our energy consumption, for this reason, our energy consumption will shift more toward renewable energy, and the use of fossil energy will be a supplement of renewable energy to make sure that we will have a suitable amount of greenhouse gas in our atmosphere to keep our planet warm.

For our transportation, after a few decades, most of the small vehicle will have solar panel installed, internal combustion engine will become obsolete, and solar power will replaces oil to become the main fuel for small vehicles. However, oil will mainly be used in aviation purpose since solar power will not be able to provide enough propulsion for high-speed flight.

Coal and natural gas will be mainly used in industrial and manufacture purpose, they will not be used to generate electricity. Most of the electricity demand will be generated by renewable source, mainly by solar energy. Many techniques will be adopted such as large solar panel array, solar thermal energy capture and solar power satellites.

So to sum up my prediction, first, I predict that nuclear power generations will disappears from the market. Second, the price of fossil fuel and the price of renewable energy will become similar. And third, the usage of fossil energy will drop significantly, and solar power will be the main power source to satisfy our energy consumption.