
Alternative Metropolitan Power Strategy

I PRO 302
Illinois Institute of Technology

Final Report
Spring, 2010
Sponsored By: Sargent & Lundy

1. Executive Summary

I PRO 302 was established to come up with a hypothetical design that can account for 20% of the City of Chicago's power needs using renewable sources such as photovoltaic solar, solar thermal, and wind turbines. The system will be secured by using combustion turbines when the environmental conditions are not met in order to run the renewable sources.

The team established itself as AMPS – Alternative Metropolitan Power Strategy, and is being sponsored by Sargent & Lundy, one of the industry's leading power consultation companies. They have provided the group with very specific guidelines, and expect a final proposal meeting all requirements. At the end of the project, the team will give a formal presentation of results to both Sargent & Lundy and I PRO judges during I PRO day.

The team went through three basic phases: preliminary research, extensive research and design synthesis, and compilation of presentations and deliverables. In the preliminary research phase, information on environmental and power consumption for the city was found. Additionally, case studies of existing wind, solar and CT facilities were reviewed in order to determine the cost range of operation for these facilities. During the extensive research and design phase, the team collected in-depth information about the technologies and compiled it into a renewable energy design for Chicago. The economic viability of each option was assessed, and costs per kWh were calculated. After the design was completed, the presentation and report phase began, resulting in a deliverable proposal that will meet the needs of Sargent & Lundy, as well as the I PRO committees.

To provide at least 20% of Chicago's yearly electricity demand through renewable sources and 2) to provide at least 358.8 MW of power to Chicago instantaneously at any moment over the year.

2. Table of Contents

1.....	Executi
ve Summary	Error! Bookmark not defined.
2.....	Table
of Contents	2
3.....	Purpos
e and Objectives	Error! Bookmark not defined.
4.....	Organi
zation and Approach	Error! Bookmark not defined.
4.1 Work Breakdown Structure	2
4.2 Team Structure	2
4.3 Project Timeline	2
5.....	Analysi
s and Findings	Error! Bookmark not defined.
5.1 Technology Background	2
5.2 Case Studies	2
5.3 Power Requirement	2
5.4 Solar	2
5.4.1 Solar Resources	2
5.4.2 Capacity Factor	2
5.4.3 Installation Costs	2
5.4.4 Calculation of Installation Costs	2
5.5 Wind	2
5.5.1 Wind Resources	2

5.5.2 Capacity Factor	2
5.5.3 Installation Costs	2
5.5.4 Yearly Costs	2
5.5.3 Combustion Turbine	2
5.5.4 Location.....	2
5.6 Power Requirement.....	2
5.7 Combustion Turbine Selection & Cost.....	2
5.4.1 Natural Gas Costs.....	2
5.4.2 Capacity Factor	2
5.8 Comparison of Solar, Wind, Traditional Coal based Power Plant	2
5.9 Integration	2
5.9.1 Integration research	2
5.9.2 Transmission Losses	2
5.9.3 Financial Calculation	2
6.	Conclu
sions and Recommendations	Error! Bookmark not defined.
7.	Appen
dix A – List of acronyms.....	Error! Bookmark not defined.
8.	Appen
dix B – Definition of Terms.....	Error! Bookmark not defined.
9.	Appen
dix C – Assumptions	Error! Bookmark not defined.
10.	Appen
dix D – References	Error! Bookmark not defined.
11.	Appen
dix E – Sponsor Background	Error! Bookmark not defined.
12.	Appen
dix F – Ethics & Team Values	Error! Bookmark not defined.

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3. Purpose & Objectives

The objective of this project is to identify and evaluate renewable energy technologies that will support 20% of the electricity demands for the City of Chicago. To accomplish this mission, we will:

- Analyze the electrical requirements for the City of Chicago and assume a hypothetical legislated renewable portfolio standard (RPS) of 20% must be met. This RPS, which is being considered on the Federal level and is law in the State of California, would require that 20% of the power sold into the market must be produced by renewable energy power sources.
 - Evaluate the electrical requirements on an hourly, daily, and yearly basis to fully understand the system load profile.
 - Evaluate wind and sun conditions in state of Illinois on an hourly, daily and yearly basis to determine how well it matches the demand profile.
- Analyze performance of commercial wind turbines (data available on websites) and how they will perform according to your wind analysis.
 - Calculate how many turbines will be required to meet full load and supply backup power sources as necessary to fully support the demand profile.
- Analyze and select back up power sources to economically support the system.
- Estimate distribution of wind turbines and/or solar facilities.
- Estimate transmission distances from source of power to end user in the city.
- Estimate power losses due to transmission and distribution systems.
- Include sufficient renewable capacity of wind turbines and/or solar panels to support power requirements of back up source and transmission losses.
- Calculate total renewable system cost estimate for wind turbines and solar systems, backup power source, land requirements, maintenance roads and transmission lines to City of Chicago.

Calculate \$/kWh of production and compare with today's current coal-based power rate.

Additionally, consider the cost of CO₂ emissions and look into its impacts on the future cost of coal-based power.

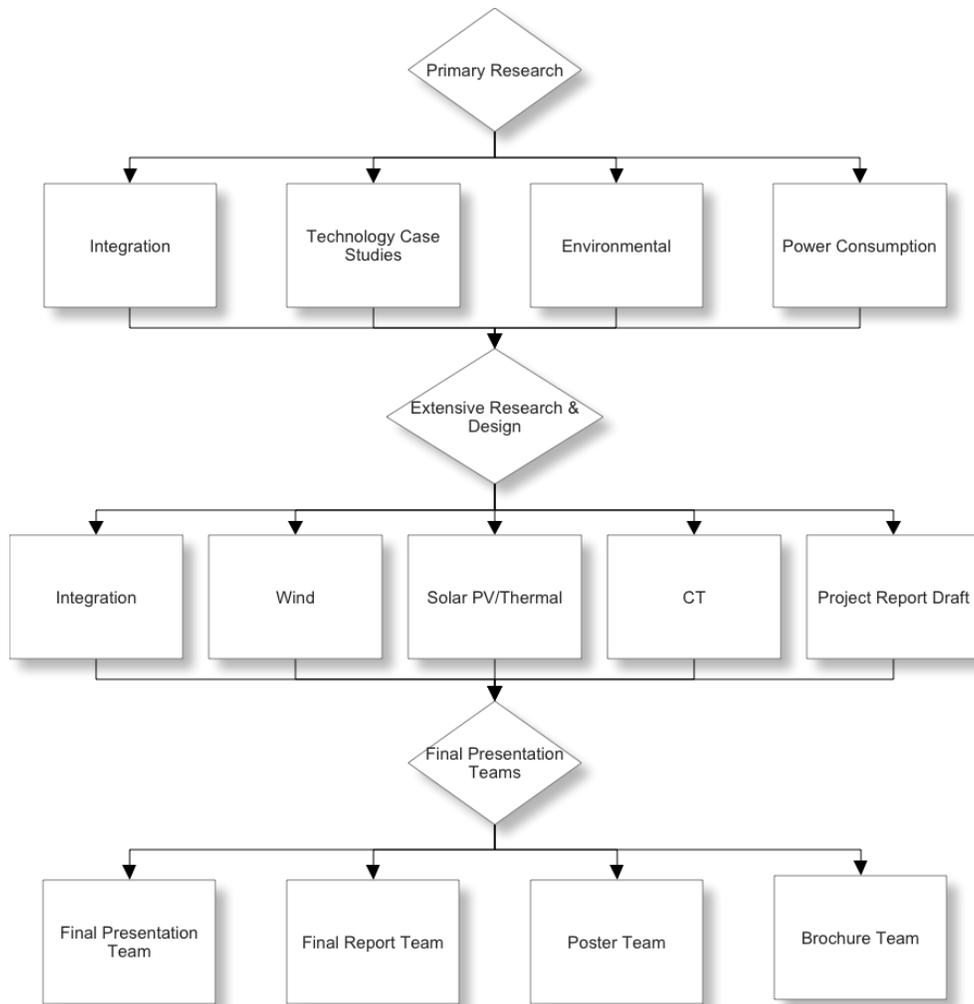
4. Organization & Approach

4.1 Work Breakdown Structure

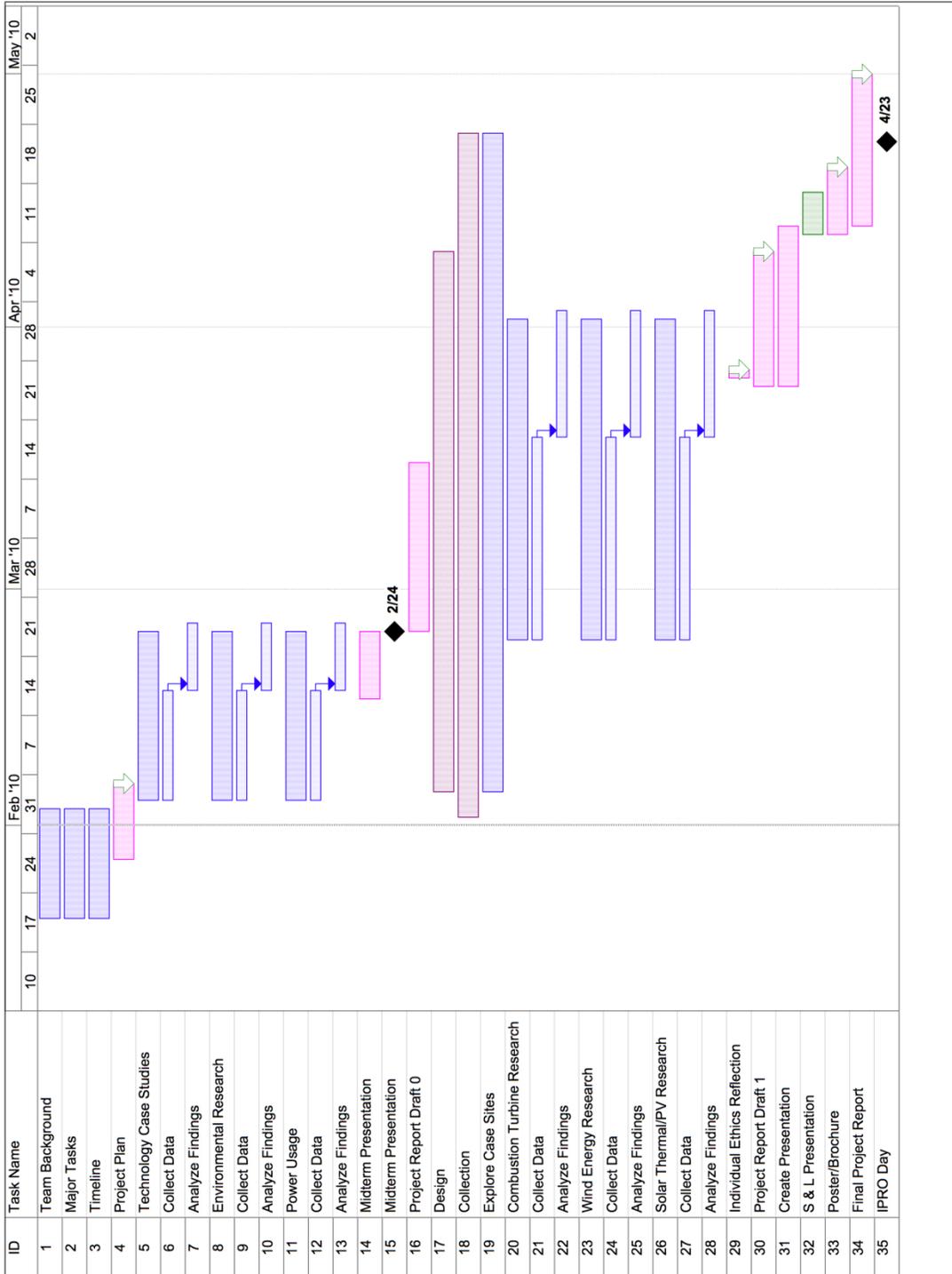
The IPRO team divided the project into three phases: primary research, extensive design and research, and the final presentation teams. The team was split into four sub teams during each phase of the project. The Team Structure section shows the sub team divisions.

During the primary research phase, the team became familiar with wind, solar, and combustion turbine technologies and accomplished the first two tasks of the objectives by obtaining environmental information about Illinois and assessing Chicago's electrical demand. During the extensive research and design phase the team studied the technologies with greater attention to detail, and began selecting locations and designing power plants and wind farms. Throughout both phases, the integration team coordinated the efforts of the other teams and researched the financial calculations necessary to turn the power plant designs into a cost per kWh.

4.2 Team Structure



4.3 Project Timeline



5. Analysis & Findings

5.1 Technology Background

Power demands are currently met through a combination of nuclear, fossil fuel, and natural gas based generation. Nuclear power generates most of the baseline power, the minimum power needed on a daily basis, because it produces the cheapest energy after initial construction costs have been met. The amount of nuclear generation also can't be changed easily, making it the perfect candidate for baseline power. Fossil fuel plants generate the balance of the needed baseline power, and more plants turn on as the day starts goes on to meet increasing demand. Natural gas generation, or combustion turbines (CT), is used to meet peak demands because the generators can turn on quickly. This IPRO is going to look at three types of renewable power generation in order to replace 20% of the standard generation profile.

Solar Thermal energy is a technology that harnesses the heat from sunlight to generate electricity. Low and medium temperatures can't be used to efficiently convert the heat to electricity, so the sunlight is concentrated using mirrors to bring the temperature to 350-700°C. The heat is generally converted into electricity by making steam and using a conventional turbine generator. One benefit of solar thermal energy over photovoltaic solar energy (described below) is that heat can be stored more efficiently than electricity can. Solar thermal plants have the option of storing heat during sunlight hours and using that heat later to generate electricity during overcast days or nighttime hours.

Photovoltaic solar energy is a technology that uses the photons from light to excite electrons in a semiconductor (almost always silicon). There is one positively charged layer and one negatively charged layer of semiconductors in a PV cell, and when exposed to light a voltage is created between the two. Unlike solar thermal energy collectors, increasing the heat of the solar cells decreases the efficiency; any temperature above room temperature generally reduces the performance of PV cells.

Wind energy is produced by taking the kinetic energy of the wind and using it to turn a turbine to generate electricity.

One of the largest problems with alternative energy is that it is non-dispatchable, meaning that power is only available when the wind is blowing or there is sun, and not easily predictable for short term operation. Since the power generated by plants has to match the power demand at the current time, large amounts of alternative power can cause instability in the power grid.

5.2 Case Studies

We wanted to carry out some preliminary research before starting the extensive research phase. Reading existing case studies was one of the best ways to get acquainted with the necessary technologies, variables, attributes in the calculation of LCOE. A lot of studies were available in the

market and we were very careful while selecting the ones to study. We made sure that we select study that was carried out by a governmental institution or a legit source. The Wind team worked on

5.3 Power Requirement

The Power team was responsible for finding the load information for Chicago and calculating the amount of power that needed to be supplied by renewable resources throughout the year. At the Start of the project we decided that we would produce our 20% power in the form of an average. In some months we would produce more than we needed in that month, and some months we would produce less than that in renewable energy and use combustion turbines to make up any difference between supply and demand.

We were able to find hourly load data for the entire Comm Ed area of Illinois and peak power usages broken down by each bus for the Comm Ed area of Illinois. In order to find the average power used by Chicago we took the sum of the peak usages for all of the Chicago buses and divided that number by sum of the peak usage for all buses in the Comm Ed area of Illinois. We found that the peak usage of Chicago was 16% of the total peak usage in the entire Comm Ed area.

Sum of Chicago Bus' peak loads: 3590MW

Sum of all Comm Ed Bus' peak loads: 22380MW

Ratio: $3590/22380 = 0.1604 = 16\%$

In order to find the average Chicago usage which is what we needed for our calculation we used the ratio we found using the peak load data and applied it to the hourly load data we had for the entire Comm Ed area. We added up all of the hourly demand numbers in order to get a total yearly demand and then took 16% of that number as the yearly Chicago Demand. Then in order to find the average hourly demand we divided the yearly demand by the number of hours in a year. We calculated 358MW as the amount of power that needs to be supplied to Chicago each hour (on average) through our renewable resources.

Power	Calculation	Result
Comm Ed area demand		98,200 GWh
Chicago demand	$98,200 * .16$	15,700 GWh
We need to produce	$15,700 * .2$	3,140 GWh

$$\text{Average Demand} = 3140(\text{GWhours/year})/8765.8(\text{hours/year}) = 358.2\text{MW}$$

The Power consumption team was also responsible for finding transmission grid maps of Illinois so that the solar and wind teams could place their plants close to existing substations and high voltage lines in order to minimize the cost of having to build new transmissions lines.

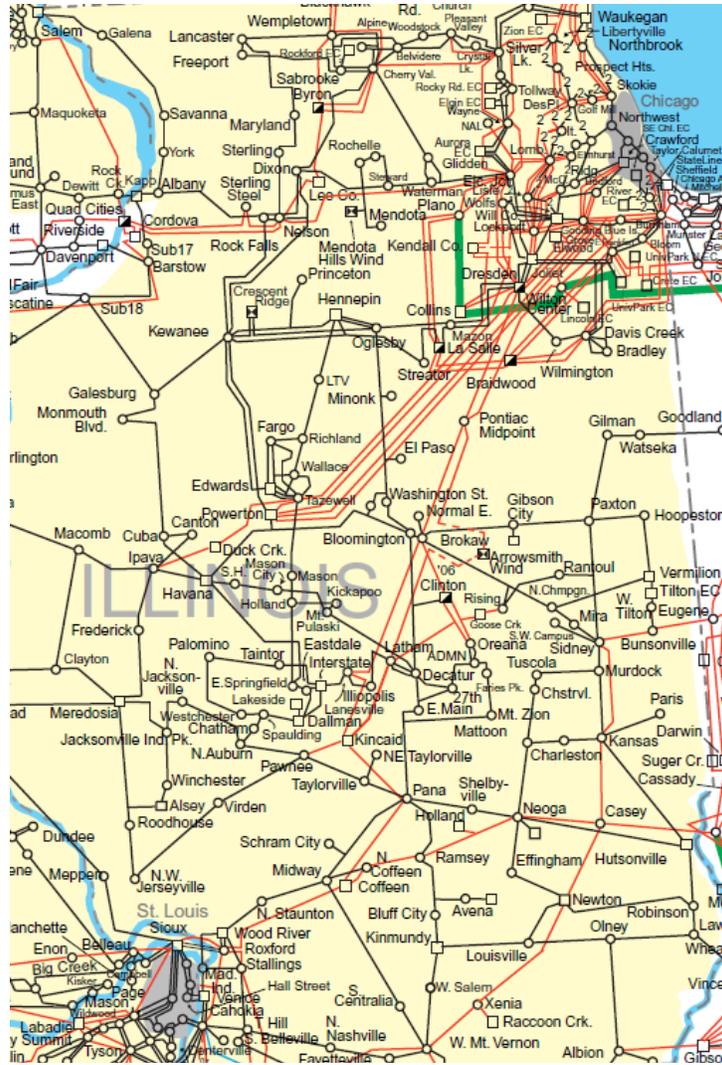


Figure 5.1

Assumptions

- (assumption about exactly what was included as "Chicago")
- The renewable energy we are producing will replace an existing plant of equivalent size
- Our renewable energy sources will never be producing more power than the entire Chicago area demand

- There are power sources in use that can scale back their production when our renewable resources are producing more than the average demand.

5.4 Environmental Data

The Environmental Data team was responsible for gathering information about the environmental resources available for renewable power production. They limited their research to the state of Illinois in order to prevent excessive transmission losses over great distances. They researched both wind and solar conditions throughout the state.

Generally the consistency of wind is better the higher off the ground the blades are, so the IPRO team decided to use 80 meter wind turbines. The map of Figure X shows the wind resources of Illinois available to wind turbines at a height of 80 meters.

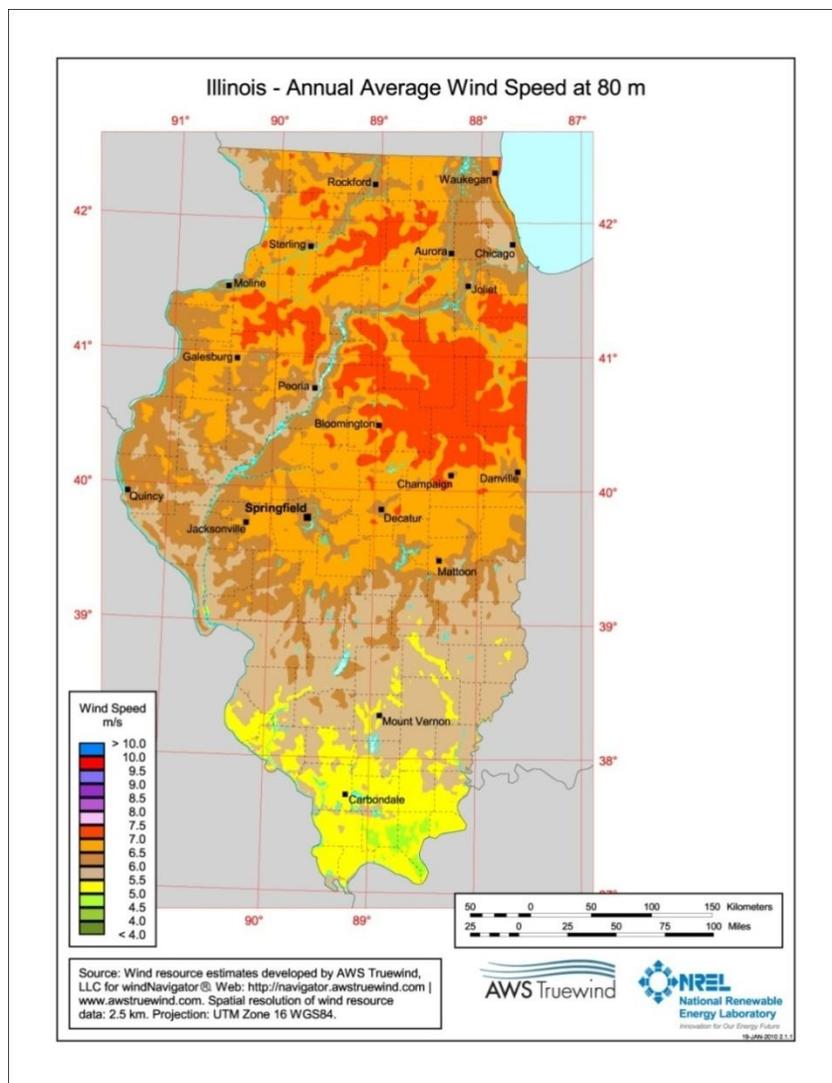


Figure 5.2 [DOE 20% wind]

Wind Resources of Illinois at 80 Meters

The chart of Figure X+1 shows the wind resource potential of Illinois as a plot of cumulative rated capacity vs. capacity factor.

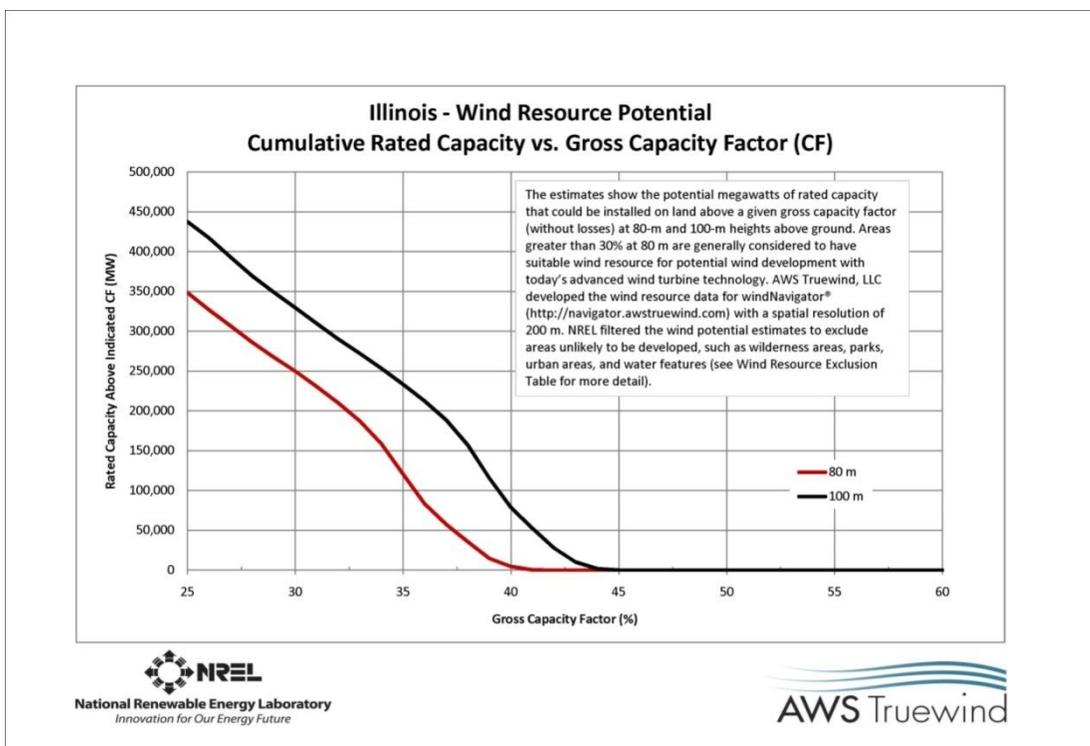


Figure 5.3 [Src: http://www.windpoweringamerica.gov/wind_maps.asp]

Rated Capacity vs. Gross Capacity Factor

5.4 Solar Photo Voltaic (PV) and Concentrating Solar Thermal (CSP)

This section covers the solar resource, capacity factors, installation costs, and O&M costs for PV and CSP. As PV and CSP do not require any fuel, the installation and lifetime O&M costs are the major components to find the Levelized cost of energy (LCOE).

5.4.1 Solar Resource

PV uses direct as well as indirect solar insolation whereas CSP use only direct insolation. This attributes to the fact that PV systems are more popular than CSP systems. Figure 1 illustrates the photovoltaic solar resource in the United States, Germany, and Spain for a flat-plate PV collector tilted south at latitude. The solar insolation levels in U.S range from around 1000-2500 kWh/m²/Year whereas 4-5 kWh/m²/Day in Illinois.

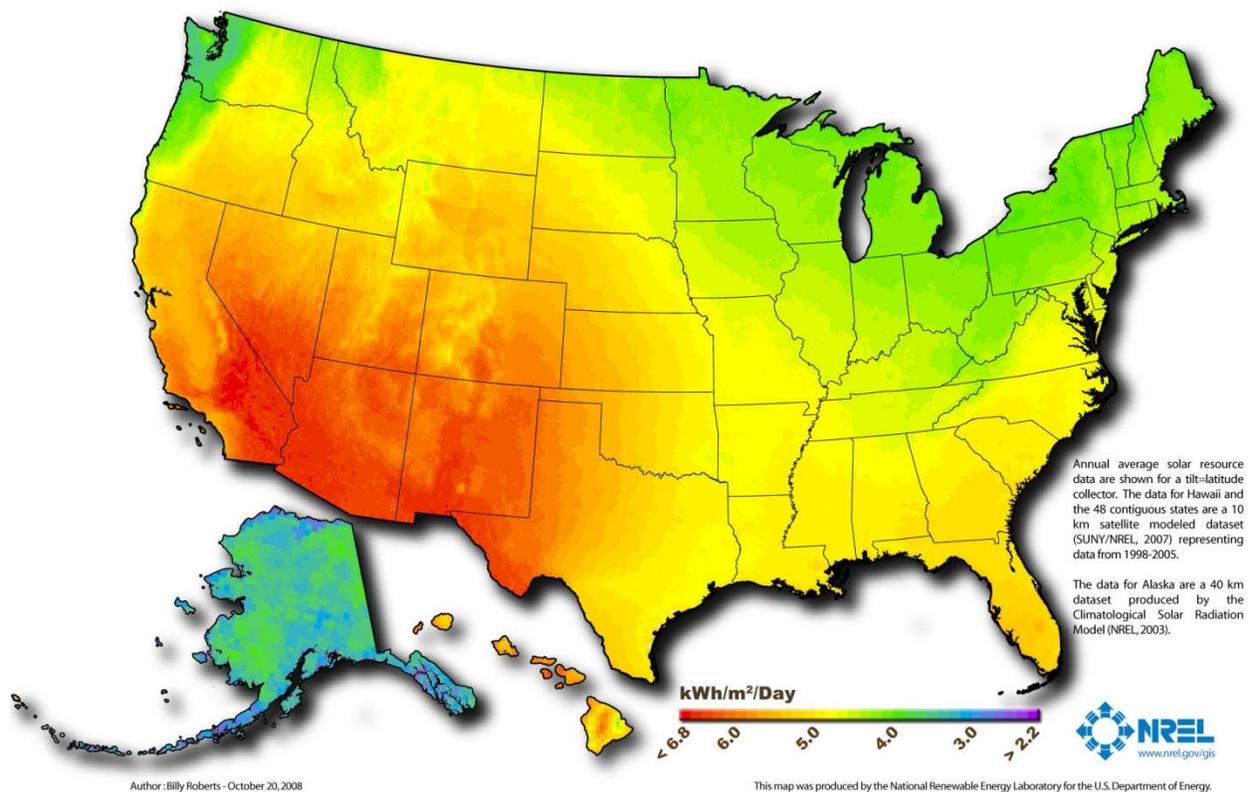


Figure 5.4 Photovoltaic solar resource for the United States

(NREL 2009d)cite website

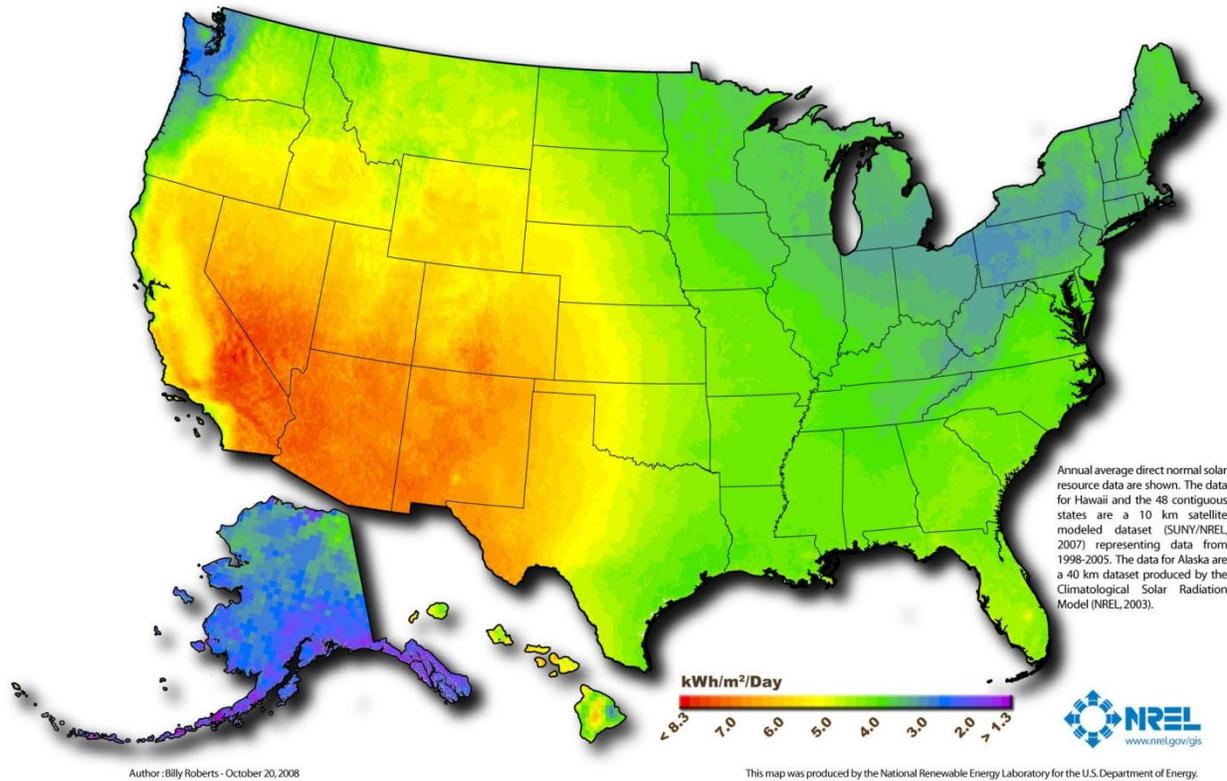


Figure 5.5 Concentrating solar resource for the United States
(NREL 2009d)

The Solar insolation levels for CSP range 3.5-4.5 kWh/m²/Day for Illinois. The geographic area that is most suitable for concentrating solar power is smaller than for PV because CSP uses only direct insolation. In the United States, the best location for CSP is the Southwest, but we still will discuss capital cost for CSP.

5.4.2 Capacity Factor

Capacity factor is the ratio of an energy-generation system's actual energy output during a given period to the energy output that would have been generated if the system ran at full capacity for the entire period. For example, if a system ran at its full capacity for an entire year, the capacity factor would be 100% during that year. Because PV and CSP generate electricity only when the sun is shining, their capacity factors are reduced because of evening, cloudy, and other low-light periods. This can be mitigated in part by locating PV and CSP systems in areas that receive high levels of annual sunlight. The capacity factor of PV and CSP systems is also reduced by any necessary downtime (e.g., for maintenance).

Figure 3 gives us an idea where Chicago stands. The capacity factor for PV ranges from 0.33 in Phoenix to 0.14 in Seattle.

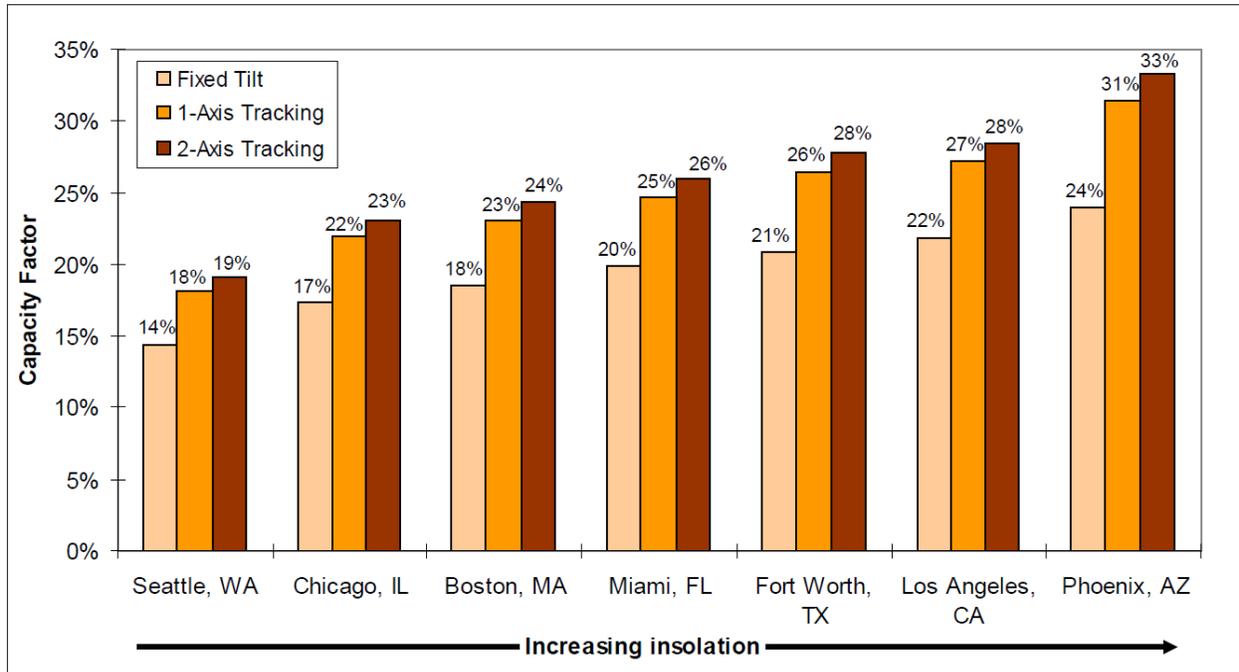


Figure 5.6 PV capacity factors varying by insolation and use of tracking systems (NREL 2009)

Looking at the environmental data, we were sure that if there would be a Utility Scale Solar Plant (PV or CSP) in Illinois it would be in central or south western Illinois. This was because we wanted it away from the city of Chicago to reduce the land cost, but we didn't want to increase the electricity transmission cost by setting it up in a very remote location.

So for our study we used a capacity factor of 21% for PV. For CSP the lower limit of the industry standard capacity factor is 26% which is what we assumed.

5.4.3 Installation Costs

The installation costs were based on the industry indexes provided by the government and other research institutions. For PV the cost includes the Module, Inverter, Other Material, Labor, Overhead, Regulatory, Compliance, and other extras. For CSP the installation cost comprises of solar field components (like mirrors, reflectors, structure etc), Power block, Overhead, and etc. The installation cost we used for our calculations was \$6-7/watt for PV and >\$5/watt for CSP. Figure 4 compares it with other sources

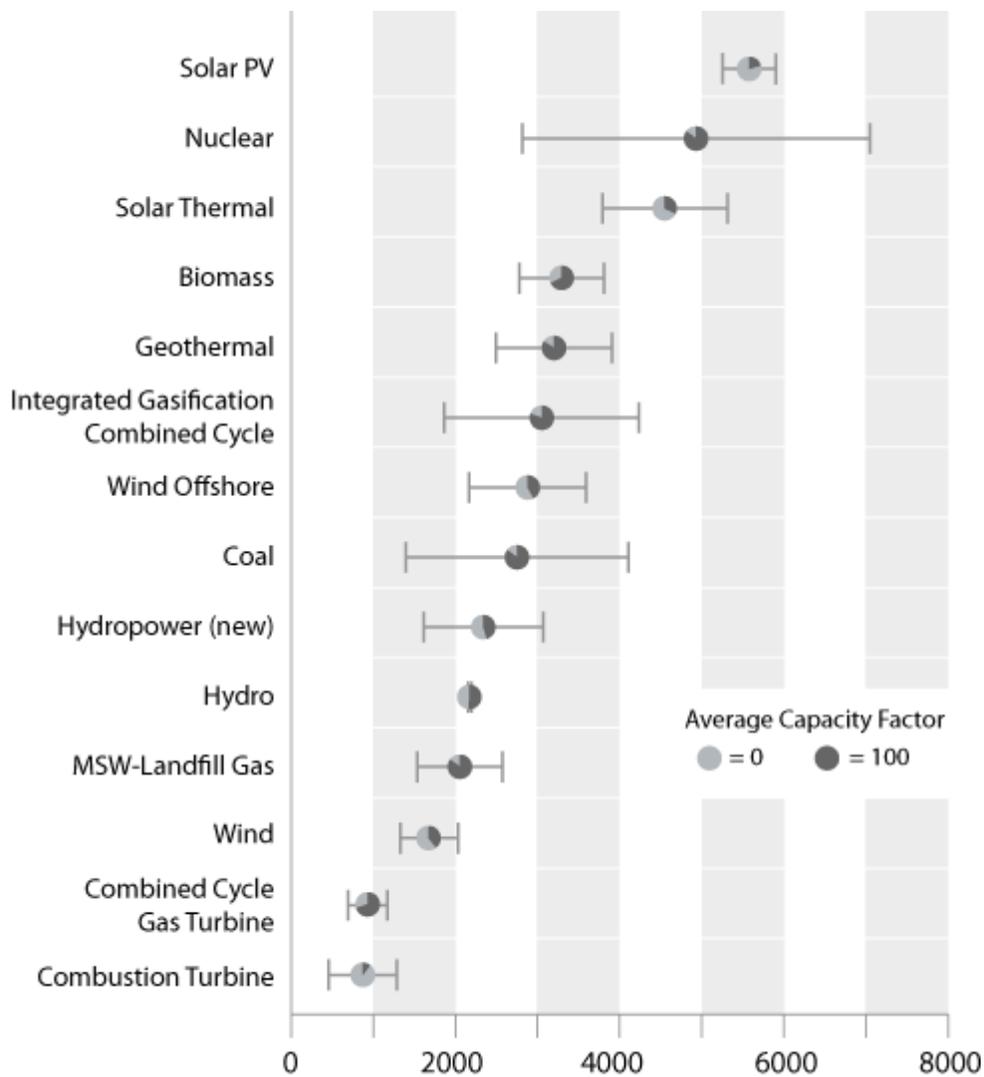


Figure 5.7 Capital (overnight) cost 2006\$/Kwh

5.4.4 Calculation of the Total Installation Cost

Having the power requirement, capacity factors, and the installation costs we can calculate the Total installation cost or the overnight capital cost. As explained above, the capacity factor is the ratio of an energy-generation system's actual energy output during a given period to the energy output that would have been generated if the system ran at full capacity. For PV and CSP, the power requirement (i.e. the power we need to produce) divided by the capacity factor would give us the size of the system we would have to install to achieve that amount of output.

According to our estimate a PV plant of 1708.52MW or a CSP plant of 1379.96MW would suffice the city's power demand. These numbers multiplied by the installation cost per watt would

give us the total installation cost (capital overnight cost). So, PV technology would require an overnight investment of \$10.25 - \$11.96 billion and CSP would require an > \$5.60 Billion.

	Power (we need to produce)	Capacity Factor	Power (we have to install)	Installation Cost	Total Installation Cost
PV	358.79 MW	0.21	1708.52 MW	\$ 6- \$7 /Watt	\$10.25 - \$11.96 Billion
CSP	358.79 MW	0.26	1379.96MW	> \$ 4 /Watt	> \$5.60 Billion

Figure 5.8

5.5 Wind

This section covers the wind resources, capacity factors, installation costs, and O&M. Wind turbines do not require any fuel so the installation levelized cost of energy is based mostly on the initial capital costs and the O&M costs.

5.5.1 Wind Resources

Wind energy is produced by taking the kinetic energy of the wind and using it to turn a turbine and generate electricity. The amount of energy that can be harnessed in a given area is based on the magnitude and consistency of wind speeds in that area. Generally the consistency of wind is better the higher off the ground the blades are. We decided to use 80m towers for our calculations.

5.5.2 Capacity Factor

The capacity factor of a wind farm is the ratio of the average power output of the farm over the maximum possible output. The capacity factor of wind farms are affected by times that the wind is not blowing and downtime for maintenance on the towers. The decision of what capacity factor to use for our calculations was taken based on the average wind speed graphs. For the areas with the best average wind speed in Illinois where we plan to build our wind farms the capacity factor is listed as somewhere between .3 and .4. We decided to use the capacity factor of .3 in our calculations to avoid underestimating the cost.

5.5.3 Installation Costs

The installation costs of wind turbines includes the cost of all the parts, for shipping the parts, for construction of the turbines on site, and the cost of building transmission lines to bring the power from the turbines to nearby substations. For our analysis we decided to use 2.5 MW General Electric wind turbines which have a total installation cost of \$1.7 Million per megawatt of installed capacity.

	Approximate Location	Power Generated (MW)	Capacity Factor	Distance (miles)	loss from transmission	loss From Transformers
Farm 1	Rochelle	72	0.3	80	0.01888	0.03
Farm 2	University Park	72	0.3	40	0.00944	0.03
Farm 3	Frankfort	72	0.3	35	0.00826	0.03
Farm 4	Braidwood	72	0.3	60	0.01416	0.03
Farm 5	Braidwood	72	0.3	60	0.01416	0.03

Adjusted Power (MW)	# of units	Capital Cost (Millions \$/MW)	Unit Capital Cost	Transmission Line Cost	Total Cost (Millions)
237.3605507	95	1.70	403.5129362	8.192	411.704936
235.1650074	95	1.70	399.7805127	4.096	403.876513
234.8934171	94	1.70	399.3188091	4.096	403.414809
236.2576784	95	1.70	401.6380532	6.144	407.782053
236.2576784	95	1.70	401.6380532	6.144	407.782053
					2034.56036

Figure 5.9

We calculated transmission losses based on the distance of the wind farm from the city and assumed one step up transformer and one step down transformer, each with a loss of 1.5%. To calculate the cost of building transmission lines we assumed we would build transmission lines to the nearest couple of tie in points to the high voltage grid and estimated how many miles of transmission lines we would need to build in order to do so. In order to keep installation costs as low as possible we needed to build our wind farms in areas with good wind near existing high voltage lines as close to Chicago as possible. To choose these locations we overlaid a wind speed map with a map of the high voltage lines in Illinois.

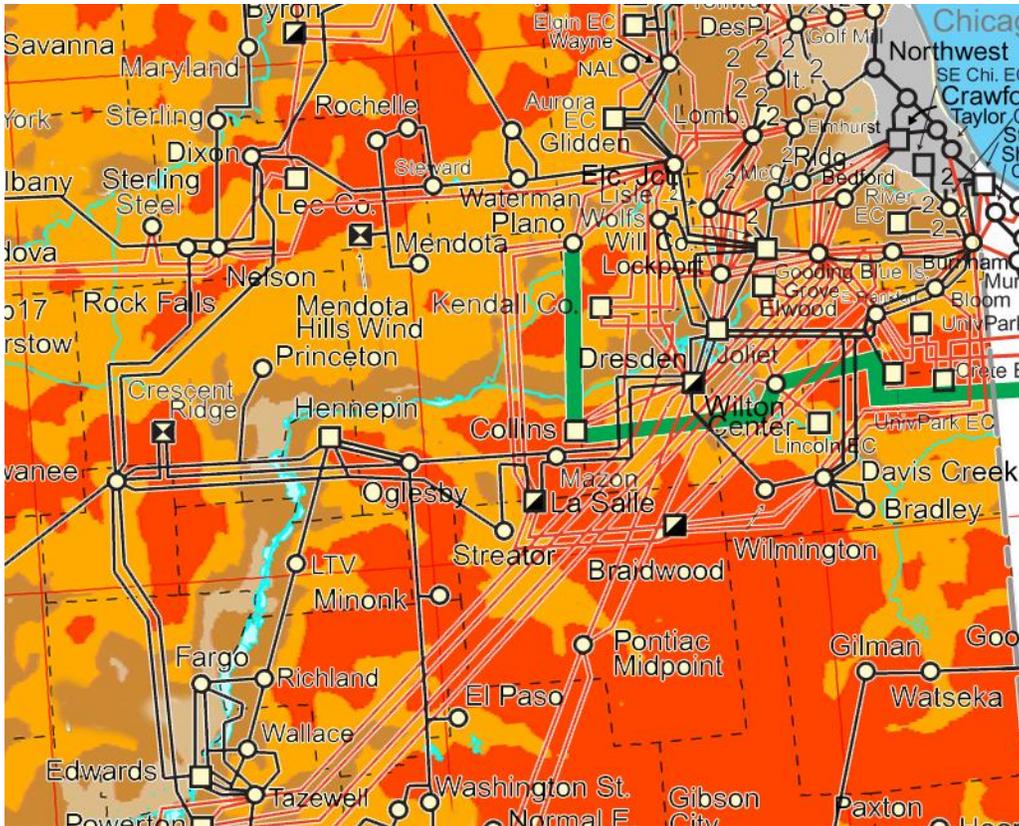


Figure 5.10

5.5.4 Yearly Costs

Yearly costs of the wind farms include all of the costs that can't be accounted for as a lump sum at the start of the project. This includes the operating and maintenance costs for running the wind farm and making repairs over the lifetime of the wind turbines. We decided that instead of purchasing all of the land that would be needed for the wind farm, we would lease the land required for the footprint of the wind turbine and necessary maintenance roads. So the cost of leasing the land is added to the yearly costs.

(Chart for Maintenance costs here)

5.5.5 Combustion Turbine

The Combustion Turbine team was responsible for designing a backup system for the renewable energy sources that ensures that Chicago can be supplied with the power necessary regardless of environmental conditions at any given time. As suggested by the IPRO sponsor, the team focused on natural gas-fired combustion turbines for this backup system. The responsibility of the combined

renewable and combustion turbine systems, as discussed in the problem statement, is 1) to provide at least 20% of Chicago’s yearly electricity demand through renewable sources and 2) to provide at least 358.8 MW of power to Chicago instantaneously at any moment over the year. The combustion turbine backup system is the solution to the second half of the objective. At any time when the energy production of the wind turbines drops below the instantaneous requirement of 358.8 MW, the combustion turbines can be brought up to provide the difference. In the worst-case scenario, the combustion turbines would be responsible for providing all 358.8 MW. The system being designed must therefore be capable of being quickly brought up, and must be able to provide Chicago with 358.8 MW instantaneous power, but remain as cost-effective as possible as a system run only occasionally.

5.5.6 Location

The combustion turbines needed to be located near natural gas pipelines or storage facilities to supply the turbines, and unnecessary transmission losses needed to be avoided by situating the plant as near to the city of Chicago. The team chose to locate its turbines in area of the city of Joliet because, as can be seen from the images of Figure X.1, it is ideally located near both natural gas lines and storage facilities, and is near to Chicago. The proposed location of the plant is shown as a black square on both maps. Blue lines are natural gas lines; red triangles are natural gas storage facilities.

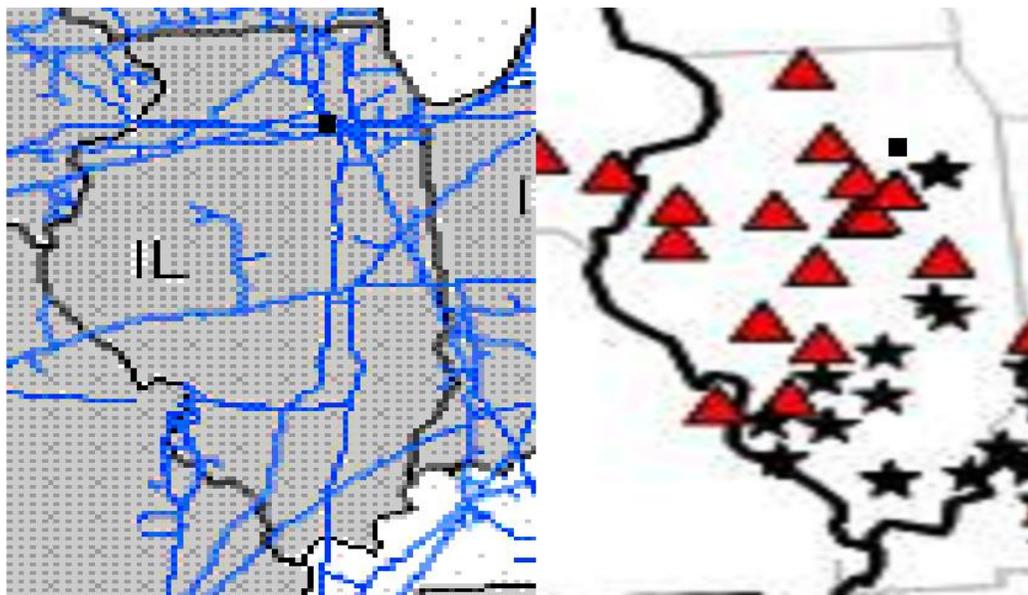


Figure 5.11

Natural Gas Lines & Storage Facilities in the State of Illinois [src: about natural gas pipelines]

5.6 Power Requirement

As discussed in the introduction to this section, the combustion turbine system is responsible for providing at least 358.8 MW to the city of Chicago when all turbines are running. However, transmission losses from the location of the plants to the city of Chicago had to be considered.

Transmission losses from this location were calculated using the methods discussed in Section X.X, and found to be 4 MW. The combustion turbine system must therefore be able to produce:

20% of Chicago’s average demand + transmission losses =

$$358.8 \text{ MW} + 4 \text{ MW} = \mathbf{362.8 \text{ MW}}$$

5.7 Combustion Turbine Selection & Cost

There are two types of combustion turbines: simple cycle and combined cycle. The CT team researched both types of technology to determine which should be used for this project. ‘Simple cycle’ refers to a combustion turbine system that has only a gas turbine, and no system for the recovery of waste heat. Combined cycle combustion turbines convert use the heat from the exhaust of the primary turbine to run a secondary system to produce more energy. Because of this, the efficiency of a combined cycle CT higher than that of a simple cycle CT, and the energy production is cheaper. However, the capital cost and maintenance cost is higher due to the greater complexity of the system. For the relatively small energy production needed, the team determined that the cheaper price of energy production did not outweigh the greater capital and O&M costs for combined cycle turbines, so simple cycle turbines were selected for the backup system. A cost comparison of the two technologies is shown in Table X.1 [20% Wind]

	CT	CC
Capital Cost [\$/kW]	750	780
Fixed O&M Cost [\$/MW/yr]	6600	14400
Variable O&M [\$/MWh]	2.8	3

Table 5.12

Cost Comparison of Simple Cycle vs. Combined Cycle Technology

The team chose two turbines to provide the power required: a GE Model 7EA 85MW and a GE Model 9FB 279MW [GE doc]. These two combustion turbines are together capable of providing 364 MW instantaneous power. Table X.2 shows capital and operating and maintenance costs for both simple cycle and combined cycle combustion turbines. These were calculated using the costs per MW from Table XX1 and the 364 MW to be produced by the turbines.

	CT	CC
Capital Cost [\$]	273000000	283920000
Fixed O&M [\$]	2402400	5241600
Variable O&M [\$]	880064.64	942926.4
Total O&M [\$]	3282464.64	6184526.4

Table 5.13

Costs for Simple Cycle & Combined Cycle Turbines Producing 364 MW

The costs of Table X.2 were used by the Integration Team to calculate the Levelized Cost of Energy and the cost per kWh for this technology.

5.7.1 Natural Gas Costs

The combustion turbine team also calculated the quantity of natural gas needed by the turbines and the cost associated with the gas. However, the gas prices are included in the operating and maintenance costs given in Table X.2, so the costs in this section were not used for the final analysis.

The fuel needed was calculated using the following formulas:

$$\text{Heat Requirement} = \text{Heat Rate(BTU/kWh)} * \text{Energy Requirement(kWh)}$$

$$\text{Total Natural Gas(ft}^3\text{/y)} = (\text{Heat Requirement}/1250) * \text{Capacity Factor}/\text{Efficiency}$$

Table X.3 shows the actual values calculated based on heat rates obtained from the Department of Energy document “20% Wind by 2030.” Gas prices were also obtained from the “20% Wind” document, which based its projections off the 2007 Annual Energy Outlook. Because of the fluctuation of gas prices, a minimum and maximum price is provided in Table X.3.

	CT	CC
--	----	----

Heat Rate [BTU/kWh]	8900	8670
Heat Requirement [BTU]	0	0
Natural gas [ft ³ /year]	2.2379E+10	2.18E+10
NG with Efficiency [ft ³ /yr]	6.3939E+10	4.3601E+10
NG with Capacity Factor [ft ³ /yr]	6393939017	4360091674
Gas Min Price [\$/yr]	2.8453E+10	4.4037E+10
Gas Max Price [\$/yr]	6.4579E+10	4.4037E+10

Table 5.14

Natural Gas Requirements & Costs

5.8 Comparison of Solar, Wind, And Traditional Coal based Power Plant

It would be interesting to compare the cost of Solar, Wind and traditional coal based technologies. The most basic cost would be installation cost of the power plant. Following the same calculations we carried out for PV and CSP, we can find the capital overnight cost for Wind and Coal based power plants. So, Figure 5 extends to Figure 6 with the inclusion on Wind and Coal. Wind would require a capital of about \$2.04 Billion and out traditional coal plant would require \$ 0.72 - \$1.08 Billion. A point to note is that the capacity we have to install for the coal is the same as the requirement because the capacity factor would not cause an effect on the two variables. This is because the fuel for coal based plants is coal and it is not affected by the time of the day. Also the total installation costs do not include the O&M costs for all four technologies and the fuel cost (Coal) for Coal based power plant. The fuel cost for Coal based plants have a significant effect on the LCOE relatively compared to other technologies.

	Power (we need to produce)	Capacity Factor	Power (we have to install)	Installation Cost	Total Installation Cost
PV	358.79 MW	0.21	1708.52 MW	\$ 6- \$7 /Watt	\$ 10.25 - \$11.96 Billion
CSP	358.79 MW	0.26	1379.96MW	> \$ 4 /Watt	> \$ 5.60 Billion
Wind	358.79 MW	0.3	1195.97MW	\$1.7/Watt	\$2.04 Billion
Coal	358.79 MW	0.85	358.79 MW	\$ 2- \$3 /Watt	\$ 0.72 - \$1.08 Billion

Figure 5.15

5.9 Integration

The integration team's responsibility was to direct the research of the other teams to ensure the completion of the objectives and to work throughout the semester towards the final goal of a cost per kWh of the recommended renewable energy system.

5.9.1 Integration research

During Phase 1 of the project, the integration team researched existing financial equations relating about wind, solar, and combustion turbine technology. The team attempted to find established and commonly used equations for the levelized cost or cost per kWh based on the history of the technologies; however, because of the relative newness of renewable technology and the competitiveness of the current industry, there was not as much published data as expected and 'design equations' for the technologies were unavailable.

During this time the team also researched rough numbers for capital and operating and maintenance costs for the three technologies, as a starting point for beginning cost calculations. The actual numbers used are discussed in the Wind, Solar, and Combustion Turbine sections of the report.

5.9.2 Transmission Losses

One of the integration team's tasks during the second phase of the project was to estimate transmission losses from the locations of the renewable energy sources to the city of Chicago. For simplicity, the losses were estimated using the distance from the proposed renewable energy plant to the intersection of Madison and State St.

The team used 0.236 kW/MW-mile as the estimated transmission loss, based upon the transmission assumptions in Appendix B.5 of the "20% Wind by 2030" Department of Energy document.

5.9.3 Financial Calculation

6. Conclusion & Recommendations

Final \$/kWh numbers for each technology at a given IRR; levelized cost

Recommendations: which technology is most cost-effective?

Future tasks for next IPRO

7. Appendix A- List of acronyms

CT	combustion turbine
LCOE	Levelized cost of Energy
O&M	operating and maintenance
PV	photovoltaic
CSP	Concentrating solar thermal plant
S&L	Sargent and Lundy, the IPRO sponsor

8. Appendix B- Definition of Terms

Nameplate Capacity

9. Appendix C- Assumptions

Power Supply & Demand

During the first phase of the project, after research and discussions with the sponsor, the IPRO team made the following key assumption: Chicago's current power infrastructure was assumed to be sufficient to provide for all of the city's power demand, with peaking reactors to make up the difference between the peak power demand and the base power provided by coal and nuclear plants. This assumption was sufficient to support the following conclusions:

- The renewable power provided will make up for the decommissioning of one or more coal-fired power plants that provide a base quantity of electricity equal to 20% of Chicago's average power demand over 1 year
- The renewable power provided, averaged over 1 year, must be equal to 20% of Chicago's average power requirement over that year
- The combustion turbines used as backup for the renewable energy sources will be responsible for providing the difference between the instantaneous power provided by the renewable system at any moment and 20% of the average power demand for Chicago over that year
- The currently existing peaking reactors will continue to provide for the city's demands above the base load provided by coal & nuclear plants combined with 20% of Chicago's average power demand
- (assumption about exactly what was included as "Chicago")
- The renewable energy we are producing will replace an existing plant of equivalent size
- There are power sources in use that can scale back their production when our renewable resources are producing more than the average demand.

Transmission Assumptions

For the purpose of calculating power loss due to transmission, the distances of transmission were estimated using the distance from the proposed renewable energy plant to the intersection of Madison and State St.

Solar PV Module Lifetime Degradation

A unique concern arises when considering solar photovoltaic technology. Over the equipment lifetime, PV panels degrade in efficiency. However, in the US standard warranties guarantee that panel output after a lifetime of 25 years will be at least 80% of the rated output [Solar Tech Market Report p 58-59]. In order to simplify calculations, the IPRO team assumed that this degradation occurs linearly over the lifetime, and averaged the output of the solar panels over the lifetime

Financial Assumptions

In order to simplify calculations for this approximation, the possibility of producing more power than required by the city of Chicago is disregarded. Any excess produced by renewable power sources is considered to be absorbed by shutting down peaking plants. Inherent in this assumption is the assumption that the power demand is always larger than the base loading power produced by coal and nuclear plants, and that these plants will never need to be shut down to accommodate peaks in renewable power production.

10. Appendix D- References

“Heavy Duty Gas Turbine Products.” General Electric publication. General Electric Company, 2009.

“20% Wind by 2030: Increasing Wind Energy’s Contribution to US Electricity Supply.” Department of Energy. DOE/GO-102008-2567: July 2008.

“About Natural Gas Pipelines—Transporting Natural Gas.” eia.doe.gov. Energy Information Administration, 2007. 8 Apr 2010.

11. Appendix E- Sponsor Background

Providing complete consulting, engineering, and project development services for all types of fossil-fuel, nuclear, and renewable power generation, Sargent & Lundy has established itself as a leader and innovator in the electric power industry and related businesses since 1891. From their first assignment pioneering the design of the Harrison Street Station for Chicago Edison Co. in 1892, to their new 790-MW supercritical station in Iowa, the first plant in the U.S. to use advanced supercritical technology, S&L continues to be at the leading edge of innovation. Their record of accomplishment includes the design of 884 power plants totaling 122,149 MW, and more than 5,000 circuit miles of high-voltage and extra-high-voltage transmission line with more than 100 substations.

Sargent & Lundy serves their clients progressively by placing emphasis on in-depth services for operating power facilities, and by helping shape clients' plans for the future of their power business assets. Operations and maintenance support services assist clients by providing consulting services such as due diligence reviews and condition assessments, improving performance, meeting regulatory compliance issues, and improving the bottom line.

Based in Chicago, Sargent & Lundy has a global presence with project teams on every continent. ISO 9001:2008 certified compliance with SL-QAP and SOPs is mandatory for all work across the company. Approved by the United States Nuclear Regulatory Commission, Sargent & Lundy's compliance with their nuclear quality assurance program, SL-TR-1A, is also required.¹

¹ Most of the Sponsor Background was provided by the Sargent & Lundy website.

¹ Most of the Sponsor Background was provided by the Sargent & Lundy website.

12. Appendix F- Ethics & Team Values

During any project, certain ethical considerations need to be addressed. For the project, it is important that the team as a collective whole maintains a high standard of integrity and cite all sources used during the research and design stages. Prior work must be cited and credit given to the original authors.

Internal ethical concerns come about with honesty and accountability. Each team member is responsible for producing quality material that is not offensive and contributes to the greater good of the team. Additionally, slanderous or hurtful comments or actions towards other team members will not be tolerated.

The team should also make sure that external concerns are met, and that at no point should the team attempt to hurt other IPROs or damage the reputation of any group or individual.

Team Values:

- To be proactive and take initiative.
- To treat one another with mutual respect and fairness.
- To be punctual and responsible for our commitments.
- To show enthusiasm and energy as we accomplish difficult tasks.
- To take pride in learning from others, testing our abilities and boundaries, and willing to ask for help or admit mistakes.
- We value openness in discussing any idea and honesty in tackling any problem, and we will use the full extent of both technical (IGroups, email) and non-technical (team/sub-team leaders, group discussion) means to communicate while developing solutions.
- When confrontations arise, they shall be handled appropriately by the sub-team leader, then team leader, then adviser, and in that order.
- To work cohesively and produce a quality product