Central United States Renewable Energy Portfolio

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1. Introduction

Two hundred years ago when most people lived in a world where horses were used as transportation tools, energy did not seem to be a problem. However, two hundred years later, in a highly developed and modern society now, no one could ever continue to say that. As a matter of fact, energy problem is more than just serious, which, if not handle appropriately, would ruin the every achievement that we have and essentially human civilization.

This problem has two concerns: one is the energy exhaustion and the other one is environment. Many studies claim that with the present exploiting speed, the fossil fuel that human live on, especially petroleum and coal will run out in less than two hundred years. Meanwhile, the long time dependence of fossil fuel, and consequently the heavy amount of CO_2 emitted from it, also created a serious problem of environment, for example global climate change. Those two prospects are the basic concerns in our study.

This research will focus to create a most achievable and sustainable energy scenario for the area of middle U.S. based on its natural resource and economic perspective. Out goal of this study is to find the best scenario to substitute the present energy structure in middle U.S with sustainable energy within 100 years, which we believe is an appropriate timeline for the substitution.

The definition of “sustainable” from Merriam-Webster is: of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged.Practically during our study, we believe the following aspects are required for sustainability:

- Supply of energy resources: the energy should have sustainable supply in resource, and the utilization including exploitation and transformation should be effective and efficient.
- Environmental concern: the energy should be environment friendly, which means that air pollution, acid precipitation, ozone depletion, forest destruction and emission of radioactive substance should not be its result.
- Engineering practicality: it includes economic perspective, public acceptability, reliability, applicability and scarcity of supply.
- Technology: the energy should be supported by technology during its lifetime, including production, deliverability, initial and maintenance cost as well as collection and conversion efficiency. Technology is an important factor during our substitution.

In our study, the energy structure is divided into two sections: transportation and non-transportation. The traditional transportation depends on liquid fuel, while the non-transportation consumed including liquid fuel and electricity. The liquid fuel are provided by petroleum, and electricity have varies sources. Table 1.1 shows the energy source andconsumption of electricity in middle U.S. area.

State	Primary energy source	Net generation(MWh)	Total retail sales(MWh)	Price (cents/kWh)
North Dakota	Coal	30,881,137	11,245,238	6.21
South Dakota	Hydroelectric	7,132,243	10,056,387	6.7
Nebraska	Coal	31,669,969	27,276,292	6.07
Kansas	Coal	45,523,736	39,751,302	6.89
Oklahoma	Coal	70,614,880	54,905,314	7.3
Texas	Gas	400,582,878	342,724,213	10.34
Minnesota	Coal	53,237,789	66,769,931	6.98
Iowa	Coal	45,483,462	43,336,835	7.01
Missouri	Coal	91,686,343	82,015,230	6.3
Arkansas	Coal	52,168,703	46,635,624	6.99
Louisiana	Gas	90,921,829	77,467,748	8.3
Wisconsin	Coal	61,639,843	69,820,749	8.13
Michigan	Coal	112,556,739	108,017,697	8.14
Indiana	Coal	130,489,788	105,664,484	6.46
Ohio	Coal	155,434,075	153,428,844	7.71
Illinois	Nuclear	192,426,958	142,447,811	7.07

Table 1.1: Energy sources, generation and consumption of electricity in middle U.S. (Source: EIA)

From Table 1.1 we could figure out that most states in middle U.S. depend heavily on coal to produce electricity. The minors use nuclear, gas and hydroelectric. Both coal and gas are running out, and our research will focus to find ideal substitution for liquid fuel and solution for electricity, which will also include the technique improvement for example electricity car to extend electricity's use to transportation and the environmental influences of those energy. Finally, we will finish a report including several issues:

- Suitable sustainable energy candidates for middle U.S. and the portion they share in the whole energy market.
- Comparison between high and low substituting velocity in economic and social perspectives during a 100 years time line.
- The effect of sustainable energy scenario to the environment, especially in CO_2 emission.

Our research will start from assessment of existing alternative energy solutions, which include solar, wind power, biomass, geothermal, nuclear, hydroelectric, tidal and hydrogen. The assessment will be based on our perspectives of sustainability, and promising candidates after the assessment will be considered as a reasonable solution for further analysis.

2. Literature Review

2.1 Overall energy consumption in the U.S.

The energy consumption estimates in each state in 2005 was summarized by Energy Information Administration (EIA, 2005). The data was rearranged and processed for central region. As shown by Table 1.1, central region consumes a large portion of the total energy that was consumed in the United States. Meanwhile, central region also consumes much petroleum energy.

(Units: Trillion BTU)	Total Energy Consumption	Petroleum Energy Consumption	Coal	Natural Gas	Distillate Fuel	Motor Gasoline	Nuclear	Hydropower
U.S. all areas	100369	40733	22795	22645	8755	17445	8149	2703
Central Area (% of all areas)	41306 (41.2%)	16364 (40.2%)	10692 (46.9%)	10910 (48.2%)	3196 (36.5%)	6107 (35.0%)	2725 (33.4%)	203 (7.5%)

Table 2.1 Energy Consumption Estimates by Source in 2005

EIA also summarizes the energy consumption by end-user sector. These sectors include residential, commercial, industrial, and transportation (EIA, 2005, end-user sector reports). The data was rearranged and processed as Table 1.2 for central region. According to Table 1.2, central region consumes more energy than other regions especial in the industrial sector.

(Units: Trillion BTU)	Residential	Commercial	Industrial	Transportation
U.S. all areas	21734	17950	32323	28352
Central Area (% of all areas)	7982 (36.7%)	6279 (35.0%)	16867 (52.2%)	10233 (36.1%)

Table 2.2 Energy Consumption Estimates by End-User Sectors in 2005

In addition to EIA, many other governmental research institutes provide data of sustainable energy resources. The National Renewable Energy Laboratory (NREL), as part of the U.S.

Department of Energy (DOE), is one of the primary laboratories for renewable energy and energy efficiency research and development. Much information regarding renewable energy, energy efficiency, and energy science and technologies can be found on NREL website. NREL's expertise included renewable fuels and renewable electricity, and energy system. The website of the office of Energy Efficiency and Renewable Energy (EERE) of the U.S. Department of Energy has abundant information database of analysis report, and many useful links to various public and private research institutes.

2.2 Hydropower

Hydropower uses water to power machinery or make electricity. When flowing water is captured and turned into electricity, it is called hydroelectric power or hydropower. Turbines and generators convert the energy into electricity, which is then fed into the electrical grid to be used in homes, business, and by industry. In 1998, Idaho National Engineering and Environmental Laboratory published a report of U.S. Hydropower Resource Assessment (Conner, Francort, & Rinehart, 1998). The report describes the development of a computational model, its data requirements, and its application to each state assessment. A total undeveloped capacity of about 30,000 megawatts has been determined by the modeling of undeveloped hydropower resources within the United State.

Based on the computational model and the data collected, Conner et al. estimated and summarized the hydropower capacity of each state in the United State. The hydropower resource has been categorized as (1) resource with power (2) resource without power (3) undeveloped resource. To evaluate the importance of hydropower resource in the central area, the data (Conner, Francort, & Rinehart, 1998) has been rearranged and summarized as Table 2.1. All available hydropower resource in the central area is about one-fifth of the total available hydropower resource. The undeveloped hydropower resource is about 5.30% of all the available hydropower resource. Although Table 2.1, shows that there is still a possibility to use hydropower as a sustainable energy source in central area (Conner, Francort, & Rinehart, 1993-1997), hydropower resource is not as abundant as other areas.

	All available hydropower resource (MW)	Underdeveloped hydropower resource (MW)
U.S. all areas	29,780	8,466
Central Area (% of all areas)	5,108 (17.15%)	1,577 (5.30%)

Table 2.3 A summary of hydropower resource in the U.S. and in the central area

2.3 Geothermal

Geothermal energy is an alternative source of heat and electricity generation that is customarily listed with the renewable energy sources. It is a relatively clean energy source, emits small amounts of carbon dioxide, and might appear to be inexhaustible.

Geothermal energy can be used for electricity production, for direct use purposes and for home heating efficiency. The United States has a big amount of geothermal energy. Figure 1 shows the estimated subterranean temperatures at a depth of 6 kilometers, data for which include thermal conductivity, thickness of sedimentary rock, geothermal gradient, heat flow and surface temperature.

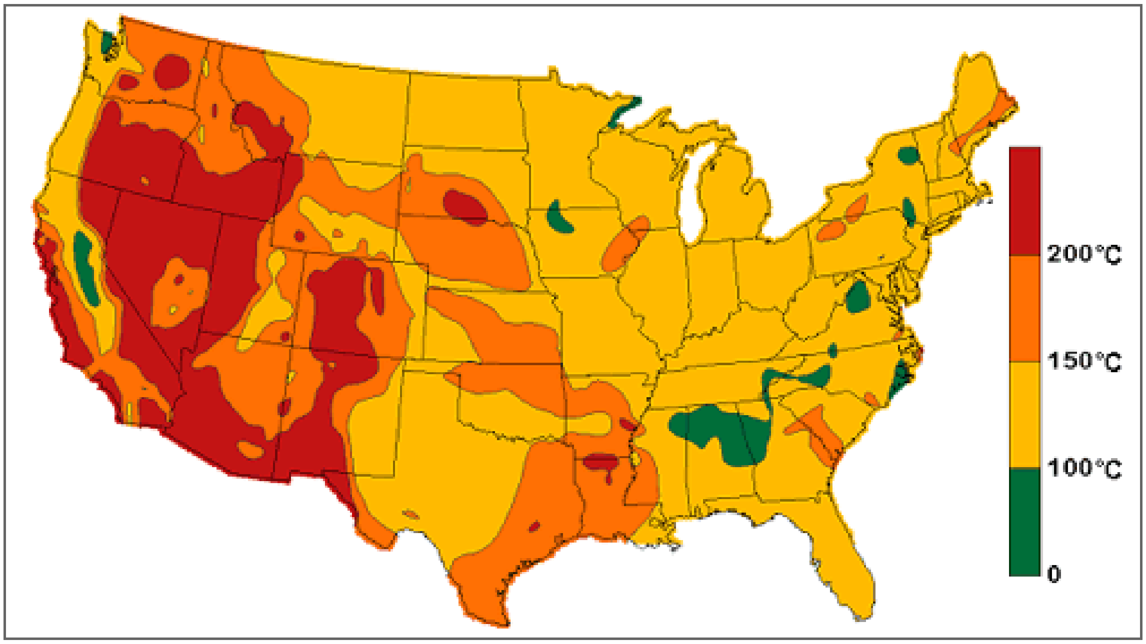


Figure 2.1: US geothermal resource (source: http://www1.eere.energy.gov/geothermal/geomap.html)

From Figure 1 we could tell that a significant portion of geothermal energy in United States lies in the west. In our researched area - the middle US, the geothermal energy does not have higher temperature as in the west for. As a matter of fact, 95% of geothermal potential is in west US. (Williams &B.G., 1995). Compared with other energy source, geothermal energy potential is unfortunately limited regionally, which limits its wide use and consequently a good potential for sustainable energy candidate for middle US.

As mentioned, geothermal energy can be used in three ways:

Power plants generate electricity from geothermal reservoirs: Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that drive turbines that drive electricity generators. However, favorable conditions are found only in certain regions around the globe where tectonic motion in recent geologic times (25 millions years) has allowed magma intrusions into the earth's crust. Such regions are, naturally, also those where there is volcanic activity, or was in recent geologic times. Within the U.S. A (lower 48 states), exploitable geothermal sites are most likely in the far west, with the prospects for steam only around the fault line paralleling the Pacific Coast(Cassedy, 2000).

Direct-use piped hot water warms greenhouses and melts sidewalk snow: hot water near earth's surface can be piped directly into facilities and used to hear building, grow plants in greenhouses, dehydrate onions and garlic, hear water for fish farming and pasteurized milk. Some cities pipe the hot water under roads and sidewalks to melt snow.

Geothermal Heat Pumps (GHPs) use shallow ground energy to heat and cool buildings: A geothermal hear pump system consists of pipes buried in the shallow ground near the building, a heat exchanger and ductwork into the building. In winter, heat from the relatively warmer ground goes through the heat exchanger into the house. In summer, hot air from the house is pulled through the heat exchanger into the relatively cooler ground.

The middle U. S. does not reserve much geothermal energy as the west U. S., especially those are suitable for power plants. For all over the country, there was the highest capacity, 2.8 GW, installed for geothermal power plants in 1990. After then, in 2000 the capacity decreased to 2.5 GW(Williamson, 2001). Giving most of the installed power plaints in west U.S., the middle U.S, which is our researched area, really does not have much potential for geothermal electric power.

In addition, the other two ways of using geothermal strongly depend on the region. They could only use locally and therefore widely spread of energy is impossible. The sustainability that we study requires a substitution of present energy scenario, which includes transportation and non-transportation. The limitation of electricity generation from geothermal energy prevents significantly its widely use, making it impossible to be use in transportation. Meanwhile, even direct use and geothermal heat pumps could substitute a small portion of electricity used in building for temperature control, the limitation of geothermal resource in the middle U.S. as well as their aggregate of energy use at present (it constitute only about 0.04% of the world total primary energy usage(Palmerini, 1993)) show that geothermal energy might not be a promising candidate for sustainable energy.

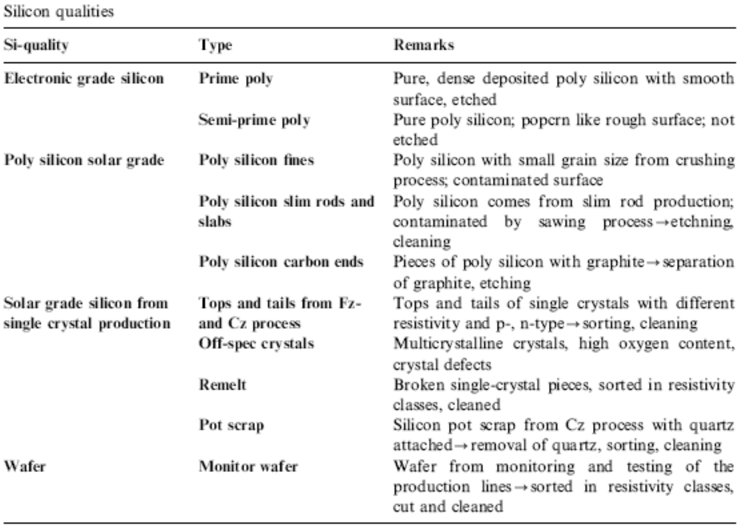
Finally, geothermal energy has several economic and environmental issues. The effluents carry corrosive salts and pollutant gases. The salts build-ups require steady maintenance to keep them from clogging boiler tubes. In addition, the combination of salts and low-temperature steam requires steam turbine blades to be made of special alloys that do not require frequent replacement because of corrosion. The gases emitted after release from geological pressures underground include hydrogen sulfide, CO_2, and radon. The hydrogen sulfide must be scrubbed out in order to eliminate this explosive poisonous gas with its noxious "rotten eggs"smell. The disposal of toxic wastes from this scrubbing and the processing of geothermal fluids must also be done with care. If the geothermal fluids are not re-injected, then pollution of other usable ground water will occur(Asif & Muneer, 2007). All those concerns would increase the cost of geothermal energy and its sustainability development.

For the limited geothermal potential in middle U.S. and its usage, economic and environmental prospects, and because the time limit for this research, we will not include the geothermal energy as a major promising sustainable energy candidate for middle U.S. area.

2.4 Solar

Solar power is ultimately the source from which all the power on earth is derived. Even coal and other fossil fuels are derived from ancient plants that utilized the sun's energy to grow and create organic matter, which later got transformed into carbon-based fuels deep underground. However, with global energy use and concerns of climate change increasing, we must find a way to decrease our release of carbon dioxide into the atmosphere through the use of more efficient and less fossil fuel dependent energy sources. The most common solution touted by many is the use of photovoltaic cells to generate electricity with nothing more than sunlight as fuel, but they often fail to realize the large carbon footprint of the production of silicon-based solar cells. The use of thermal solar generators that use concentrated sunlight to turn water into steam and turn a turbine to generate electricity have been proposed and implemented in very limited quantities, but are still in their infancy. In all, if implemented in a large scale, solar power will never be able to completely eliminate our output of carbon dioxide, but in areas of ample sunlight can replace our current power sources with sources that put out less than one tenth of the carbon dioxide per kilowatt-hour of electricity.

Photovoltaic cells can be manufactured from many different primary materials. By far the most common type of PV cells are silicon-based and it is likely to remain that way in the long run. Compounds such as cadmium telluride (CdTe), gallium arsenide (GaAs), indium gallium phosphide, and germanium (Ge) are used in modern high-efficiency solar cells for applications such as space vehicles, but are still working to overcome high cost, low availability, and in most cases toxicity to the environment (Conibeer, 2007). In comparison, silicon is a non-toxic and mature technology with the cost per MWp constantly being reduced by better refining techniques and ever-increasing cell efficiency. According to Dominique Sarti, between the years 2000 and 2010, production solar cell cost will nearly be cut in half while in the same time period gaining 3% efficiency and using 20% less silicon per cell. This trend is confirmed in a more recent publication stating that the cost will be approximately 69% of the baseline cost with an improvement of 5.3% compared to the baselines listed by Sarti (Event Report 2007). The only current problems with silicon-based PV cells are the large amounts energy and carbon used to refine the silica into silicon and the competition for silicon production between the electronics and the photovoltaic industry.



Silicon qualities

Si-quality	Type	Remarks
Electronic grade silicon	**Prime poly**	Pure, dense deposited poly silicon with smooth surface, etched
	Semi-prime poly	Pure poly silicon; popcrn like rough surface; not etched
Poly silicon solar grade	**Poly silicon fines**	Poly silicon with small grain size from crushing process; contaminated surface
	Poly silicon slim rods and slabs	Poly silicon comes from slim rod production; contaminated by sawing process → etchning, cleaning
	Poly silicon carbon ends	Pieces of poly silicon with graphite → separation of graphite, etching
Solar grade silicon from single crystal production	**Tops and tails from Fz- and Cz process**	Tops and tails of single crystals with different resistivity and p-, n-type → sorting, cleaning
	Off-spec crystals	Multicrystalline crystals, high oxygen content, crystal defects
	Remelt	Broken single-crystal pieces, sorted in resistivity classes, cleaned
	Pot scrap	Silicon pot scrap from Cz process with quartz attached → removal of quartz, sorting, cleaning
Wafer	**Monitor wafer**	Wafer from monitoring and testing of the production lines → sorted in resistivity classes, cut and cleaned

Table 2.4: Silicon Qualities (Woditsch, 2002)

To refine silica into silicon, carbon electrodes are used in an electric arc furnace to reduce the silica (SiO_2) into Silicon while turning the carbon electrodes into carbon dioxide. When the carbon dioxide from the reaction is combined with that emitted from the power plants that provide the power to the furnace used for the silicon refinement, at approximately 2200°C, it becomes a very energy and carbon intense process (Murray, 2006). It is only from the lack of emissions for the rest of the 20 year lifetime of the solar panels that the carbon footprint is approximately 17 – 49 gCO_2/kWh of electricity (Fthenakis, 2007). Compared to the carbon dioxide emissions from the current electricity mix of the Central United States of approximately 695 gCO_2/kWh, solar offers an extremely attractive alternative (Fthenakis, 2007).

No reliable data is available to analyze the carbon emissions associated with the creation and maintenance of solar concentrating power facilities, but in the near-term they are the best solar-based alternative energy source. Using aluminum at 1000 Angstroms thick (Martinez, 2000) as the source of the reflective surface for the mirrors in place of the silicon used in PV cells, the energy used and carbon dioxide emitted by the creation of these facilities will be approximately 1000 times less than the equivalent photovoltaic power system. The only limitation with the solar concentrating power plants that is the required land area as with all other forms of solar power.

2.5 Wind

In the old time the wind power were mostly used for sailing, pumping water and grinding grains. However, modern wind power is mostly supplying electricity to utility grids and remote-site users around the world. For the already gained competitive cost and revenue compared with legacy electricity plant, wind power is facing a bright future for becoming part of the electric generation mix of many utilities, especially in North American and Northern Europe.

United States has a great potential of wind power, especially in middle U.S., even though most of it has not been fully made use of. Figure 1 shows an atlas of annual wind energy resource of United States.

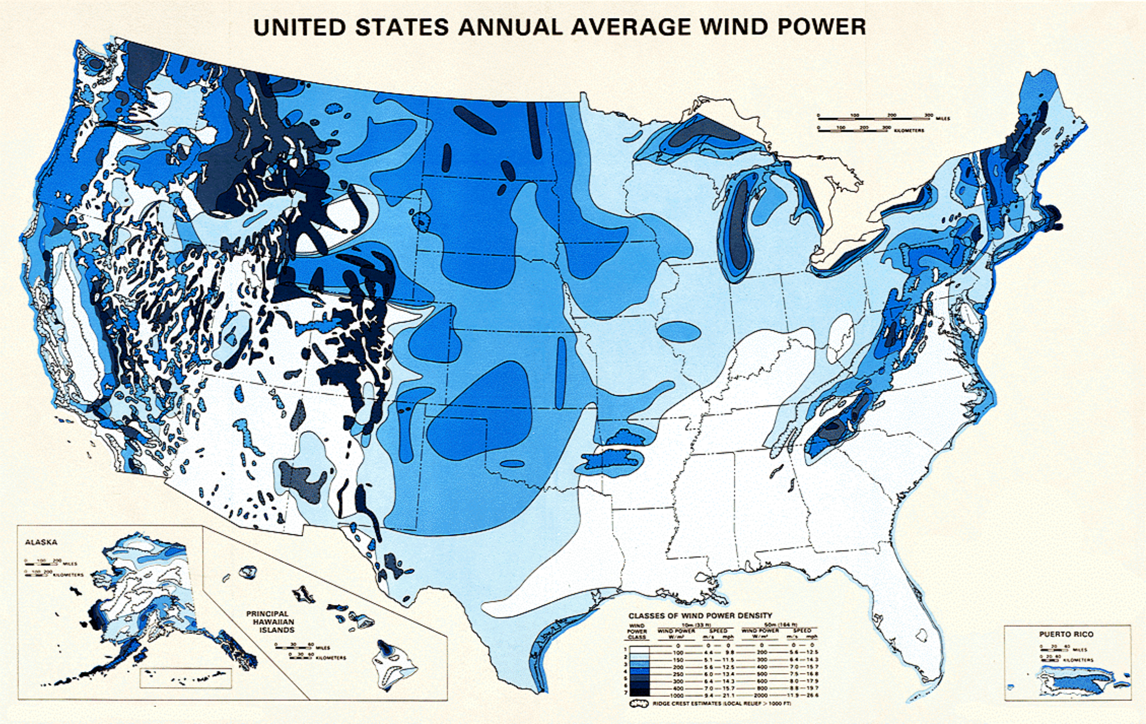
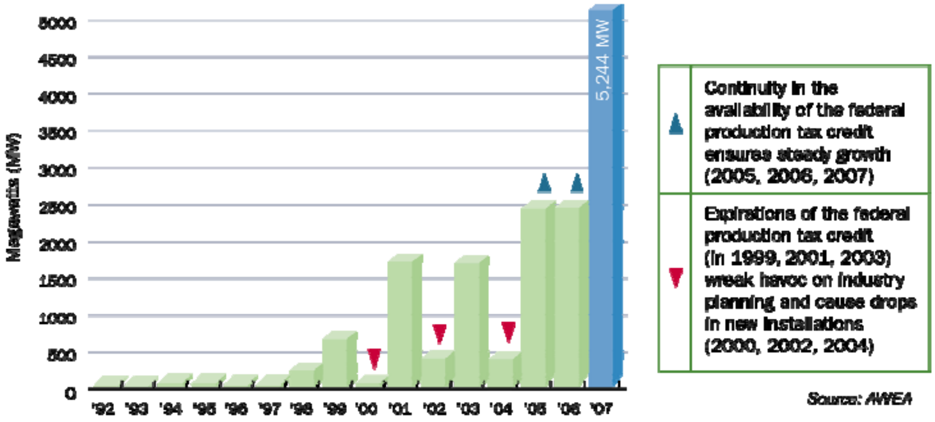


Figure 2.2: Annual wind energy resource of United States (source: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html)

From Figure 1 we could easily see that there is a huge wind potential in the middle US. Even the area of highest rank wind power is less than that in west U.S., but the plainness of terrain, rather than the mountains in west, make it comparatively easy to install wind turbine in middle U.S. and consequently a large area for using wind energy. North Dakota has the highest wind potential in the middle U.S., which is 500 W/m^2 at least, while Louisiana has the lowest power potential, which is below 200 W/m^2.

The technique of using wind power greatly improved over time. Modern wind turbines are designed on the aerodynamic principle of lift similar to that of aircraft wings or sail boat. Lift forces are created on an aerofoil when its leading edge is oriented at small angle to the direction of the incoming wind. It forces the blade rotating to generate usually 690V electricity, which will be transformed to 10~30 kV for transmission (Kuvlesky et al., 2007).

Development of wind energy is speeding during the past decade. In 2007, the wind power industry hit a recorded 45% increase in new-installed capacity, which is over 5200 MW (Association), 2008). With the aggregate, wind power is now one of the largest sources of new electricity generation of any kind. Figure 2 shows the growth of annual installed capacity of wind power.



Source: AWEA

Figure 2.3: Annual installed wind power capacity

The fast increasing investment in wind power makes U.S. the leading country all over the world in developing wind energy. The middle U.S., plays an important role in this achievement. Wind power development in Texas continues to outstrip the rest of the country, with 1618 MW added in 2007, the most of any state by far, and another 1200 MW under construction as of early 2008 (Association), 2008). With Texas as the first one, the top 15 states of totally installed wind power capacity have half of them in middle U.S. (Association), 2008)

The amount of power captured from a wind turbine is specific to each turbine and is governed by:

$$Pt=0.5\rho ACpV_w^3$$

Where, Pt is the turbine power, ρ is the air density, A the swept turbine area, Cp is the coefficient of performance and V_w is the wind speed. The coefficient of performance of a wind turbine is influenced by the tip-speed to wind speed ratio or TSR given by:

$$TSR=\omega r/V_w$$

Where ω is the rotational speed and r is the turbine radius. Figure 3 shows a typical relationship between TSR and coefficient of performance, and consequently the turbine power (Baroudi, Dinavahi, & Knight, 2007). Figure 4 shows a typical relationship between wind velocity and output power (Edelstein, Walcek, Cox, & Davis, 2003).

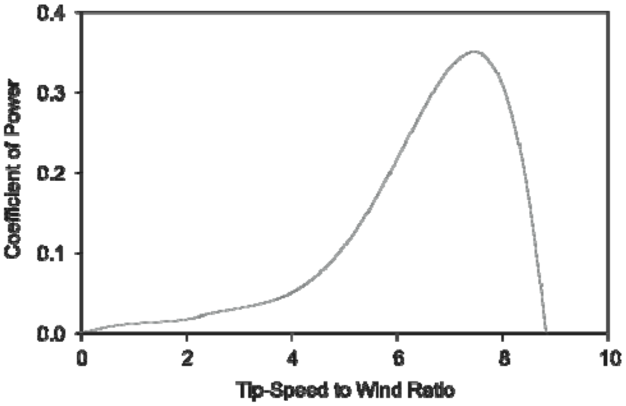


Figure 2.4: Typical coefficient of power curve

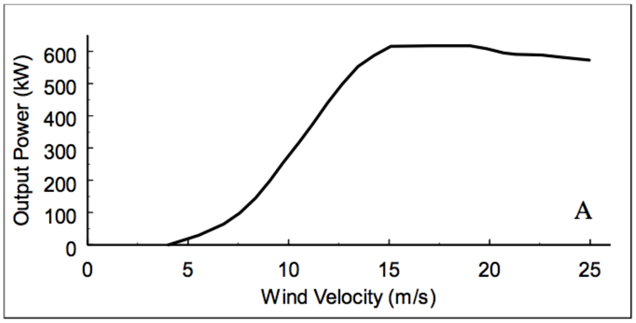


Figure 2.5: Typical power curve of wind velocity

High wind velocity would also decrease the cost of wind turbine, and so are larger output wind turbines. There is a trend of increasing capacity during the past years for wind turbines installed. In 2007 United States had an average of 1.6 MW wind turbines installed, and larger capacities of wind turbines are on draft (Association), 2008). New techniques are being used into wind turbine to extend the working time and double the output (Frankovic & Vrsalovic, 2001), which will significantly promote the development of wind energy.

Even claimed as “non-emission” energy, wind turbines still emit green house gas during their lifetime. The materials used for building those wind turbines will consume energy and emit GHG when they are being made. But later calculation will demonstrate that the CO_2 emission per energy unit will be much lower than those from fossil fuel, and the energy generation will be larger than those consumed. What is more, wind turbines usually have a short lifetime, which is about 20 years, and the net profit has been observed only positive on some large output power project. However, new techniques are kept implementing to existing wind turbine, and high output set, either large wind farm or larger wind turbine, is continuing to reduce the cost of wind power plant. Figure 5 (Onat & Canbazoglu, 2007) shows the reduction in cost through the increase of output:

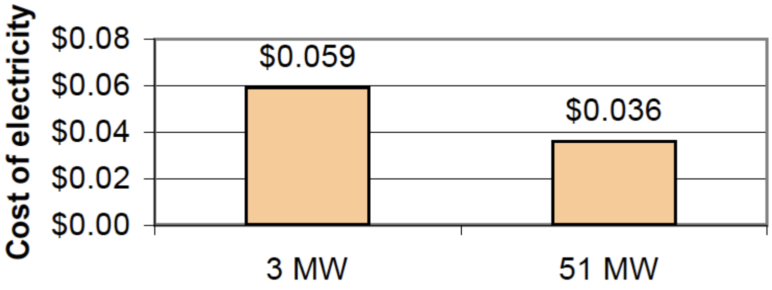


Figure 2.6: Cost of energy - large wind farm vs. small

The middle U.S. has a large amount of wind potential, although most of it has not been developed yet. The improvement in wind energy use keeps speeding during the past years. The 45% increase in capacity during 2007 demonstrated the admission of market as well as the society’s expectation. Giving the improving technology, the cost of wind power electricity could already be competitive to fossil fuel electricity, and the huge un-developed wind potential in this area is showing a bright sustainable future. The barriers at present will definitely be crossed with scientific research. Therefore, we believe that wind energy is an important sustainable energy candidate which will devote a significant part in our future energy scenario.

2.6 Biomass

Biomass is organic materials which are composed of chemical bonds. Researchers characterize plant biomass as four main types; woody plants, herbaceous plants/grasses, aquatic plants and manures. Since biomass is converted into useful energy sources like bio-fuels and bio-gases via various processes, they are tabulated in Table 2.1.

Type	Energy source	Process
Grain starches or sugar crops	[1]Bio-ethanol	Fermentation
lignocellulosic fractions of crops or wastes		Acid/enzymatic hydrolysis & Fermentation
[2]Vegetable oil (rapeseed, soybean oil), animal fat	Bio-diesel	Mechanical conversion & Trans-esterification
[3]Syngas		Fischer-Tropsch
[4]Starch gel, wood sawdust		Fast pyrolysis & hydrotreatment
[4]cellulose, hemicellulose and lignin	Gases (H_2, steam, CH_4)	Pyrolysis
[5]Wood, grass, saw dust, sewage sludge		Fluidized-bed gasifier
[1]Landfill gas, sewage biogas		Biological, chemical & heating processes

Table 2.5 Biomass Types and Their Converted Energy Sources via Chemical and Physical Processes (1 : Bridgwater, 2006, 2 : Ma and Hanna, 1999, 3 : Greene et al, 2004, 4 : Yaman, 2004, 5 : McKendry, 2002)

Although the production of bio-diesel is still low, America is the world largest producer of bio-ethanol with Brazil. However, since the amount is just 3% of the country's total gasoline consumption, researchers and government have been looking for the way to increase its production. Most ethanol produced in America is obtained from corn. Especially, Midwest area (IL, IA, MN and NA) in the central USA grows more than 50% of total corn in the USA. According to a survey (Perlack et al, 2005), US land is composed of 33% of forest, 26% of grassland pasture and range, 20% cropland, 8% public facilities and 13% of urban land and desert. Total cropland is around 400 million acres, among which 90 million acres is for corn and 70 million acres is for soybean (http://www.ipm.iastate.edu/ipm/icm/2007/4-2/acreage.html). And, corn production for bio-ethanol occupies around 12% of total corn use (http://www.ers.usda.gov/AmberWaves/April06/Features/Ethanol.htm). Under the limited cropland, it is hard to increase the cropland for corn to get more bio-ethanol. Consequently, bio-ethanol process for grain starch like corn has been suggested to step into the process for lignocellulosic franctions like grasses and woods in order to increase its production.

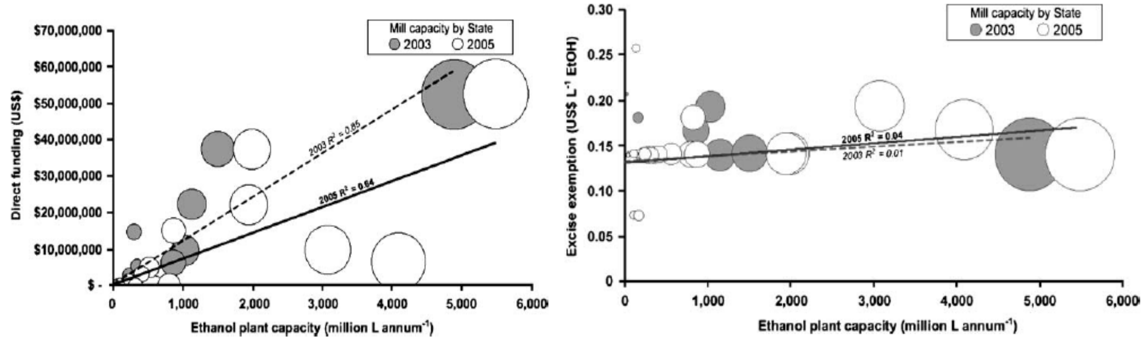
There have been many researches regarding energy production from biomass. Table 2.2 shows energy generation from biomass and its yield.

Energy type	Generation	Yield	Reference
Electricity	150 – 300 kWe	1000 dt/y/100 ha	Bridgwater, 2006
	1 MWe	1000 ha	Franco and Giannini, 2005
	100 kWe	55 ha (SRC willow)	McKendry, 2002
Bio-ethanol	50 gallons/dt	12 dt/y/ha (switchgrass)	Greene et al, 2004
	97 – 102 gallons/dt 89 – 108 gallons/dt	7.5 – 9.0 dt/ha (corn) 8.2 – 33.6 dt/ha (poplar, corn stover, swithgrass)	Hammerschlag, 2006

Table 2.6 Energy Generation from Biomass and Its Yield

Although ethanol from switchgrass is less productive than from corn at present, the former has been regarded as a promising biomass to replace corn. The NRDC report and McLaughlin et al displayed that since it needs less fertilizer and herbicides than food-crops, land erosion and water contamination are much reduced as well as less fossil fuel usage on farm. However, since it is composed of much cellulosic portion, it needs more processes such as hydrolysis & acid treating than corn does. Moreover, the government should induce farmers to replace their some farmlands for corn and other crops, and forest area with switchgrass. Accordingly, proper national policy is important to proceed this work as well as research development to increase the production yield of bio-fuels.

Although bio-fuels have been significantly increased thanks to the technological development, the proper national policy also plays a crucial role to encourage farmers and industries to increase their production (Mabee, 2007). Fig. 2.1 displays the role of funding program and excise tax exemption for bio-fuel production. The figure shows that funding program has a positive effect compared to tax exemption.



(a) (b)

Fig. 2.7 (a) Sum of Federal and State/Provincial-level Funding Programs for Renewable Fuels vs. Cumulative State/Provincial Bio-ethanol Production Capacities, 2003 and 2005 (b) Sum of Federal and State/Provincial-level Excise Tax Exemptions for Bio-ethanol vs. Cumulative State/Provincial Bio-ethanol Production Capacities, 2003 and 2005

Unlike the burning process of fossil fuels, burning biomass doesn't contribute new CO_2 to the atmosphere because CO_2 is absorbed and returned for a biological cycle. Argonne National Laboratory released the model, which is called GREET, in order to estimate whole GHG emissions from the farm to vehicles (WTW) for transportation fuels (Wang, 2007). Fig. 2.2 shows the relative GHG emissions compared to gasoline for various ways to produce corn ethanol and cellulosic ethanol. The figure clearly exhibits that corn ethanol emits less GHG even though it is processed with various methods using natural gas. However, the reduction of the emissions is the most pronounced with cellulosic ethanol than with corn ethanol.

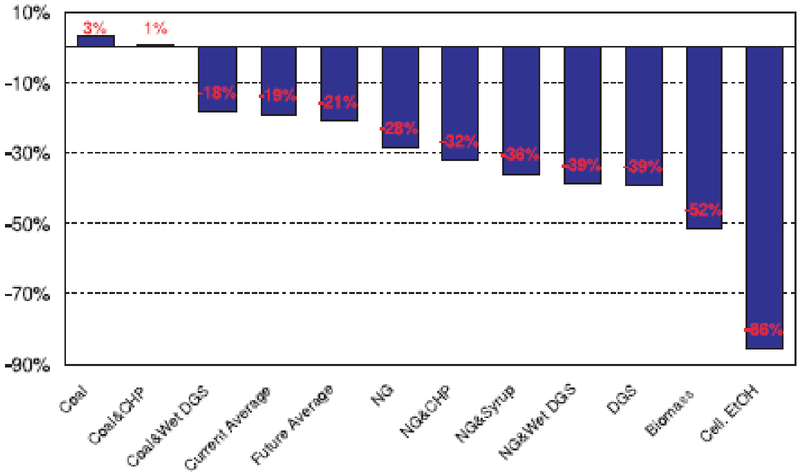


Fig. 2.8 Well-to-Wheels GHG Emission Changes by fuel Ethanol Relative to Gasoline (Wang, 2007)

Although many researchers also showed the similar result as the above, Fargione et al gave a different opinion on the CO_2 emissions from bio-ethanol. They used a worldwide agricultural model to estimate emissions from land use change and found that corn-based ethanol nearly doubles greenhouse gases over 30 years. Fargione et al. claimed that converting rainforests, peatlands, savannas or grassland to produce food-based biofuels in Brazil, Southeast Asia, and the United States creates a 'biofuel carbon debt' by releasing 17 to 420 times more CO2 than the annual greenhouse gas reductions incurred by displacing fossil fuels. These two researches implied that the biofuels made from other sources, such as waste products or biomass grown on abandoned agricultural lands, is more favorable. The idea of 'Biofuel carbon debt' suggested the importance of considering the source materials and pathway for producing energy, however, the credibility of the results are still questionable.

In the biofuel data in our project, we refer to the data based on the model (GREET) developed in Argonne National Laboratory (Wang et al). Wang and coworkers found that different ethanol plant types can have distinctly different energy and greenhouse gas emission effects on a full fuel-cycle basis. In particular, greenhouse gas emission impacts can vary significantly – from a 3% increase if coal is the process fuel to a 52% reduction if wood chips are used. In our model, we chose two cases of Wang's report as our biofuel options. The first scenario is to produce ethanol from corns, 87.5% by dry milling plants and 12.5% by wet milling plants. The second scenario is to produce cellulosic ethanol from switch in the future. Due to the time limit of this project, in our simulation, we chose the second scenario in our energy demand and supply optimization. Further study regarding the ethanol production methods is possible and can be added to our model.

3. Energy Projection

3.1 Energy consumption in America

According to the data from EIA, America consumed 100 quadrillion BTU in 2005, which is more than 20% of world energy consumption(Holte, 2006). As shown in Fig. 3.1, the consumption of liquid fuels is largest, and coal and natural gas are followed in their consumptions. Compared to these fuels, the portion of nuclear and renewable energy, which emit much less CO_2 emissions, is relatively small.

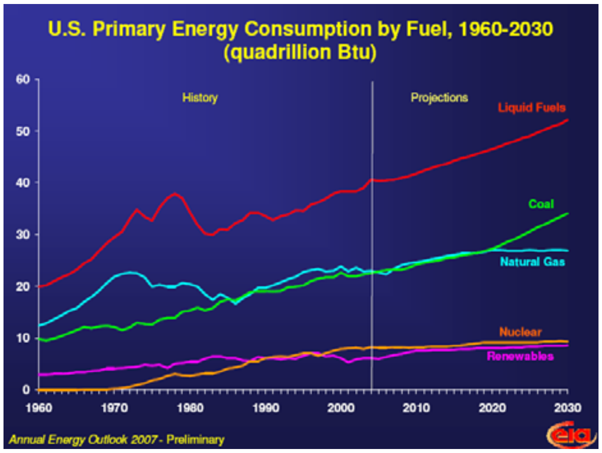


Fig. 3.1 Primary Energy Consumption by Fuel in the USA

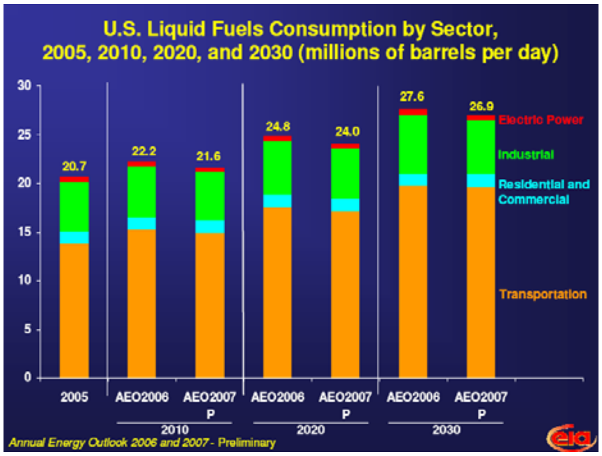


Fig. 3.2 Liquid Fuel Consumption by Sector in the USA

As displayed in Fig. 3.2, two thirds of liquid fuels have been used for transportation and Industry also used much of liquid fuels. Annual Energy Outlook (AEO) in 2006 and 2007 expected that these energy consumption trends would not change much until 2030.

3.2 Energy consumption in the central USA

Since EIA provides energy consumption in each state, we summed up all the energy consumption by fuel in the central USA (ND, SD, NB, KS, OK, TX, LA, AK, MO, IA, MN, WS, IL, IN, MI, OH) as shown in Table 3.1.

Fuel	Consumption (trillion Btu)	Energy portion in Central (%)	Energy portion of each fuel in the USA (%)
Coal	10,262	25.6	45.0
Natural gas	10,668	26.6	47.0
Petroleum	15,918	39.7	39.1
(Transportation)	(9,898)	(24.7)	-
(Non-transportation)	(6,020)	(15.0)	-
Nuclear	2,678	6.7	32.9
Hydro	194	0.4	7.2
Others	413	1.0	-
Total	40,133	100	40.0

Table 3.1 Energy Consumption by Fuel in the Central USA

As shown in Fig. 3.1, the trend of fuel consumption in the central USA is similar to that of the whole USA. Petroleum occupies almost 40% of the total consumption and both of coal and natural gas have been used around 26%. However, nuclear, hydro power and others including renewable energy don't contribute much. Table 3.1 also exhibits how much each fuel in this area has been used compared to its total consumption in the USA. Accordingly, the central USA consumed 45% of coal, 47% of natural gas and 39.1% of petroleum. Therefore, we can conclude that this area consumes more fossil fuels than the other areas while it does much less hydro power than the other areas. Consequently, it seems that the central USA generates more CO_2 emissions than the other areas.

America emitted almost 6 billion metric tons of CO_2 (6.0×10^{15} g CO_2) in 2005. (Holte, 2006). According to our calculation, the central USA did 38% of total CO_2 in the USA, which is almost the same ratio like the total energy consumption. Fig. 3.3 shows the CO_2 emissions from each fuel as shown in Table 3.1. The emissions from petroleum occupy 40% of total emissions in the central area because its energy consumption is highest among fuels. Although energy consumption of coal is similar to that of natural gas, the former emitted much more emissions than the latter. Again, we calculated the ratio of CO_2 emissions in the central USA to the emissions in the whole USA for each fuel. The result showed that coal and petroleum in the central area contributed 37% and 34%, respectively, to the whole emissions, and natural gas did 46%. Thinking of the energy consumption of each fuel, the percentages of the emissions for coal and petroleum are much less than expected. Although we didn't find the reason, it is assumed that some of coal and petroleum in the central area are used for some facilities which emit less CO_2 emissions.

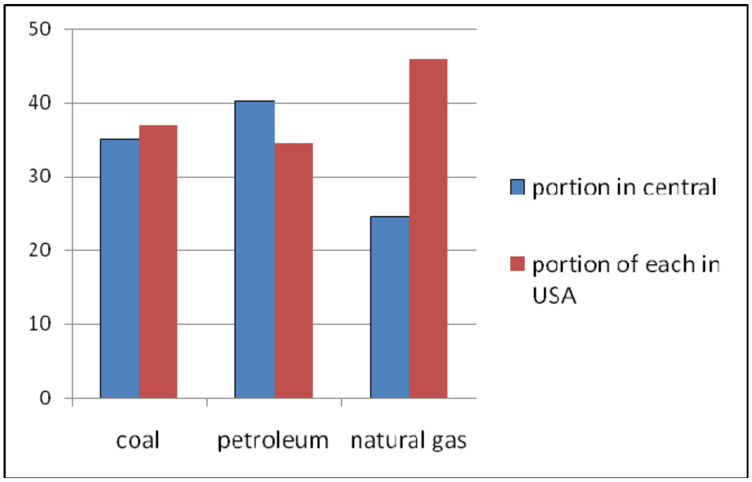


Fig. 3.3 Ratios of CO_2 Emissions from Each Fuel

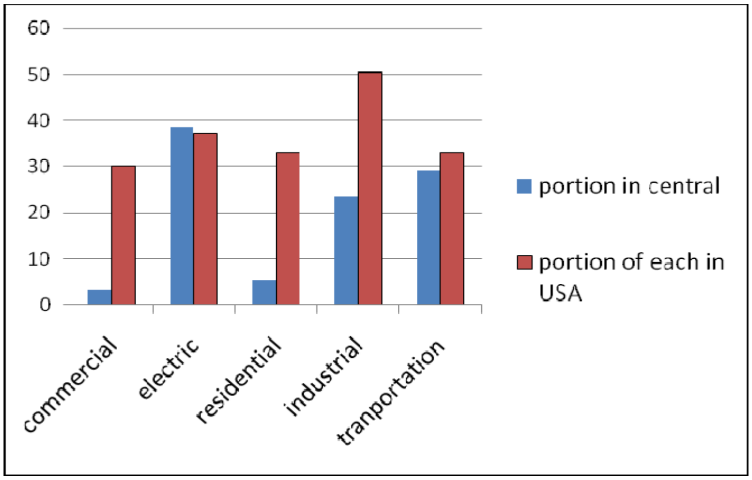


Fig. 3.4 Ratios of CO_2 Emissions from Sectors

The CO_2 emissions in the central USA are also analyzed according to sector in Fig. 3.4. It shows that electricity is the biggest part and transportation and industry are followed in their emissions. The CO_2 emissions from electricity are much related with coal and natural gas, and those from industry are due to the natural gas and petroleum. And also, the figure displayed that the industrial sector in the central USA emits much more CO_2 than the other areas in the USA, so it seems that the more industry-oriented structure of the central USA generates more CO_2 emissions.

3.3 Reference model

Since our goal is to replace the energy consumption with renewable energy in 100 years, we constructed our reference model to calculate energy consumption and CO_2 emissions. Energy consumption in our timeline is projected from the assumption that the population in the central USA will consume same amount of energy they did in 2005, although we also employed policy and technology impacts in the model. The overview is shown in Fig. 3.5.

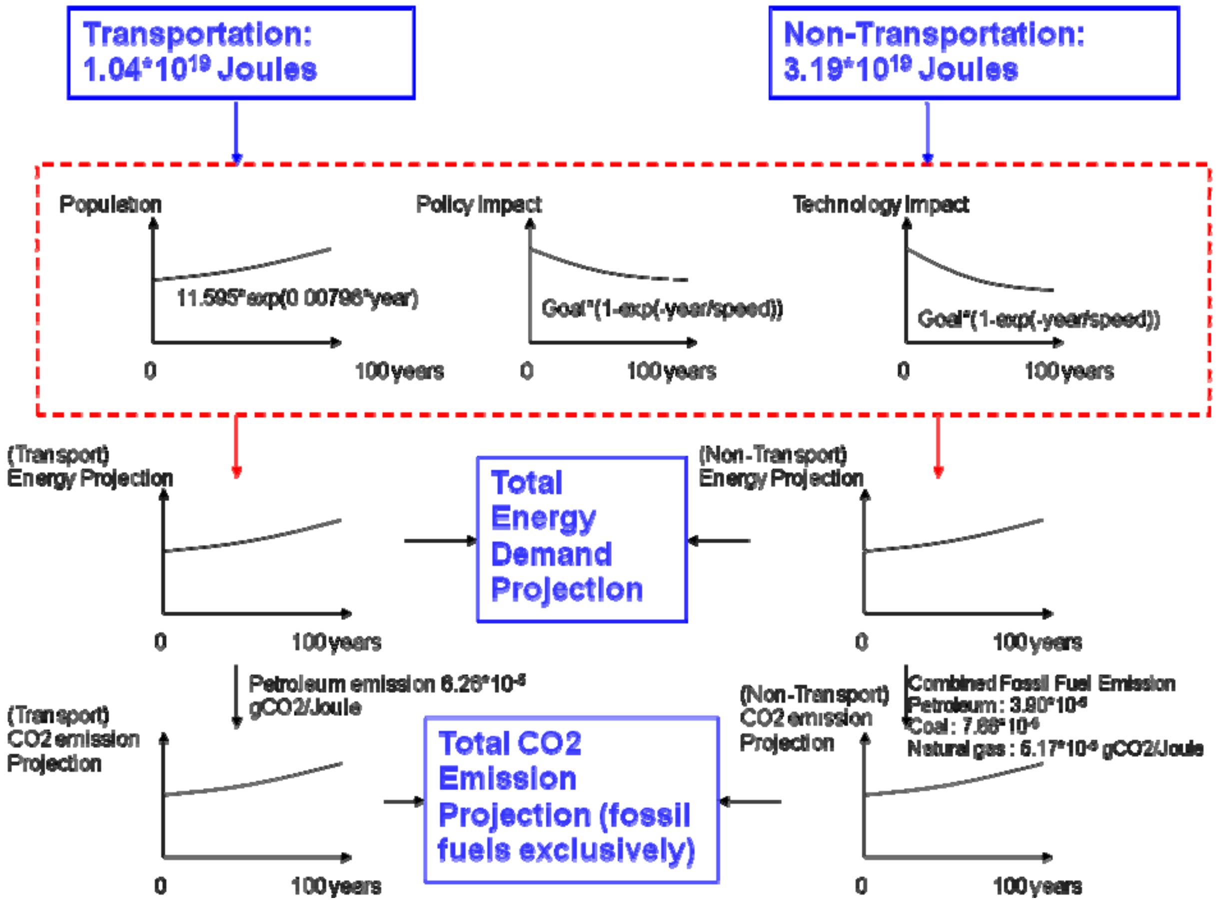


Fig. 3.5 Overview of Our Reference Models to Project Population, Energy Demand and CO_2 Emissions in the Central USA

Fig. 3.6 shows the history of the population and our projection in the future in the central USA. Since we assumed that it would increase exponentially, the population growing equation is obtained like (3.1)

$$\text{Population} = 11.5946*\exp(0.00796*\text{year}) \qquad (3.1)$$

After then, we normalized the values based upon the population in 2005.

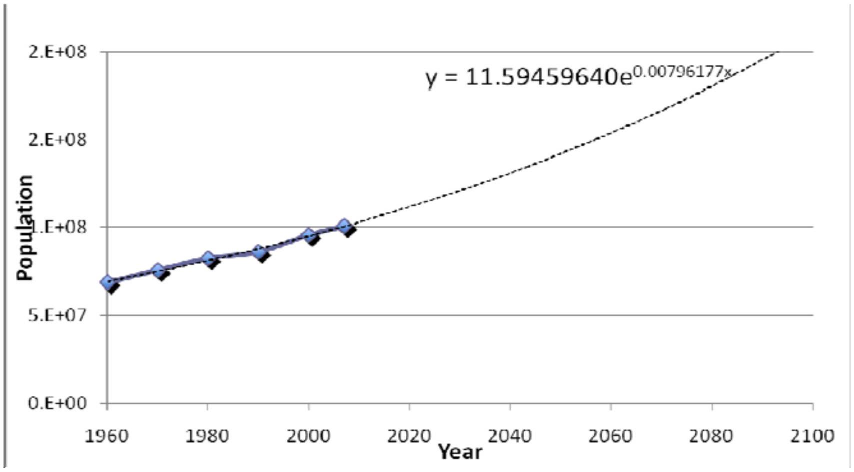


Fig. 3.6 Projection of the Population in the Central USA

Before we reflect population growth to the calculation of energy consumption, we considered policy and technology impacts in our model because they will affect much energy consumption as we discussed in the review part.

Impact factor (policy, technology) = Goal*(1-exp(-year/speed)) (3.2)

Since they have different goals and speeds, we separated their impacts on the energy demand to adjust those values.

Unlike other sectors, transportation uses liquid petroleum fuels as a main fuel. Therefore, we divided transportation section and non-transportation section to investigate their energy consumption trends when alternative energy is applied in the future. For the sake of easy access, we assumed that petroleum is the only fuel in transportation and its percentage in total energy consumption is the same throughout our timeline. As shown in Table 3.1, the central USA consumed 24.7% of total energy for transportation in 2005, which is 1.04×10^{19} Joule. Finally, we multiplied energy consumption in transportion and non-transportion separately with normalized population, policy impact and technology impact.

The reference CO_2 emissions are also calculated for transportation and non-transportation separately according to their energy consumptions. We also assumed that the ratio of each fuel in 2005 is the same throughout our timeline. In addition, we introduced CO_2 emissions per unit energy for each fuel in our model assuming that each fuel generates fixed amount of CO_2 per unit energy consumption. Because the generated CO_2 from petroleum is different for trasportation and non-transportation, we divided CO_2 emissions and energy consumption of petroleum carefully as shown in Table 3.2.

Sector	Fuel	CO_2 emissions (10^{14} g)	Energy consumption (10^{19} J)	CO_2 emissions per unit energy (g/J)
Non-transportation	Coal	7.863	1.0827	7.662×10^{-5}
	Natural gas	5.512	1.1255	5.167×10^{-5}
	Petroleum	2.475	0.6351	3.697×10^{-5}
Transportation	Petroleum	6.539	1.0443	6.262×10^{-5}

Table 3.2 Energy Consumption Per Unit Energy Consumption for Each Fuel

Since we fixed the ratio of each fuel consumption, we could project CO_2 emissions from transportation and non-transportation of reference throughout our timeline.

3.4 Comparison of others' projections with ours

There are several projection data about population growth, energy consumption and CO_2 emissions in the USA. Since these don't provide the projections for the central USA, each parameter in the central USA is calculated according to the ratio of the central USA to the whole USA as displayed in Table 3.3.

Parameter	Projected data	Ratio of central USA to whole USA (%)	Reference for the ratio data
Population	[1]Paper [2]US census	33.8	US census 2004
Energy consumption	[1]Paper [3]IEO2007 [3]AEO2007	37.7	EIA 2005
CO_2 emissions	[1]Paper [3]IEO2007 [3]AEO2007	40.0	EIA 2005

Table 3.3 Projection Criteria in the Central USA (1: Tol, 2007, 2: EIA, 2007, 3: US Census, 2004)

Our reference projection for population is compared to those of the model of paper and US census in Fig. 3.7. The population projected by US census until 2050 is almost the same of ours. However, the paper's projection is less than ours and US census'. As aforementioned, the population by our model increases exponentially while that by the paper does linearly. Since the paper considered fertility, mortility and migration in the USA, it might estimate it more reasonably. Government policy and economical situation in the future, however, may excelerate this increasing rate like our projection, so we sticked to our projection for further calculation.

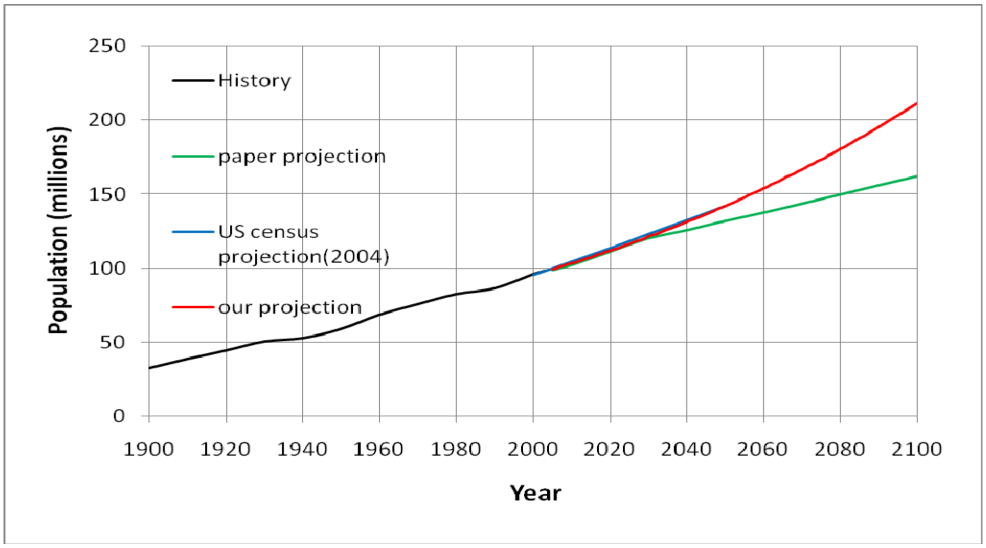


Fig. 3.7 Comparison of Our Projected Population with others'

In Fig. 3.8 our projected energy consumption is compared to IEO2007 (International Energy Outlook, AEO2007 (Annual Energy Outlook) and the paper's. The AEO projected by EIA, estimates much less energy consumption than others. Especially the paper expected that the USA would spend more energy in the future than they did in the past. Although our model projects more population than the paper's, the former does less energy consumption than the latter. It might be because policy and technology impacts in our model were employed more aggressively than some parameters in the paper's model. Since our projection is much similar to AEO's, it looks reasonable to calculate CO_2 emissions from this data.

Fig. 3.9 shows several projected CO_2 emissions. The trend of emissions for each projection is similar to that of energy consumption because the former must be estimated from the latter. The projected energy consumption of the paper increases linearly, but the increasing rate of its emissions seems to become slower after 2080. It is because the paper expected that nuclear and renewables which emit much less CO_2 will displace much portion of present fossil fuels. Although the trend of our model follows that of the AEO's projection like energy consumption, its starting point is underestimated. Although nuclear, hydro and renewables emit CO_2 during their construction, EIA data excluded their emissions. Since we projected the CO_2 emissions from the emissions per unit energy as shown in Table 3.3, their energy consumption was not employed for this calculation process in non-transportation sector.

Although the starting point of ours is 9% lower than the real CO_2 emissions in 2005, we extended our model for the application of renewables based upon this reference model.

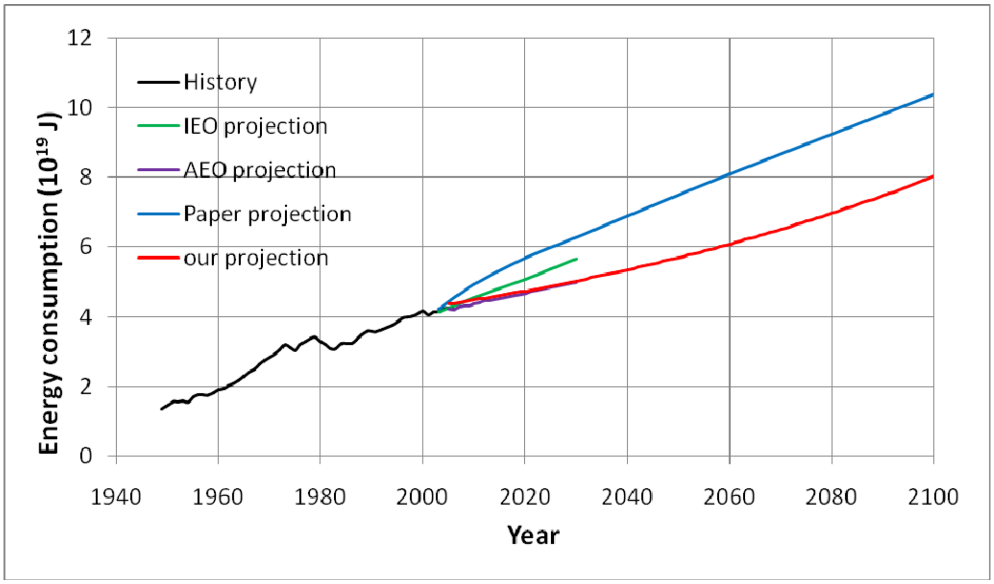


Fig. 3.8 Comparison of Our Projected Energy Consumption with Others'

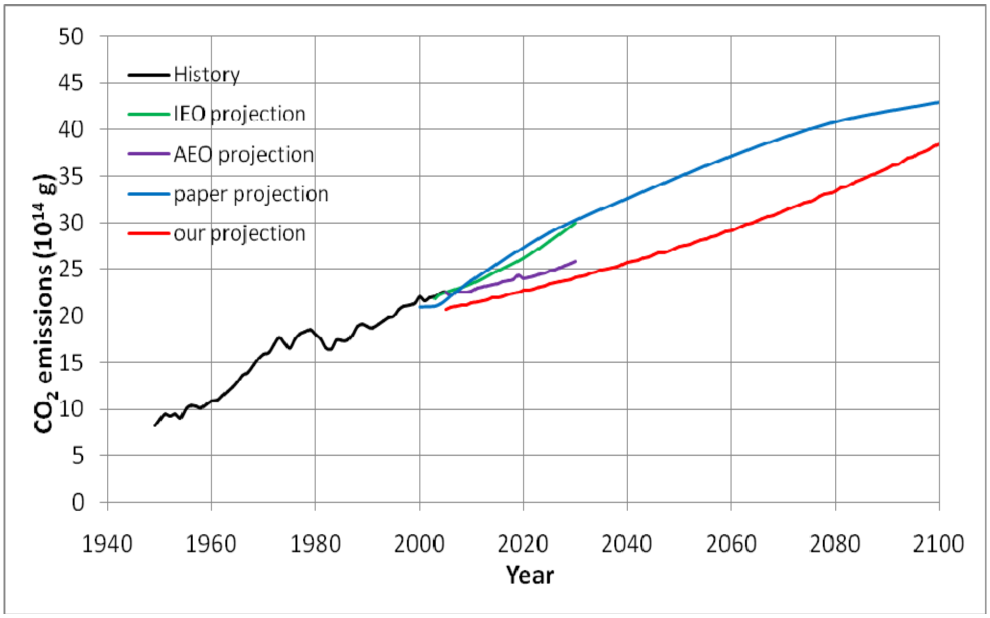


Fig. 3.9 Comparison of Our Projected CO_2 Emissions with Others'

3.5 Energy Reduction

There are four main ways to save significant energy that are invisible to the consumer with regards to appliance performance and beneficial to consumer with respect to cost and energy consumption: fluorescent lighting, energy star appliance rating, and working towards the One Watt Initiative, and CAFE standards for transportation vehicles. Compact fluorescent lighting offers lighting equal to standard incandescent bulbs but consume approximately 75% less energy. The fluorescent bulbs cost approximately two to three times as much as an incandescent but more than make up for their higher initial cost through an increased lifespan and vastly lower electricity consumption. As is seen in Table 3.4 consumers will save on average 33 dollars and over 500 kg of carbon dioxide from being emitted by replacing one 100 watt light bulb with the equivalent compact fluorescent unit. If all incandescent light bulbs were replaced with CF lighting, approximately 2% of the total carbon dioxide currently being emitted could be mitigated.

	Incandescent	Compact Fluorescent
Lifespan of Bulb (Hours)	4000	10000
Cost Per Bulb (Dollars)	1	3
Bulbs Required per 10k Hours	2.5	1
Electricity Use (Watts)	100	26
kW-hrs Used per 10k Hours	1000	260
Cost Per kW-hr (Dollars)	0.0455	0.0455
Total Bulb Cost (Dollars)	2.50	3.00
Total Electricity Cost Per 10k Hours (Dollars)	45.50	11.83
Total Cost per 10k Hours (Dollars)	48.00	14.83
CO2 per 10k Hours (kg)	695	180.7
Monetary Savings per 10k Hours (Dollars)	0.00	33.17
CO2 Savings per 10k Hours (kg)	0	514.3

Table 3.4: Assumptions and Cost/Effects of Compact Fluorescent Lighting

Many opponents of fluorescent lighting argue that the mercury in compact fluorescent lighting is too substantial to justify the energy savings from them. However, when according to Figure 3.10, one can see that assuming 100% of the electricity for lighting comes from coal, more nearly twice as much mercury is emitted by incandescent bulbs. In the United States approximately 50% of the electricity is derived from coal, therefore the mercury emissions associated with compact fluorescent light bulbs and incandescent bulbs are almost identical.

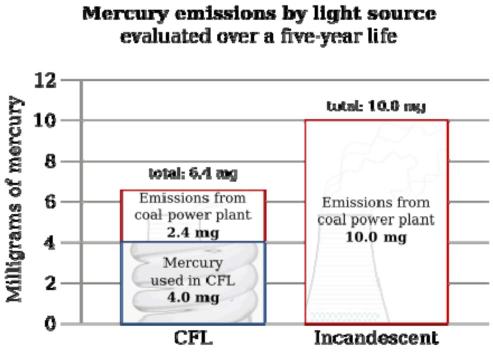


Figure 3.10: Mercury Emissions from Lighting Assuming 100% Coal Electricity

Energy star appliances are designed to perform the same duties as standard appliances but while consuming significantly less energy and resources. Table 3.5 summarizes the minimum energy savings of different energy star certified products. When these savings are factored into the average energy used by each appliance in a household every year, by switching to energy star certified appliances we can save more than 1% of our total carbon dioxide emissions every year.

Dishwashers	41%
Televisions	30%
Refridgerators	15%
Buildings	15%

Table 3.5: Example of Energy Star Certification Required Energy Savings

The One Watt Initiative is an effort to minimize the standby power use of household appliances. Current appliances use between 1 and 25 watts even when turned off. When this is multiplied by the billions of appliances in the United States the standby power use accounts for approximately 2% of the total carbon dioxide emissions in the United States: reducing standby power use to a fraction of a watt will help to eliminate this.

When all three of the above energy savings techniques are combined with CAFE standards on transportation vehicles, our group calculated a total of 11% energy savings is possible without incorporating visible regulations on the general public. By imposing the stricter standards on the corporations that create the appliances and transportation vehicles, the general public will in fact save money at the same time as save energy.

3.6 Policy and Regulation Impacts

The US government, however, has rejected mandatory targets for curbing emissions under Kyoto Protocol, and has instead pursued voluntary mitigation measures amid a larger push for clean coal and next generation nuclear technologies. Nevertheless, action within the US is indeed moving forward, with states, cities and regional partnerships filling the federal leadership gap (Byrne, 2007). Therefore, in the central area, it is possible to set up a portfolio standard or regulation according to the natural resources and energy consumption specifically. Geller et al (Geller, 2006) shows that well-designed policies can result in substantial energy savings as demonstrated in the US where nine specific policies and programs reduced primary energy use in 2002 by approximately 11%. In our energy demand and supply model, we would use the result of this research. In our model, energy demand reduction coefficient is evaluated as follows:

$$Policy\_and\_Regulation\_Impact\_Ratio = 1 - Target\_value \times (1 - \exp(\frac{-year}{speed}))$$

We set our target goal of energy reduction as 11%, but a relatively slow enforcement speed (100) to prevent a radical change to our society. Figure 3.11 is the pathway that is used in our model.

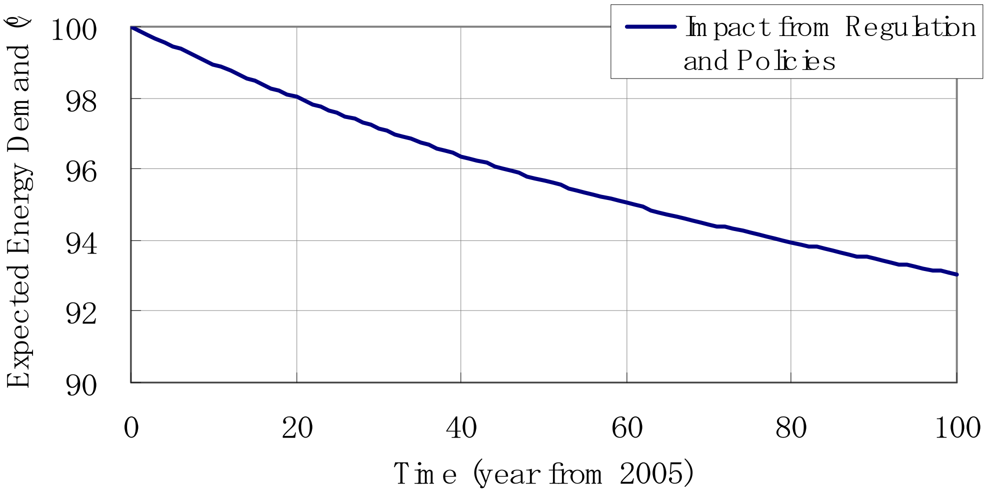


Figure 3.11 The expected energy demand reduction

4. Possible Renewables

4.1 Solar

The Central United States used approximately 1.36 trillion kWh worth of electricity for homes in 2001 (Energy Information Administration, 2001). In order to model the land area needed to generate solar-based electricity on the same order of magnitude as the current power consumption we can use the recently built “Nevada Solar One” as a model. Built in 2007, the Nevada Solar One utilizes modern technology to assure peak efficiency, but still only generates 134 million kWh of power over the course of a year in an area of 320 acres (half a square mile) at a total efficiency of approximately 4% (Siemens, 2008). Assuming this, the area required to generate electricity for the entire Central United States would be on the order of 5,000 square miles (the size of the state of Connecticut). Compared to the area of the Central United States this only represents slightly over 0.4% of the land area available. The obstacle in this case is the total cost of installing concentrating solar facilities at this scale. Nevada Solar One had a price of $250 million, so in order to displace 100% of the current total household energy use with the concentrating solar power; the price would reach one and a half trillion dollars (Nevada Solar One, 2008).

If photovoltaic cells were utilized in combination with concentrated solar power, the size of the land area needed for power generation would be greatly reduced since most commercially available photovoltaic cells are approximately 10 – 14% efficient. As with concentrating solar power, the problem with photovoltaic cells is the cost and scale of production required for displacement of a significant portion of current power consumption.   It is predicted that by 2013 there will be a maximum of a combined PV cell peak power output of approximately 10,000 MW, which is about equal to 1% of the total predicted power consumption in that timeframe (Event Report, 2007). In order to displace a significant portion of a household's electrical use with photovoltaic cells, it has been quoted to cost approximately $14,000 (Hemburger, 2008). When this is multiplied by the approximately 25 million households in the Central United States, the cost of using photovoltaic cells is on par but slightly less than concentrating solar power at $350 billion dollars. Unfortunately photovoltaic cells are currently manufactured from reject silicon from the electronics industry which has a very limited supply. To meet demand with the growing interest in solar power, a separate solar grade silicon feedstock industry will need to be established. Until this happens, thinner, less resource dependent solar cells are the next best solution allowing more cells to be created with the same amount of silicon.

An emerging technology that mates the advantages of low energy and carbon investment of concentrating solar power with the advantages of higher efficiency from PV based solar power with none of their downfalls is concentrating photovoltaic power. CPV power utilize the trough mirrors used in the newest concentrating solar power plants and puts a thin strip of photovoltaic material in place of the heat absorbing tubing in concentrating solar power. The reduction in use of photovoltaic material used not only allows for it to be feasible for large-scale use but it also allows for the eventual use of exotic PV materials that will push the efficiency past 30%. With large scale incorporation of CPV facilities with efficiencies surpassing 30% efficiency the land demanded for fulfilling the electricity demands of the entire central United States will drop to 0.1% of the available land at a cost of approximately $0.02/kWh.

4.2 Wind

As mentioned before, there is a huge wind potential in the middle US. Here we will try to estimate the total wind potential in middle U.S. from the information of Figure 1. Differently color in Figure 1 mean different wind energy potential density, which has a unit of W/m^2. The calculation of total wind energy potential is an estimation of product of wind power density by area of middle US. Table 4.1 shows the areas of each state in middle US and their wind power densities at a height of 50m, which is the normal height for a wind turbine.

Total potential	Area(km$^{2)}$	Wind power Density(W/m2)	Wind power potential(MW)
Arkansas	137,732	250	34433000
Illinois	149,998	310	46499380
Iowa	145,743	410	59754630
Kansas	213,096	430	91631280
Louisiana	134,264	200	26852800
Minnesota	206,189	375	77320875
Nebraska	200,345	430	86148350
North Dakota	183,112	500	91556000
Oklahoma	181,035	395	71508825
South Dakota	199,731	480	95870880
Texas	695,621	340	236511140
Wisconsin	169,639	360	61070040
Missouri	180,533	310	55965230
Indiana	94,321	270	25466670
Michigan	253,266	370	93708420
Ohio	116,096	285	33087360
Middle US			1187384880

Table 4.1: Summary of area and wind power density at 50m high of each state in Middle US (source: http://www.infoplease.com/ipa/A0108355.html)

For a high-density wind turbine farm, it usually has at least 50 meters between any other wind turbines. That is an average of one wind turbine every 2500m^2.Since wind turbines are usually installed at low population density places which there are no other buildings, places like cities with high population density are not ideal for wind turbine. We conservatively assume that only

$1m^2$ of the $2500m^2$ could be used at power. Therefore, the total wind energy power potential in middle US is:

$$1.19*10^9 MW/2500=4.76*10^5 MW$$

Assumethat the load factor is 33%, and therefore the total potential of energy generation in one year is:

$$0.33*3.6*10^6*8760*4.76*10^5=4.95*10^{15} MJ$$

A typical life cycle stages is as follows (Rankine, Chick, & Harrison, 2006):

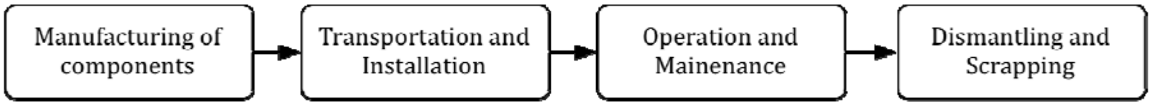


Figure 4.2: typical life cycle stages

The energy and emissions will be considered for every stage in a life cycle. The energy involves the energy consumption and production, and the emission mainly is the emitted gas from the producing of the raw material, which is CO_2. The components in a wind turbine include blades, hub and mounting, transmission, generator, nacelle cover, tower, foundations and electricity carrier (Lenzen & Munksgaard, 2002). The key materials used for building a wind turbine include glass fibre, epoxy, PVC, steel, copper and concrete. A summary of energy consumption and CO_2 emission for each components and material is as follows (Lenzen & Munksgaard, 2002)(Rankine et al., 2006):

Component	Main material	Relative mass	Energy consumption (MJ/kg)	CO_2 Emission (kg CO_2/kg)
Blades	Glass fibre, epoxy, PVC	2.7	137.1	5.7
Hub and mounting	Steel	3.5	36.8	6.1
Transmission	Steel	5.2	36.8	6.1
Generator	Copper	2.6	86.2	3.35
Nacelle cover	Glass fibre	0.3	61.8	5.7
Tower	Steel	23.3	36.8	6.1
Foundation	Concrete	60.3	3.2	0.153
Electricity carrier	Copper	2.1	86.2	3.35

Table 4.2 Energy consumption and CO2 emission for components and materials of a typical wind turbine

The mass of a wind turbine varies with it scale and consequently capacity, which will address later. The assembly of the turbine requires the use of a range of electrically powered tools. Energy consumption and CO_2 emission from that will be quantified. The carbon content of grid electricity is taken as 0.504 kg CO_2/kWh (Rankine et al., 2006). Energy consumption and CO_2 emission for transportation and installation include the fuel consumption and CO_2 emission from vehicles. A summary for transportation energy consumption is as follows (Rankine et al., 2006)(Agency., 2005) (calculated to energy based on the assumption that those heavy-duty trucks use No.2 diesel which has an average heating value of 129,500 Btu/Gal):

Vehicle	Fuel consumption (MJ/km)	CO_2 emissions (kg CO_2/km)
Curtain-side truck	10.2	0.894
Light commercial vehicle	2.4	0.212
Medium-sized car	2.0	0.155

Table 4.2: Energy consumption and CO_2 emissions for vehicles in use

The average coverage of transportation for certain capacity of wind turbine will be addressed later. The Energy consumption and CO_2 emission of installation for special case because the activities and timing for the installation vary too much to summarize a typical table. No Energy consumption and CO_2 emission will be calculated for operation and maintenance because they are significantly limited.

Recycling of wind turbine includes the separation of fibreglass, epoxy resin and PVC within rotor blades, which are of inferior quality because of the technical problems (Lenzen & Munksgaard, 2002), all major metal components and potentially some others can be recycled and consequently significantly reduce the energy consumption and emissions during the product life cycle. According to a review, the recycling on energy usage for several different wind turbines with power ratings from 0.3 to 600 kW was in the range of 12.5%-31.9% (Lenzen & Munksgaard, 2002). Energy consumption and CO_2 emissions in recycling including transportation and disassembly of wind turbine, which will be calculated according to the portion of recyclable mass. Therefore, the total energy consumption and CO_2 emissions will be calculated as follows:

$$E_C=E_M+E_T+E_I+E_R$$

$$M_{CO2}=M_{CO2,\,M}+M_{CO2,T}$$

Where, E_C is total energy consumption, E_M, E_T, E_I, E_R are the energy consumption of materials, transportation, installation and recycle, respectively. M_{CO2}, $M_{CO2,\,M}$, $M_{CO2,T}$ are the mass of CO_2 emissions of entire life cycle, materials and transportation, respectively.

The energy generated by a wind turbine will be calculated through times of load factor by average power rating by average running time per year by turbine life time as follows:

$$E_O=\lambda P_t T \bullet n$$

Where, E_O is the energy output by a wind turbine, λ is the load factor, P_t is the average power rating, T is the average running time, which is 8760h/y (Onat & Canbazoglu, 2007), and *n* is the life time a wind turbine, which is usually 20 years. The average power rating is calculated as follows (Baroudi, Dinavahi, & Knight, 2007):

$$P_t=0.5\rho AC_p v_w^3$$

Where, P_t is the turbine power, ρ is the air density, A is the swept turbine area, C_p is the coefficient of performance and v_w is the wind speed. The coefficient of performance of a wind turbine is influenced by Tip-Speed wind Ratio (TSR):

$$TSR=\omega r/v_w$$

Where ω is rotation speed and r is turbine radius. The TSR has a relationship with the coefficient of performance as follows (Baroudi et al., 2007):

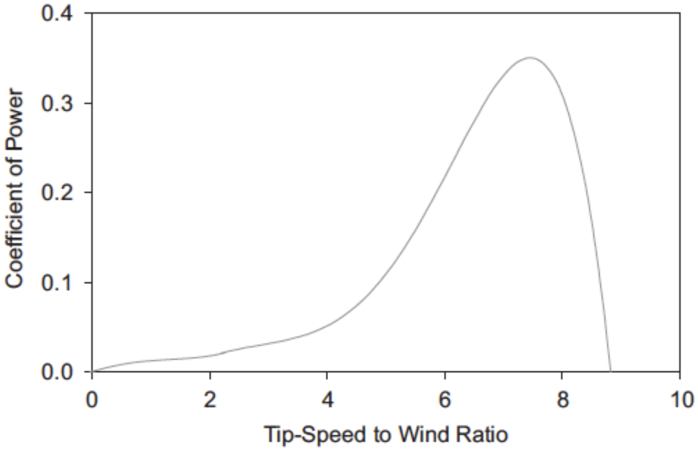


Figure 4.3: Typical coeffient of power curve

A summary between turbine rotation speed and output power is as follows (Baroudi et al., 2007):

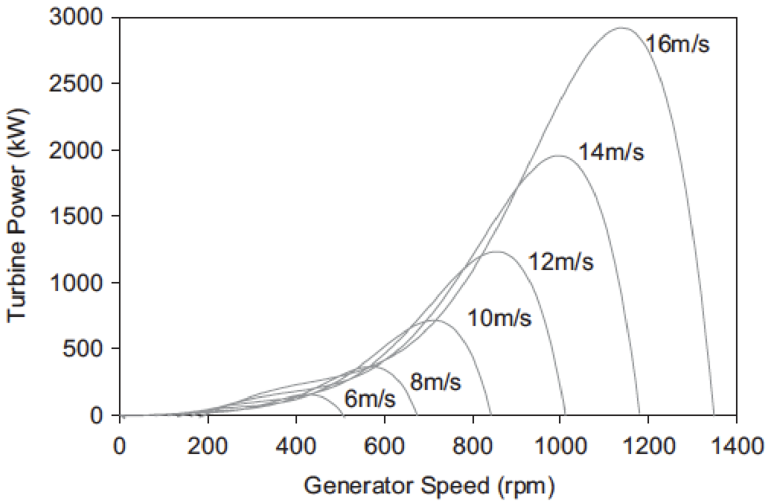


Figure 4.4: Turbine output power characteristic

Further calculation will be addressed combining with the wind resource in central US, and the net energy in the wind turbine life time is computed as follows:

$$E_N=E_O-E_C$$

Where EN is the net energy, which will be used for further sustainability analysis.

Wind turbines have different power outputs, and different wind farm sets up (large power output with small number of turbines and small power output with large number of turbines) would have different material use and energy generation rate. Giving varies power output wind turbines, the U. S has an average 1.6 MW power output of wind turbine installation in 2007 (Association), 2008). Even in the future larger wind turbines will be installed, we still consider the 1.6 MW wind turbine as a typical installation for wind energy development. Since larger wind turbines generally reduce the investment rate (Frankovic & Vrsalovic, 2001), our calculation on wind turbine is comparatively conservative. The four stages in life cycle will be accounted as follows, which we will denote a typical NEG Micon 1.6MW wind turbine as reference.

- Manufacture of components:

The typical NEG Micro 1.6MW wind turbine weighs 290 tons (Edelstein, Walcek, Cox, & Davis, 2003). From previous data, we could compute the total CO_2 emission of materials:

$$290000*(0.03*5.7+0.32*6.1+0.05*3.35+0.6*0.153)=690867kg$$

Total energy consumption of materials:

$$290000*(0.03*137.1+0.32*36.8+0.05*86.2+0.6*3.2)=6.4*10^6 MJ$$

- Transportation and installation:

The wind turbines are usually set up at population scarcity place, and therefore the transportation of materials will convincingly cover large area. There are not detail statistics on transportation of materials of wind turbines, and therefore we assume the transportation of building that wind turbine is 1000km.

So the total CO_2 emission in transportation for materials:

$$0.894*1000=894kg$$

The total energy consumption in transportation for materials:

$$10.2*1000=10200MJ$$

Data on energy consumption and CO_2 emission during the installation procedure are also unclear and it is believed to be a minor part. Therefore we will neglect the energy consumption and CO_2 emission during this part.

- Operations and Maintenance

A minor maintenance for one wind turbine usually costs 4h of 2 workers, and a major maintenance usually costs for 7h of 2 workers. The schedule for maintenance is usually 6 months. Therefore, the operation's and maintenance's parts of energy consumption and CO_2 emission are limited. We consequently neglect this part in our life cycle analysis.

- Dismantling and Scrapping

Assume 20% of total energy consumption and CO_2 emission of material could be recycled, therefore, the energy consumption and CO_2 emission savings are:

$$690867*0.2=138173kg$$

$$6.4*10^6*0.2=1.28*10^6 MJ$$

Neglecting the energy consumption and CO_2 emissions in the building of wind turbine, the total energy consumption and CO_2 emission for a 1.6MW wind turbine in its life cycle is:

$$CO_2: 690867+894-138173=553588kg$$

$$\text{Energy consumption: } 6.4*10^6+10200-1.28*10^6=5.13*10^6 MJ$$

The energy generated from this wind turbine is, giving the lifetime is 20 years, and assume the load factor is 33%. Running time in one year is 8760h:

Energy generation: $0.33*1.6\text{MW}*3600\text{s}*8760\text{h}*20\text{y}=3.33*10^{8}\text{MJ}$

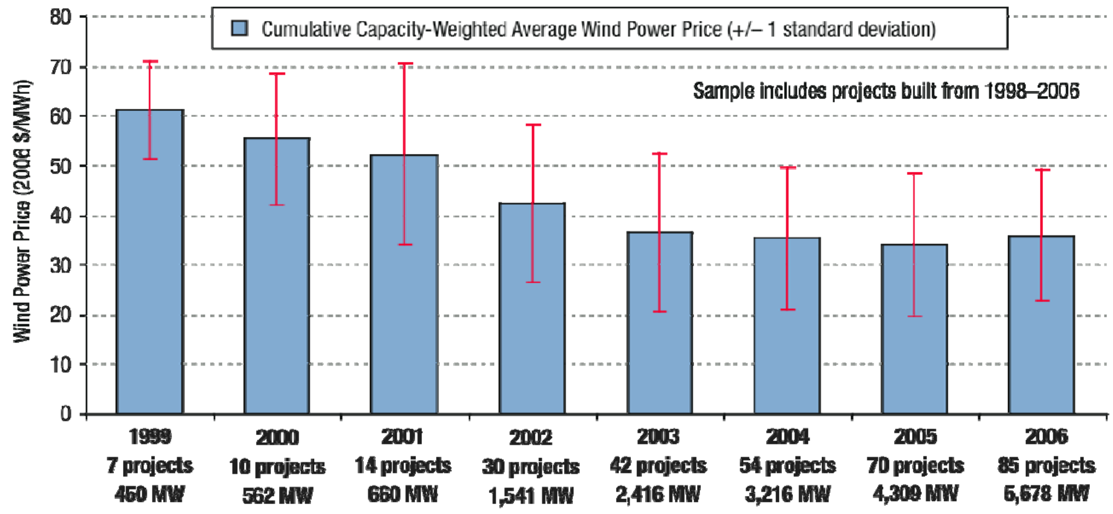
Therefore, the CO2 emission rate of this wind turbine is

$$553588/(3.33*10^{8})=1.66*10^{-3}\text{kg/MJ}$$

In addition, the energy consumption per energy unit generated is:

$$5.13*10^{6}/3.33*10^{8}=0.015\text{MJ/MJ}$$

Usually with the improvement of technique, instrument cost should decrease with time. However, because of rising cost of materials and transportation, wind turbine is facing an increasing cost during the past years. Figure 1 summarize the wind power price during the past 10 years (US DOE, 2007):



Source: Berkeley Lab database.

Figure 4.5: Cumulative Capacity-weighted average wind power price over time

From Figure 4.5 we could see that the wind power price reached a lowest point at 2005, but since 2006 the price has increased. The reason for that trend could due to the increased cost of materials, less places for easy installation of wind turbine, etc. However, with the improvement of technology, and consequent the increased number of higher capacity factor wind turbine, the reduction of cost from technique improvement could partially offset the increased cost from materials and spaces. As a matter of factor, during the past five years the wind power price has been going stable, which is around $40/MWh, therefore we could assume that the wind power price during the next 100 years will be around $40/MWh for our modeling and simulation.

4.3 Biomass

According to the USDA, the total farmland in the USA is 938.28 million acres, where the central USA has 534.1 million acres which is composed of cropland, woodland, patureland and others (http://www.ers.usda.gov/StateFacts/US.htm). As displayed in Fig. 4.6, 56.7% of the farmland is used for cropland in 2002.

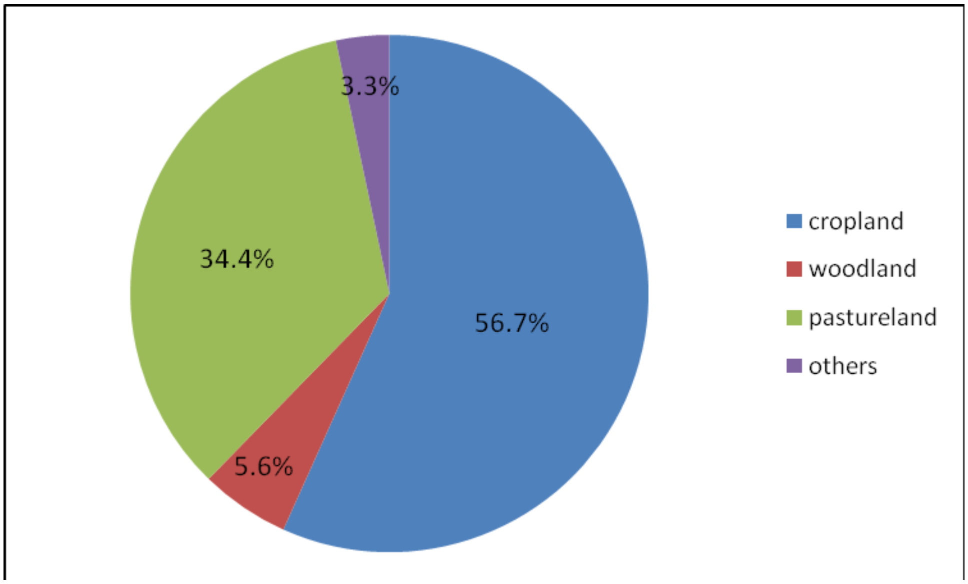


Fig. 4.6 Share of Farmland in the Central USA

Among 303.01 million acres of cropland, around 66 million is used for harvested corn (http://www.ncga.com/production/main/index.asp). The share of ethanol in whole corn use is 12% in 2004/2005 and it is expected to grow up to 23% according to USDA (http://www.ers.usda.gov/AmberWaves/April06/Features/Ethanol.htm). As seen in the literature review, bio-diesel production is small compared to bio-ethanol production. Bio-diesel production is expected to increase continuously. Although bio-diesel and bio-ethanol are used in the different engine systems, we didn't divide both for easy calculation. And also, we assumed that additional farmland of 200 million acres would be used for bio-fuels within 40 years as well as present corn land. And also, we thought that the land for bio-fuels would occupy around 15% of this total cropland considering the share of ethanol in whole corn use. Since there is no contribution of bio-fuel in our model to calculate energy demand, we increased the land use for bio-fuels from 0% to 15% of total land, which is 266 million acreas, as shown in Fig. 4.7.

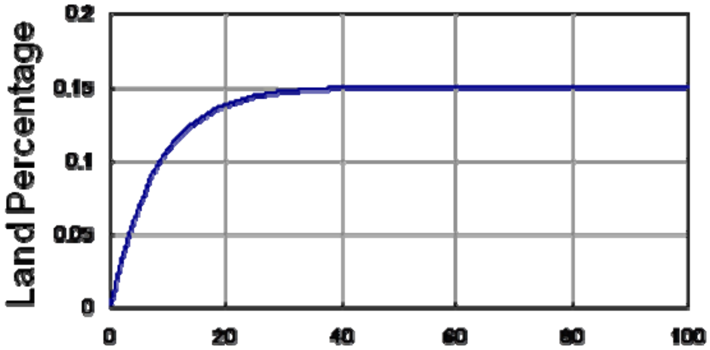


Fig. 4.7 Land Use Model for Biomass Production

Although we know the crop production yield and bio-fuel conversion yield for each biomass at present, we should also estimate its future. For more production of bio-fuels in the future, we assumed that switchgrass or other cellulosic biomass would be main biomass, and those projections are based on NRDC's report for biomass production yield and the data which was provided by north carolina department of environment and natural resources for bio-fuel conversion yield as shown in Table 4.1 (http://www.p2pays.org/ref/40/39143.pdf).

Biomass Production Yield			
	2004	2025	2050
Dry ton/acre/year	6.0	8.82-9.75	14.19-14.23
Bio-fuel Conversion Yield			
	2006	2010	2025
Gallon/Dry ton	80	86	98-104

Table 4.3 Projected Biomass Production Yield and Bio-fuel conversion Yield

5. Modeling and Simulation

5.1 Energy Demand and Supply Model

In order to design a feasible energy path efficiently, we decided to develop a mathematical model that can represent the energy demand and supply system in the central region. Matlab codes and Simulink model have been integrated to implement the energy system. And, using the model, we demonstrated the possibility to control the energy demand by applying additional energy strategies under the appearance of unexpected perturbation and noise. In addition, we implement an optimization algorithm and design the renewable energy plan for 100 years. The modeling strategy is shown in Figure 5.1.

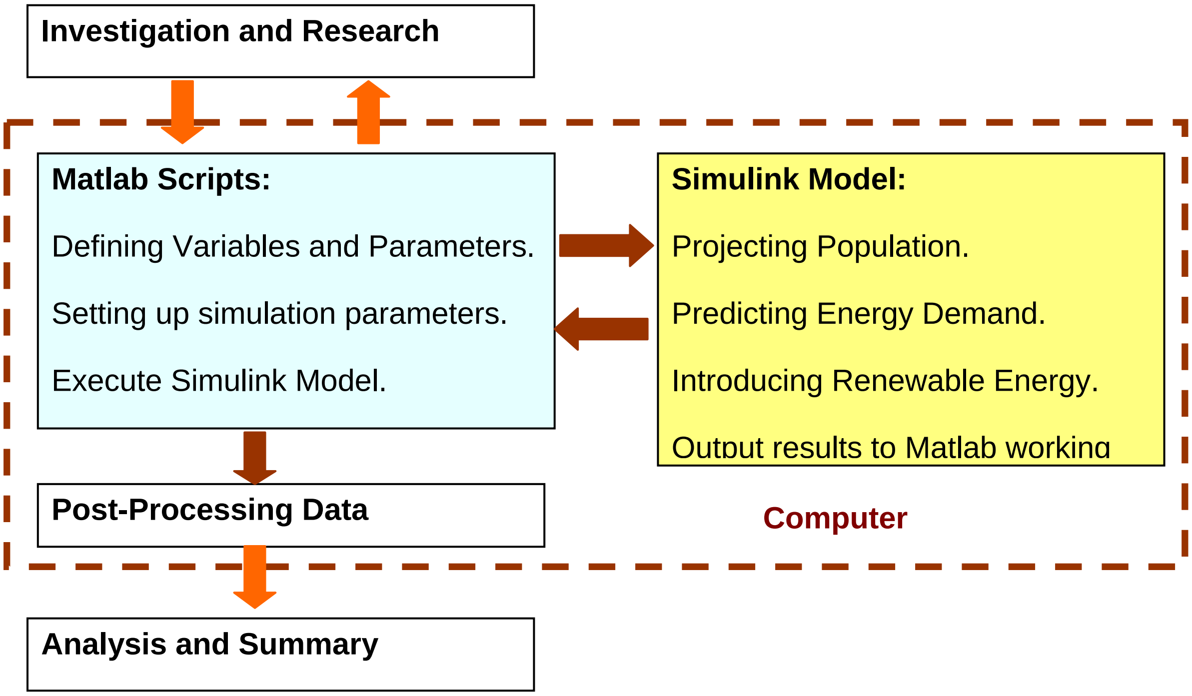


Figure 5.1 Implementation of system modeling and simulation

5.2 Parameters and Variables

The parameters and variables used in the following simulation are summarized in Table 5.1 and 5.2. The values were obtained based on our research and investigation in previous sections. Table 5.1 defines energy-related parameters and variables. Table 5.2 defines CO2 emission-related parameters. Table 5.3 defines simulation-related variables.

Parameters/Variables	Values
2005 Energy Consumption in Commercial Section	6279 (trillion BTU)
2005 Energy Consumption in Residential	7982 (trillion BTU)

Section	
2005 Energy Consumption in Industrial Section	16867 (trillion BTU)
2005 Energy Consumption in Transportation Section	10233 (trillion BTU)
Population growth function	11.59*exp(0.00796*year)
Non-Transportation Policy Reduction Target	11%
Non-Transportation Policy Enforcement Speed	100 (slack)
Transportation Policy Reduction Target	11%
Transportation Policy Enforcement Speed	100 (slack)
Non-Transportation Energy Saving Technology	11%
Non-Transportation Energy Saving Technology Development Speed	100 (slack)
Transportation Energy Saving Technology	11%
Transportation Energy Saving Technology Development Speed	100 (slack)
Available Land Area	266 (million acres)
Crop Production Base Rate (Switchgrass)	6000 (kilograms/acres)
Crop Production Rate Growth	[0 25 50 100; 1 1.63 2.37 2.37]
Fuel Yield Base Percentage	0.24 kg fuel/kg product
Fuel Yield Growth	[0 15 100; 1 1.3 1.3]
Fuel Lower Heating Value	29.8 (MJ/kg)
Energy Crop Land Portion Target	15%

Energy Crop Land Development Speed	8 (aggressive)
Biofuel Recess Year	120 years
Ratio of wind and solar energy	1:2
Portion of Wind and Solar Energy	To be determined by optimization algorithm

Table 5.1 Energy-related parameters and variables

Parameters	Values
CO2 emission from using petroleum (transportation)	$6.26*10^{-5}$ (g/Joules)
CO2 emission from using biofuel	$1.3269*10^{-5}$ (g/Joules)
CO2 emission from using fossil fuels (non-transportation)	$4.26*10^{-5}$ (g/Joules)
CO2 emission from using wind power energy	$7.6*10^{-10}$ (g/Joules)
CO2 emission from using solar energy	$3.6*10^{-10}$ (g/Joules)

Table 5.2 CO2 emission-related parameters

Variables	Values/Options
Simulation Time	100 years
Solver	Fixed Step Discrete
Fixed step size	1.0

Table 5.3 Simulation-related Variables

The energy-related variables can be visualized by Figure 5.2 (Transportation section) and Figure 5.3 (Non-transportation section) In the transportation section, because currently most of the vehicles are powered by internal combustion engine, we use all the biofuels available in the central area to replace a portion of petroleum. Then, we design energy path for using wind and solar energy to replace another portion of the petroleum in the transportation section. In the non-transportation section, we use wind and solar energy sources exclusively.

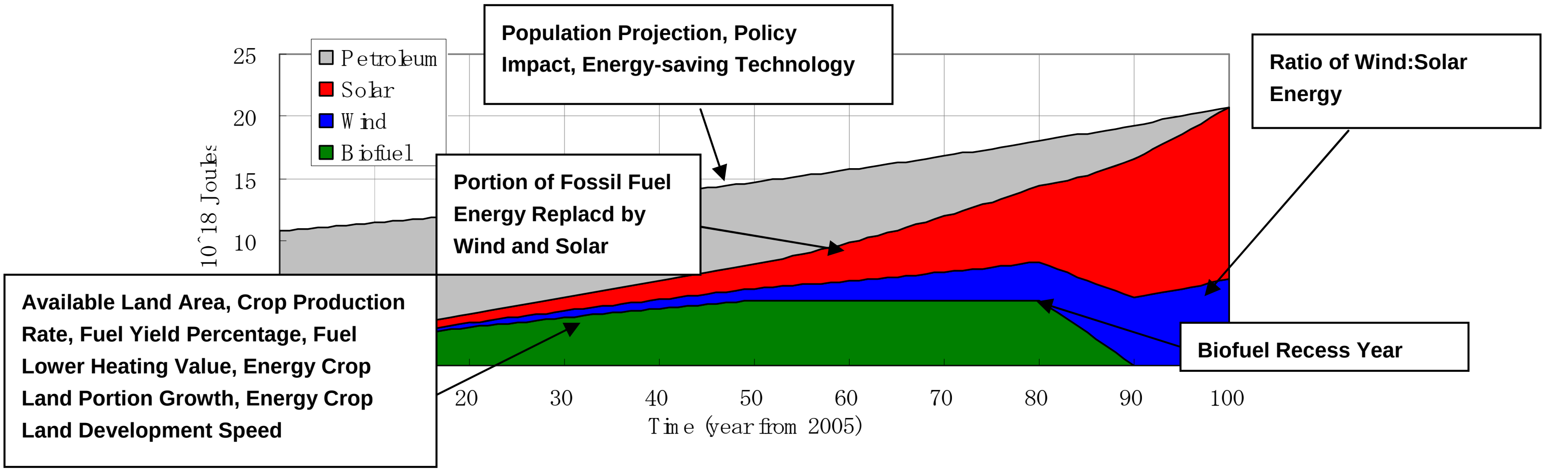


Figure 5.2 Impacts of energy-related variables in transportation section

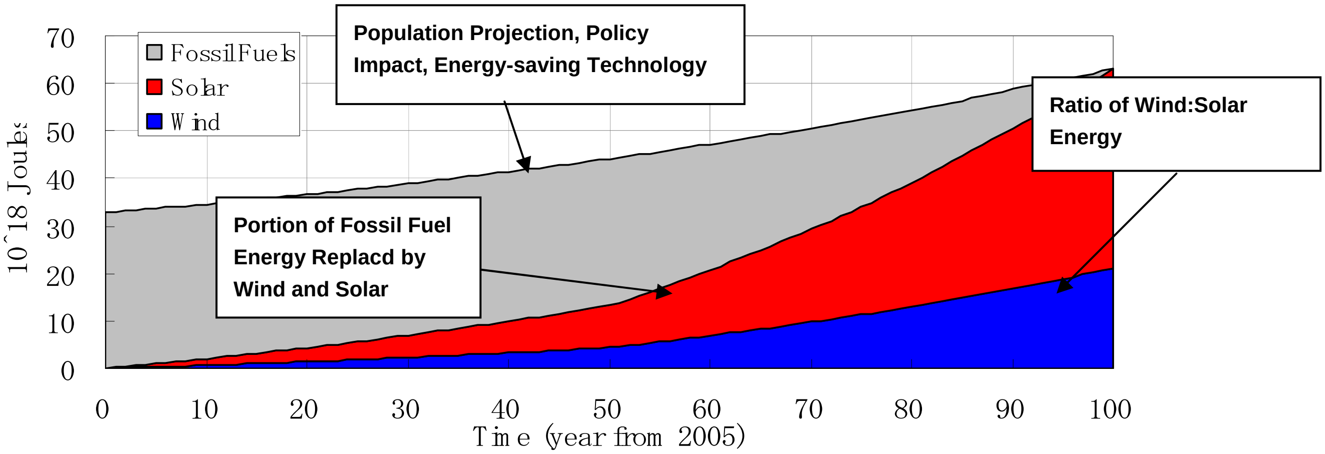


Figure 5.3 Impacts of energy-related variables in non-transportation section

With the energy demand and supply model that we constructed, we demonstrated two examples of engineering design about energy demand and renewable energy planning.

5.3 Engineering Design Example (1): Energy Demand Curve Control

A human society sometimes has unexpected perturbation and noise that cannot be accurately forecasted. In this example, we would demonstrate that a close-loop control algorithm (Kuo, 1995, and Nise and Elliott, 1995) can be developed to achieve a desired energy demand curve. Figure 5.4 shows the schematics of the control algorithm that we tested.

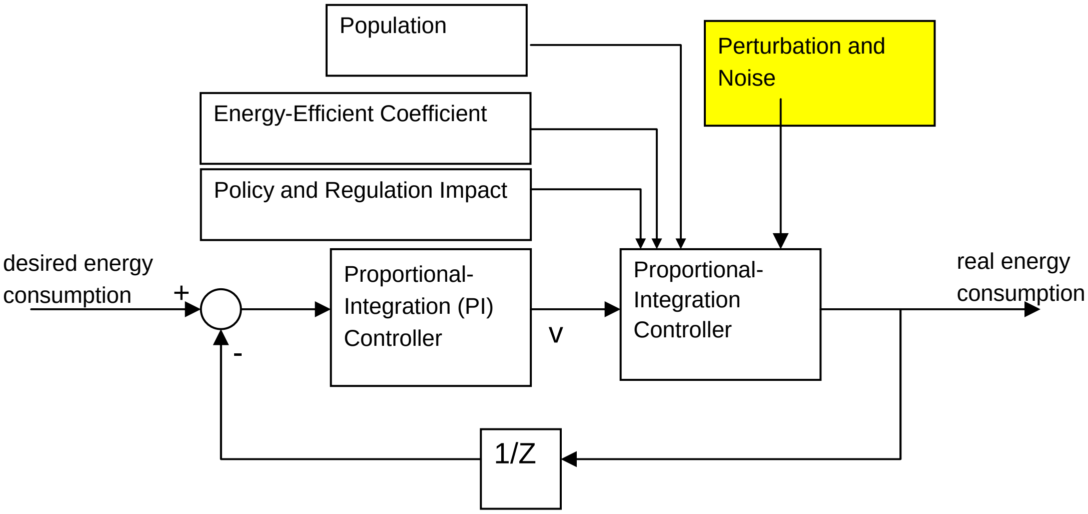
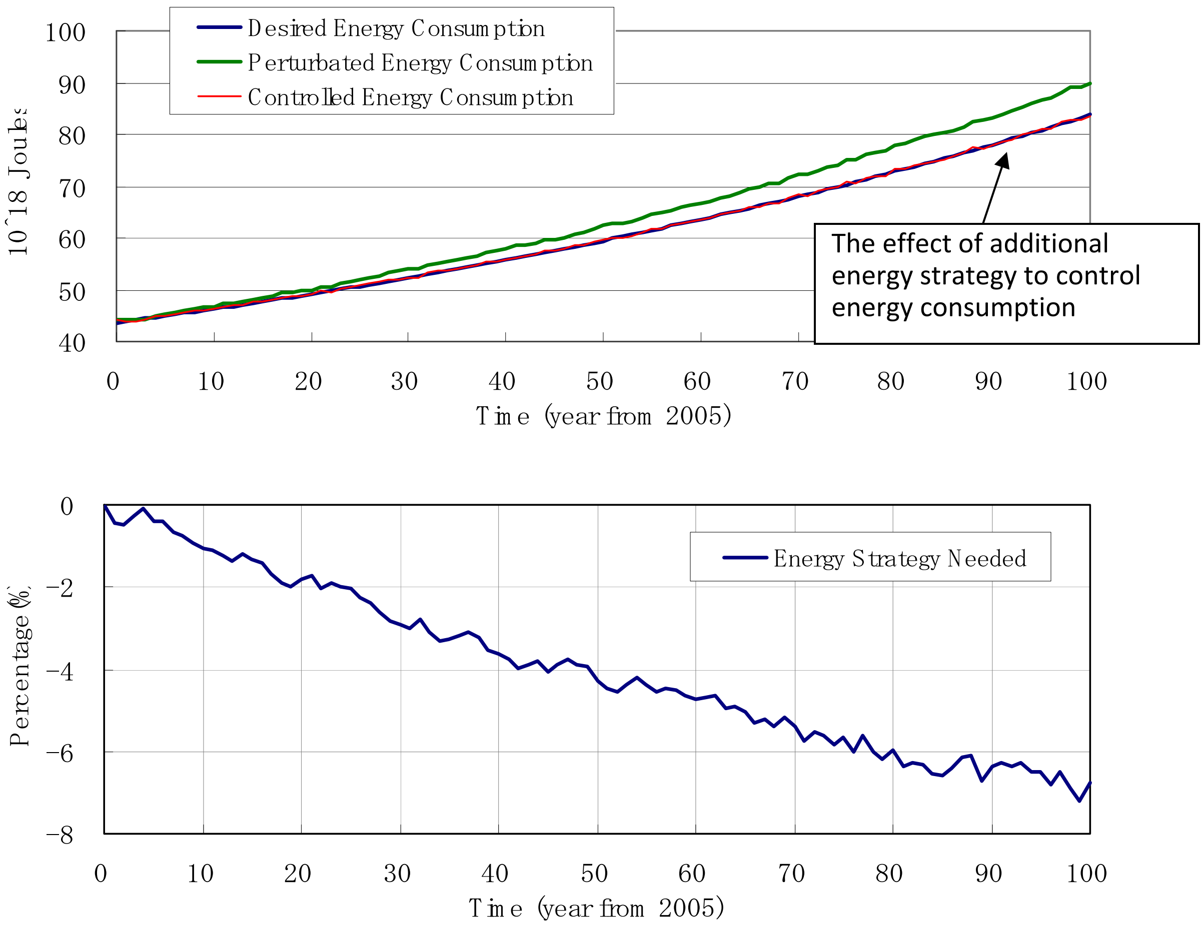


Figure 5.4 Schematics of Controlling Energy Demand Curve

The simulation results are plotted as Figure 5.5. On the top plot, the blue line is the desired energy consumption, green line is the simulation of unexpected perturbation and noise, and red line is the result of applying control algorithm. The bottom plot is the input that was obtained by applying a proportional-integral control algorithm to the error in real time. The input implies that the additional energy strategy is needed to execute in order to eliminate the unexpected energy increase and system noise. The results demonstrate that it is possible for the government to plan and control the energy consumption.



The effect of additional energy strategy to control energy consumption

Figure 5.6. Energy Demand Curve Control.

This example demonstrated the feasibility controlling the energy demand over time given a desired energy demand curve. More issues related to the stability and controllability of an energy demand system can be further studied.

5.4. Engineering Design Example (2): Planning an Energy Portfolio in 100 years

After developing a model for projecting energy demand in 100 years in central area, due to the expected shortage of fossil fuels, we consider to design a reasonable energy pathway to replace the fossil fuels by renewable energy sources. Our vision is to replace fossil fuels by wind, solar and biomass energy in 100 years. Figure 5.7 shows two different scenarios in reaching this goal. The conservative scenario characterizes a relatively slack development of renewable energy in the first half of the 100 year period. The aggressive scenario characterizes a faster development of renewable energy from the beginning.

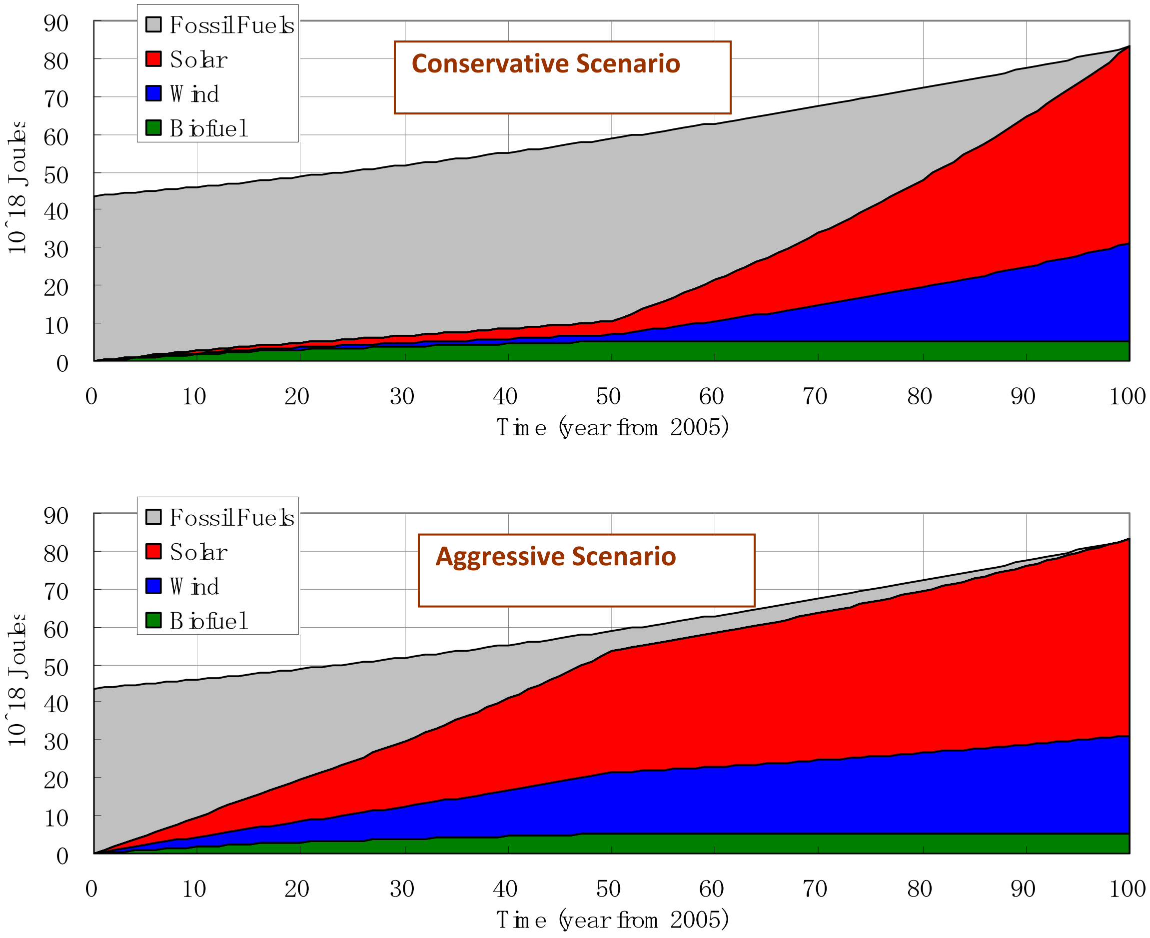


Figure 5.7 Two extreme scenarios of achieve the goal of replacing all fossil fuels in 100 years (top: conservative scenario, bottom: aggressive scenario)

Both of these scenarios can achieve our goal of replacing all the fossil fuels in 100 years. However, the cost and CO2 emission of these two scenarios are very different. The annual cost and CO2 emission are plotted as Figure 5.8. From Figure 5.8, we found that the pathway of the conservative scenario and aggressive scenario are very different even the final results after 100 years are the same.

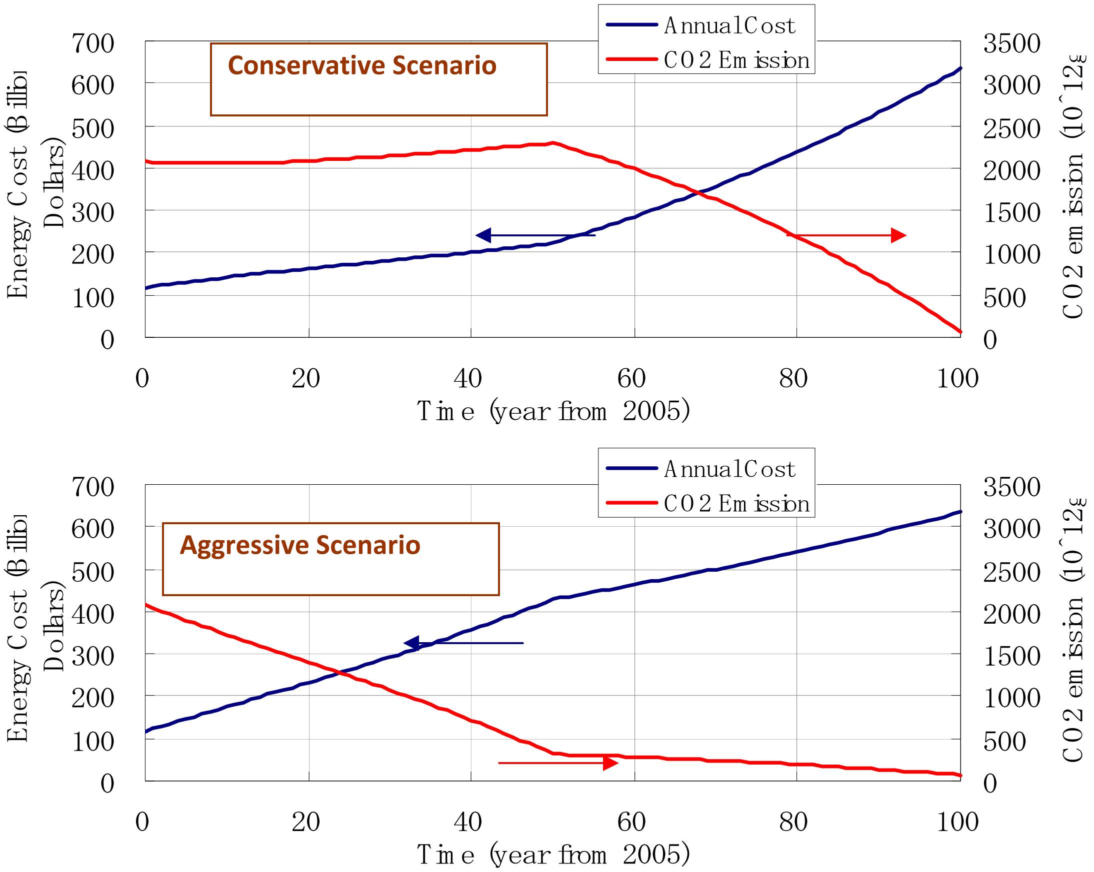


Figure 5.8 Annual energy cost and CO2 emission of two scenarios. (top: conservative scenario, bottom: aggressive scenario)

In this engineering design example, we spend an effort to investigate the possibility to decide the renewable energy scenario according to optimization principles (Papalambros and Wilde, 1988). The variable to be determined is the renewable energy ratio in the 50th year. The idea is to define an evaluation function and find the point that minimizes the value. Our first trial of the evaluation function is as follows.

$$J(x) = \sum_{year=0}^{100} A \times F(year, x) + B \times G(year, x), \quad \text{(Eq. 5.1)}$$

where x is the ratio of renewable energy (x) in the 50th year, F(year,x) is the cost of energy production, G(year,x) is the cost of CO2 emissions. A, B are weighting coefficients that address the relative importance between the energy cost and CO2 emission impact.

F(year, x) and G(year, x) are defined as follows:

$$F(year, x) = \sum_{all\_energy\_sources} energy\_\sup(joules) \times energy\_unit\_\cos t\_i(dollars/joules) \quad \text{(Eq. 5.2)}$$

$$G(year, x) = \sum_{all\_energy\_sources} energy\_supply(joules) \times CO2\_emissions(g/joules) \times CO2\_sequestration\_fee(dollars/g)$$

(Eq. 5.3)

The energy unit cost of each energy source, and CO2 emission are defined as Table 5.4 and Table 5.5. The CO2 sequestration fee is assumed to be 50 dollars/metric tons.

Energy Source	Estimated Cost (dollars/joules)
Biofuel	$1.11*10^{-8}$
Wind	$1.11*10^{-8}$
Solar	$5.56*10^{-9}$
Petroleum (Transportation)	$3.98*10^{-9}$
Fossil Fuels (Non-transportation)	$2.28*10^{-9}$

Table 5.4 Cost of Energy Sources used in modeling

Energy Source	Estimated CO2 emissions (g/joules)
Biofuel	$1.33*10^{-5}$
Wind	$7.6*10^{-10}$
Solar	$3.6*10^{-10}$
Petroleum (Transportation)	$2.26*10^{-5}$
Fossil Fuels (Non-transportation)	$4.26*10^{-5}$

Table 5.5 CO2 emission and sequestration fee used in modeling

Figure 5.7 shows ΣF(year, x), ΣG(year, x) as a function of x from 0.0 to 1.0. When x is 0, it represents the scenario that no wind and solar energy is used in the 50th year, and expand quickly in the later 50 years in the 100 year period. When x is 1, it represents the scenario that wind and solar has fully replaced the fossil fuels in the 50th year, and continued to be used in the later 50 years in the 100 year period.

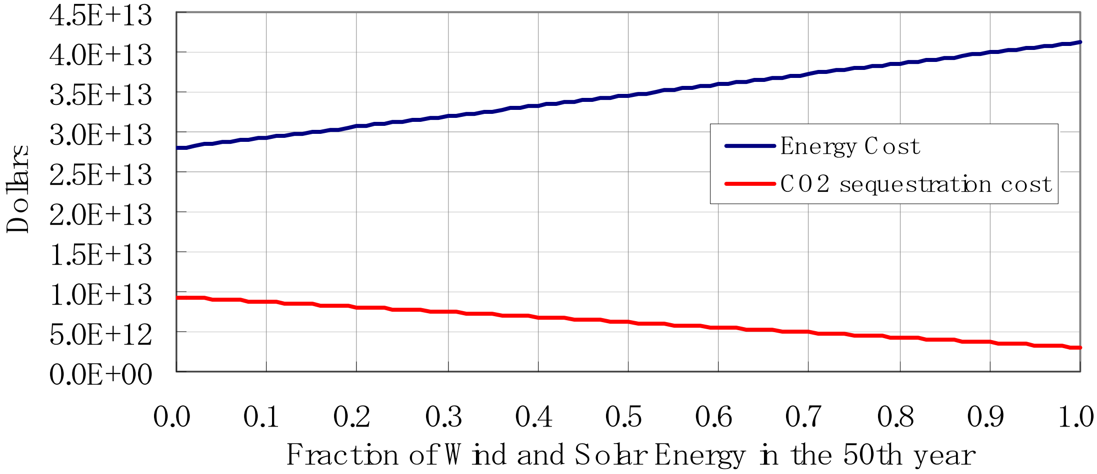


Figure 5.9 ΣF(year, x), ΣG(year, x) as a function of x from 0.0 to 1.0

Observing the trend in Figure 5.9, we found the sum of the energy cost increases almost linearly as the variable x, and CO2 sequestration cost decreases linearly. The linearity comes from our linear interpolation of the fraction of wind and solar energy in 0-50 years, and 50-100 years, and the fixed ratio between wind and solar energy. The linearity ofΣF(year, x) and ΣG(year, x) actually prevented us from finding out an optimization point between 0 and 1 if we just set the function as Equation 5.1. If we choose a constant A relatively larger than B, we would overemphasize the energy cost, and a minimum of J(x) would happened when x=0.0. It is a very conservative scenario in the first 50 years (Similar to the top plot of Figure 5.7). On the other hand, if we choose a B relatively larger than A, we would overemphasize the importance of CO2 emissions, and a minimum of J(x) would happened when x=1.0. It is a very aggressive scenario in the first 50 years (Similar to the bottom plot of Figure 5.7).

Considering the optimization results of the evaluation function defined by Equation 5.1, a third term regarding the relative difference between the energy cost and CO2 emission was included in our evaluation function. The evaluation function is refined as follows:

$$J(x)=\sum_{year=0}^{100} A\times F(year,x)+B\times G(year,x)+C\left|A\times F(year,x)-B\times G(year,x)\right| \qquad \text{(Eq. 5.4)}$$

The first term and the second term are the same as our original definition, however, the third term increases the non-linearity of the evaluation function. The third term virtually concerns how radically (or conservatively) the society solves the energy problem. Mathematically, the term $\sum \left| A \times F(year, x) - B \times G(year, x) \right|$ calculates the difference between the first term (regarding Energy) and second term (regarding CO2). Considering the top plot (conservative scenario) of Figure 5.8, more resources would be allocated to deal with CO2 emission than developing renewable energy. In this scenario, the third term of the evaluation function would have a large value. The people residing in such a society would start to feel the scarcity of fossil fuels and suffer the increasing price due to fossil fuel scarcity. On the contrary, considering the bottom plot (aggressive scenario) of Figure 5.8, more resources would be allocated to develop renewable energy than dealing with CO2 emission. In this scenario, the third term of the evaluation function would have a large value too. The people residing in such a society would feel the increasing price due to developing renewable energy sources.

In the field of design optimization, there are two major research topics. The first is how to define evaluation function, and the second is how to define the weighting in each term of the evaluation function appropriately. Observing equation (5.4), we can further collect all coefficients of F(year, x) and G(year, x), and further reduce the evaluation to the form as follows:

$$J(x) = \sum_{year=0}^{100} A \times F(year, x) + B \times (year, x) + C \left| A \times F(year, x) - B \times G(year, x) \right|$$

$$= \sum_{year=0}^{100} A(year, x) \times F(year, x) + B(year, x) \times G(year, x) \qquad \text{(Eq. 5.5)}$$

Where

A(year, x)=A(1+C), B(year, x)=B(1-B) if A×F(year, x)>B×G(year, x) and

A(year, x)=A(1-C), B(year, x)=B(1+B) if A×F(year, x)<B×G(year, x)

Therefore, we can say we increase the non-linearity of A and B in equation 5.4 (or equivalent form 5.5) based on equation 5.1 when we consider a balance between radical energy pathway and conservative energy pathway. The definition of the evaluation function of an energy demand and supply system can be extended to a further research topic.

According to the argument in the previous paragraph, a minimum point might exist such that the people residing in the society would feel comfortable because of the balance between the sources that we put in dealing with CO2 emission and in developing renewable energy in an appropriate speed. Our simulation result supports this viewpoint. Figure 5.10 shows the iterative results when we chose $A=20/10^{15}$, $B=110/10^{15}$, C=2. On the top of figure 5.10, we can observe there is a minimum of our evaluation function around x=0.57. The minimum point is a collective impact from all the three terms in equation 5.4. The third term has a minimum at when x=0.50, but the first and second term modify that minimum point toward the right hand side (0.57). This happens because we put more weight on the CO2 emission than energy cost.

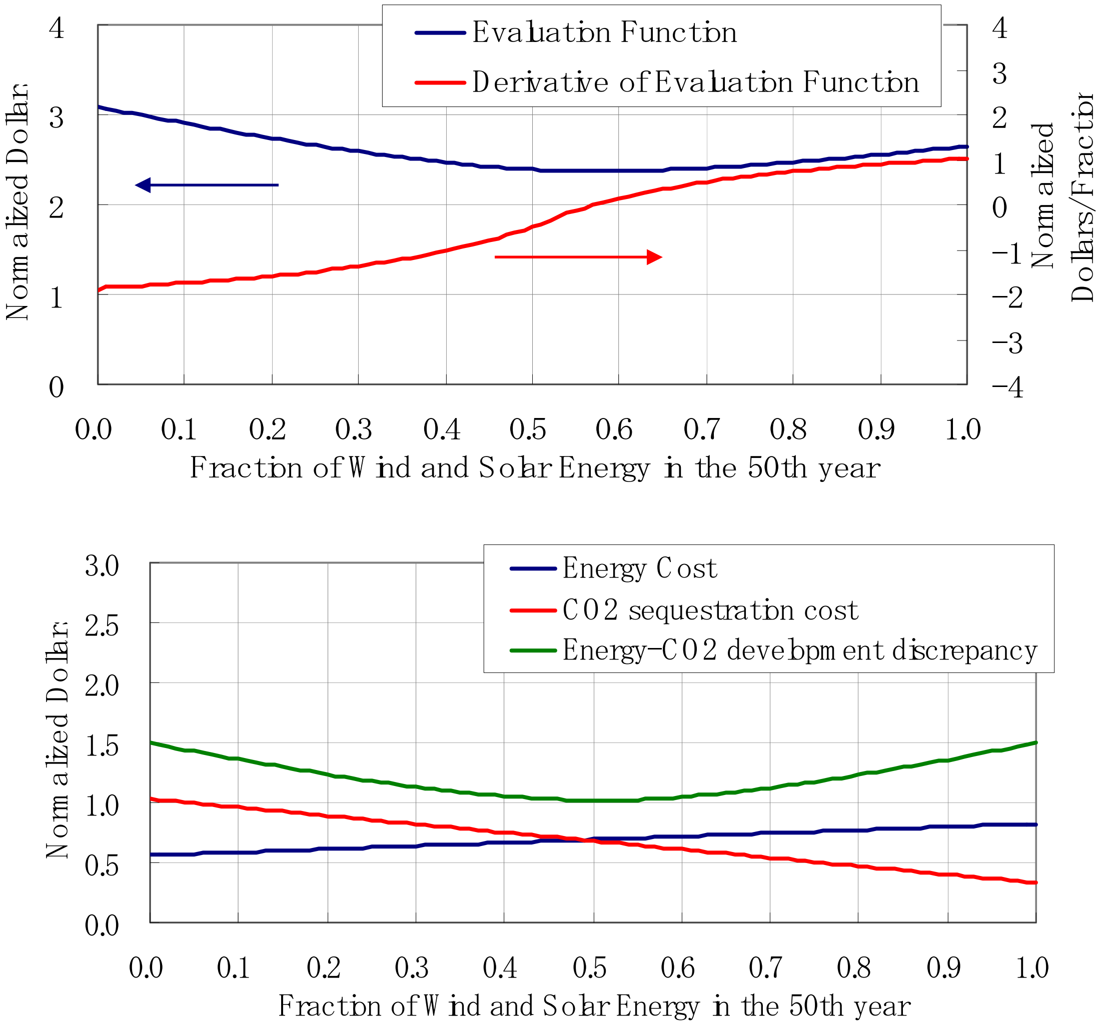


Figure 5.10 Iterative results when A=20/10^{15}, B=110/10^{15}, C=2

In this project, we would take x=0.57 as an optimal point according to our optimization analysis. Figure 5.11 shows the simulation results when x=0.57 in the transportation and non-transportation section.

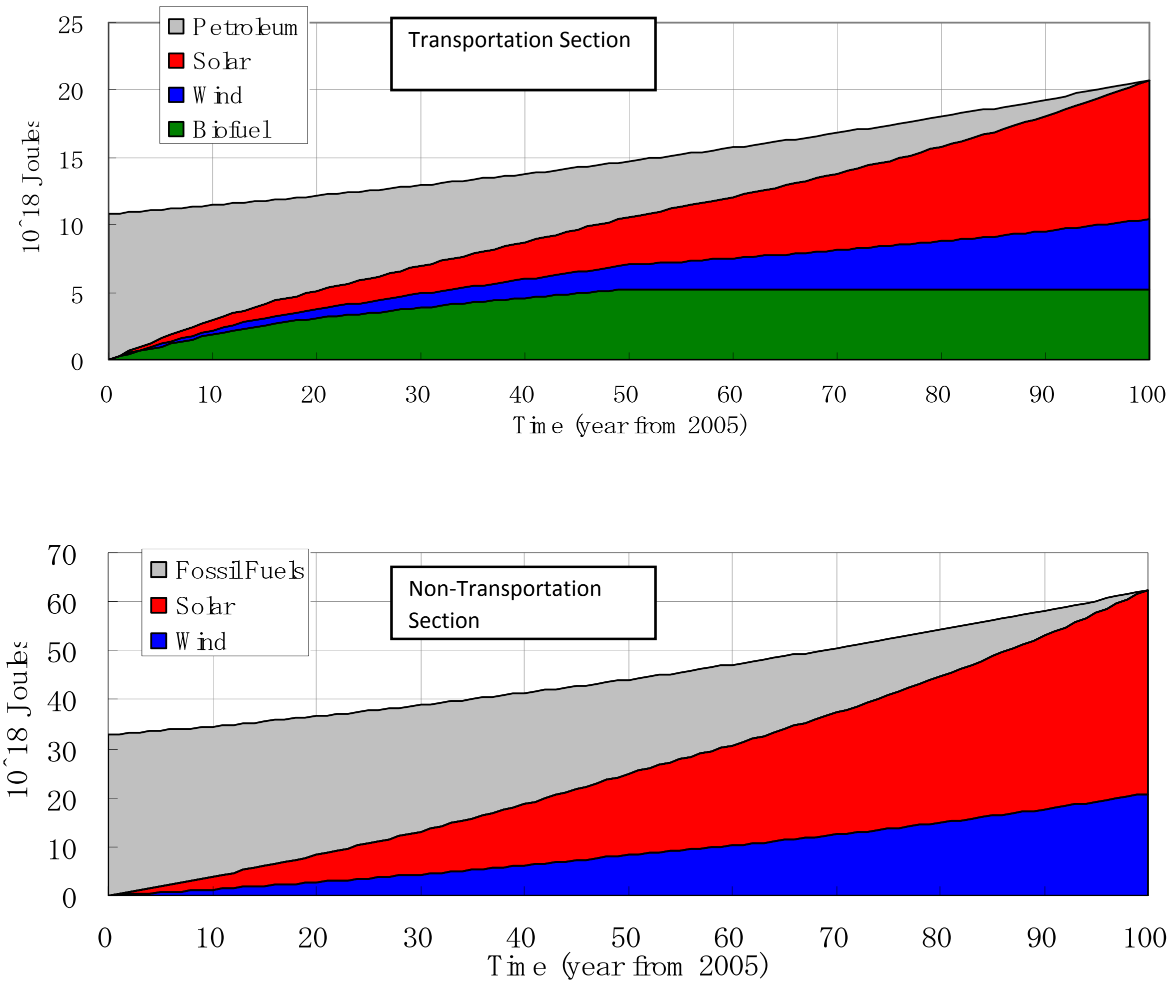
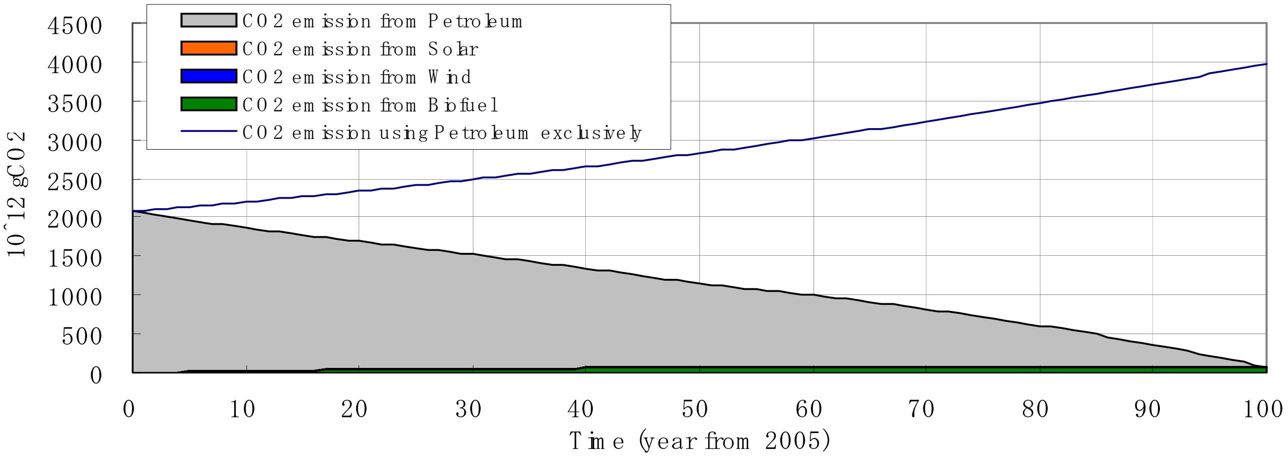


Figure 5.11 Simulation results in transportation and non-transportation section when x=0.57



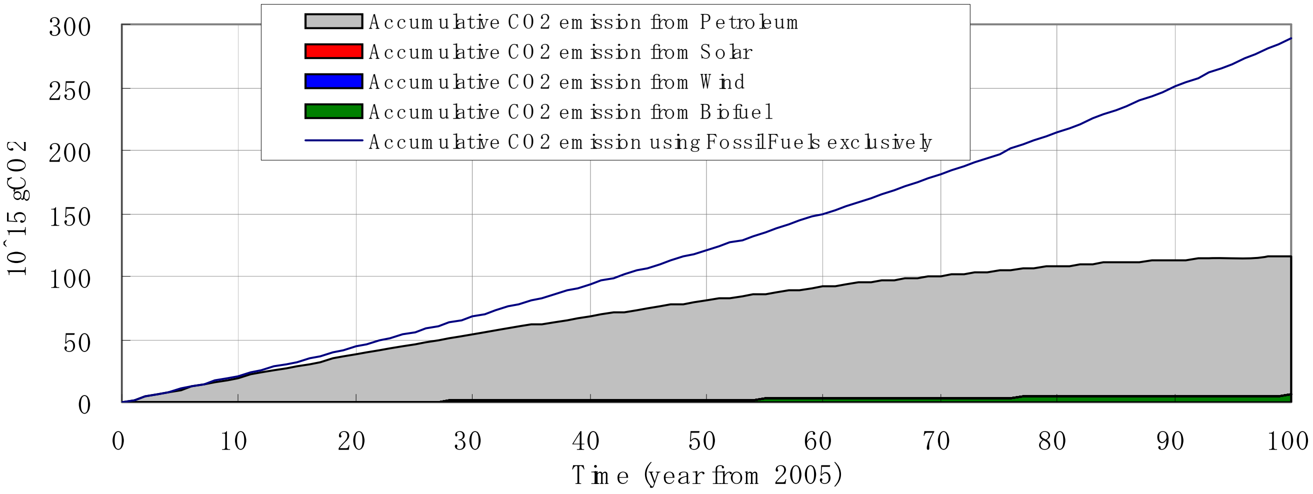


Figure 5.12 shows the overall energy pathway and the CO2 emission in our scenario. We chose this as our suggestion of energy portfolio in the future 100 years. In our portfolio, we do not only suggest a goal to replace all the fossil fuels, but we also suggest a pathway to reach our goal. The result shows that we can reduce the gross CO2 emission in 100 years by 60% comparing with the scenario without using any renewable energy.

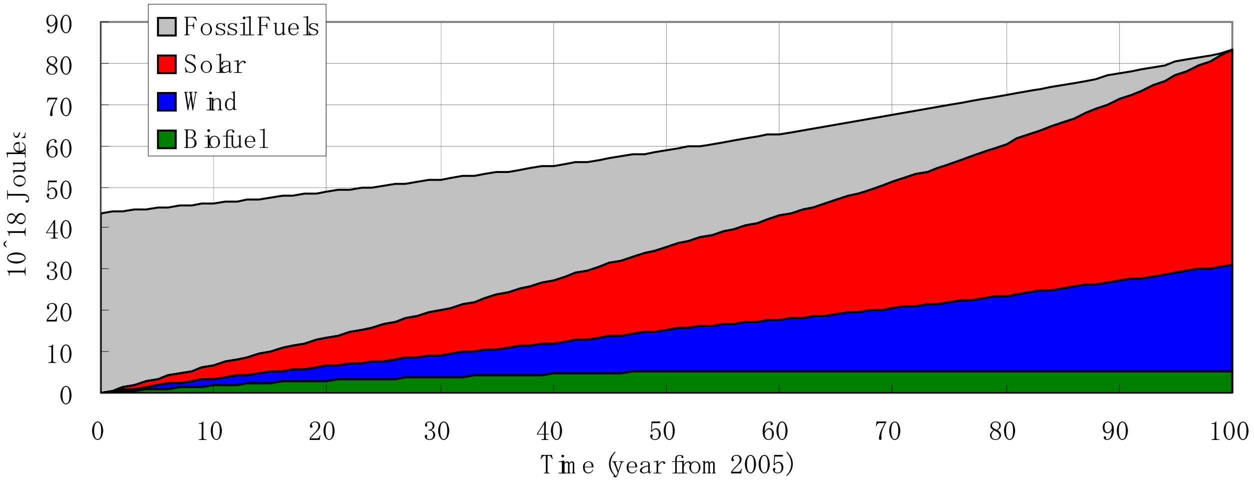


Figure 5.13 Final results of energy portfolio in 100 years.

6. Conclusions:

Sustainable energy is not only important for the future of humankind, but it is necessary for our continued existence. We had three main steps in our process of outlining a feasible and completely renewable energy portfolio for future generations of the United States: first an extensive literature review, next engineering calculations to decide on the most beneficial energy sources to use, and finally a simulation of our implementation process to confirm its feasibility.

Our literature review took place over two months during which time we gathered ample information to make educated decisions on what truly dictates a renewable energy resource and which sources of energy available in our region are renewable. We concluded that a truly renewable energy resource is one that is not only available for the foreseeable future but they must also emit much less carbon dioxide compared to fossil fuels, must be feasible for widespread implementation, require no engineering well beyond current technology, and must leave room to cover future expansion. When applying these requirements the three energy sources that our group decided to focus on are solar, wind, and biomass energy sources. Other non-fossil sources of energy such as hydroelectric and geothermal were ruled out due to very limited availability in the central region of the U.S.

During the next step we used some basic real-world assumptions to calculate the land area needed to satisfy the current energy demand and greatest possible output of each of the different resource. We found that both wind and solar require less than one percent of the available land in the central United States to satisfy current energy demands and emitted a fraction of the carbon dioxide that fossil fuels emit. This leaves plenty of room for future expansion to satisfy increasing energy demands and a large environmental benefit to implement these changes right away. The cost associated with the conversion is also sensible and almost ten times less than the money used to buy gasoline every year. After confirming the validity of energy availability we went on to the final step of simulating our conversion to renewable energy.

Our simulation was created to be extremely flexible and allow us to specify almost every aspect of our energy portfolio (renewable incorporation timeline as well as ratios of each energy source). We demonstrated that by using a combination of mild energy conservation and solar, wind, and biomass energy sources that we could provide for all current and future energy needs of the United States. Not only were we able to simulate our energy demands and sources, but we were able to show that within 100 years we can eliminate all significant sources of carbon dioxide from our energy portfolio. This allows up to live at current standards without any significant long-term environmental impact.

Resources:

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