Green Power

The Economics of Wind Energy

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For my wonderful parents, Barry and Jan White, my loving girlfriend, Whitney Chapman, and Tubby Coatsworth.

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Abstract

In response to the growing issue of greenhouse gases and global warming, scientists, politicians, and ordinary citizens alike have called for significant changes in the current US energy policy. The decision to shift from fossil fuels to more environmentally friendly renewable energy alternatives is economically unfavorable and politically unpopular, but changes will eventually be necessary. The goal of this study, like many others, is to evaluate one form of renewable energy, wind energy, and determine whether the electricity demands of a small metropolitan area could be completely met by a nearby wind farm. Fully aware of the critical role that investors will play in the advancement of environmentally friendly energy, this study will seek to illustrate that if a wind power system of this sort is not economically favorable today, it will be in the near future. Hydrogen energy storage systems and fuel cells are used to meet differences in electricity supply and demand.

Sizing and economic analyses include electricity generation, hydrogen production, hydrogen storage, transportation, and fuel cell power. For each step except generation, the technology used was compared economically with several alternatives to illustrate the array of options available to a potential investor. Present value analysis was performed over the assumed 30 year lifetime of the project. As a final note, this study sought to incorporate the externalities and rising costs associated with fossil fuel produced electricity to determine whether government legislation and the steadily deteriorating economic value of conventional energy might expedite a shift to renewable energy sources.

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Introduction

As the debate over global warming and fossil fuel dependence continues, it has become increasingly clear how influential economic market forces will be in determining the role of renewable alternative energy sources. Activists, scientists, and engineers alike have been calling for a shift away from fossil fuels for decades, yet the development of other forms of energy production has been forestalled by the simple power of dollars and cents. In examining the feasibility of the so called "hydrogen economy," it is clear that there is no shortage of alternative energy options. Moreover, the renewable energy potential of the United States is easily sufficient to meet the current domestic energy demand (*Annual Energy Review 2006*, 2007; Elliott et al., 1991; Succar, 2008b).

The growing demand for renewable hydrogen energy shows no signs of abating; in fact, the increasing volatility and decreasing supply of fossil fuel resources should accelerate the growth of and interest in renewable hydrogen. Energy consumption in the US is increasing by an average of 1.5% annually, accompanied by a corresponding increase in CO_2 emissions (Hydrogen Economy, 2004). Concerns over the contribution of CO_2 emissions to global warming and the greenhouse effect have lead to increasing pressure from the American public to expand the production of clean, renewable energy production. Currently, the US produces 9 million tons of hydrogen annually, mostly through a process known as steam methane reforming (SMR) (Hydrogen Economy, 2004; U.S. Department of Energy, 2005; Cole, 2006). There are some individuals who believe that the advancement of the hydrogen economy should be based not on renewable production sources but on this less expensive fossil fuel based production method. However, SMR hydrogen production does not significantly reduce greenhouse gas emissions, and thus does not seem to be a viable long term solution.

Renewable hydrogen production does have some serious issues that must be addressed before it can be considered as a feasible source of future energy production. Wind and other renewable technologies have issues of availability and correlation with demand. For example, wind energy typically peaks during low demand evening periods, and sites that happen to have excellent wind potential tend to be in remote locations, requiring extensive transportation networks to supply population centers (Boyle, 2004).

Some experts respond that the difficulties associated with renewable energy technology necessitate a well planned shift toward hydrogen energy driven by governmental initiatives. A Department of Energy commissioned study, published in 2003, made a recommendation along these lines. Hydrogen generation in this model would begin with small scale distributed production and storage (~500 kg/day); subsequent developments would shift production toward midsize manufacturing and storage (~24K kg/day) with delivery by tanker truck; and ultimately, the price of renewable hydrogen would become low enough to make centralized systems (~1.2m kg/day) with distribution by pipeline economically feasible (Hydrogen Economy, 2004). Another potential avenue for hydrogen development is through hybrid systems operating off a mixture of hydrogen and natural gas. The authors of this report note that most power plant technology today could run on a natural gas/hydrogen mixture, with hydrogen comprising as much as 62% of the fuel input (Hydrogen Economy, 2004). They also point out that modified natural gas pipelines could be used to facilitate hydrogen distribution while the country weans itself off of imported natural gas (Hydrogen Economy, 2004).

Others see the challenges facing large scale renewable energy as insurmountable and conclude that the hydrogen economy is an overly optimistic vision for the near future. These analysts argue that research and development should focus more on short term efficiency improvements in conventional power production rather than long term renewable power alternatives (Romm, 2004). For the time being, renewable energy should remain a small scale power source for very specific applications.

While many of these studies forecast system prices as far ahead as 2100, few take the time to examine parallel developments in the conventional fuel industries. To assume that gas prices will remain stable or merely keep pace with inflation is a rather naive assumption given the current market for fuel, the finite world oil supply, and the growing demand for oil and gas in developing countries. Furthermore, most previous renewable energy studies fail to quantitatively assess the external costs of fuels such as oil and gas when performing cost comparison analyses.

This study will assess the economic viability of a renewable energy system with wind production, hydrogen storage, and subsequent fuel cell power providing electricity to a small city (pop. 10,000-100,000). The primary goal is to illustrate the market forces that will drive the development of the hydrogen economy and to show that falling costs will make large-scale wind-produced hydrogen energy profitable in the near future. Various storage, transportation, and fuel cell systems will be compared, and each component will be evaluated economically in order to determine the most affordable system for the site. Hybrid systems have been intentionally ignored in order to simplify the analysis.

First, this study will evaluate the current economics of wind energy production. Equipment for appropriate hydrogen production and storage will then be sized and priced. This includes the electrolyzers, compressors, coolers, storage tanks, and pipelines as necessary. The most economical hydrogen system will be compared with conventional batteries appropriately sized for this particular application. For battery storage systems, electricity will be transported through the grid from the wind farm to a storage facility closer to the consumers. Hydrogen storage will require a more complex analysis, comparing various forms of transportation and fuel cell designs. This study will internalize the external costs of conventional fossil fuels, which will allow for more accurate comparison between renewable and conventional energy production. The effects of public policy, in the form of government energy subsidies, on the expansion and development of renewable hydrogen will be assessed. In addition, an attempt will be made to forecast when an optimized system of generation, storage, transportation, and consumption could ultimately compete with fossil fuel.

The Site

Texas A&M University, located in College Station, Texas, is home to 41,600 undergraduate and graduate students (Texas A&M Office of Institutional Studies and Planning, 2006)**.** The university was an ideal case study because it has electricity demands roughly representative of a town in the 10,000-100,000 person population range (although some differences will be discussed later in this section), and easily accessible, detailed power consumption data. Data was available in hourly increments from mid October 2003 to mid October 2004. This information made it possible to study both seasonal and diurnal variations in campus energy demand. The data was first organized by day of the week and hour to produce a weekly energy demand profile as shown in **Figure 1**.

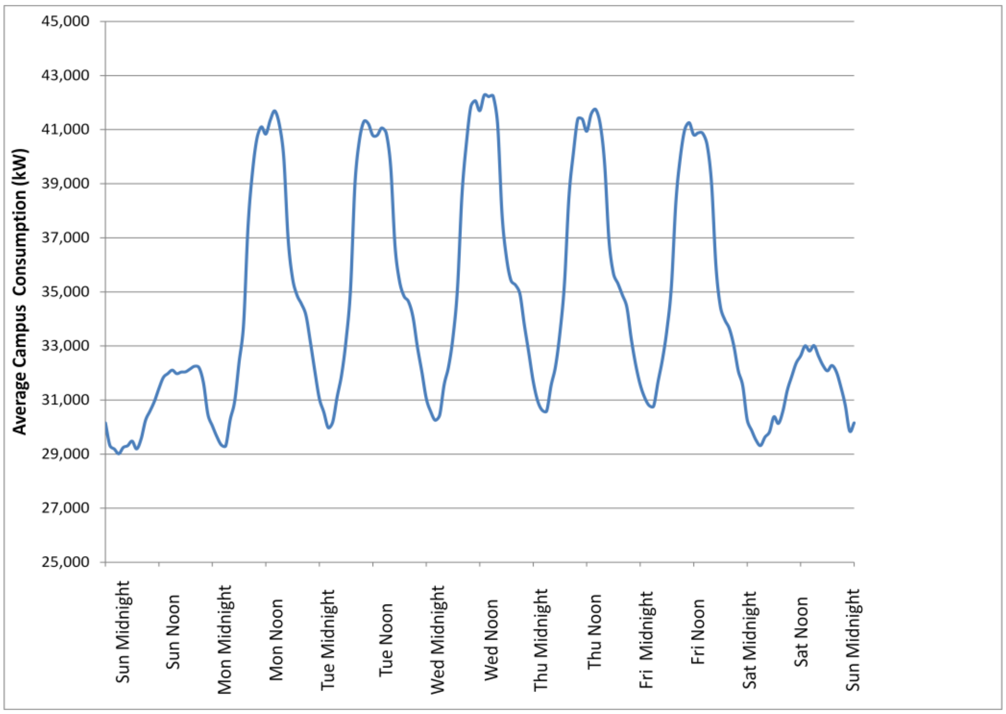


Figure 1: Standard weekly power consumption for Texas A&M
Source Data: Borer, 2008

The above figure illustrates two important trends in consumption variability, which are present at almost any potential site. First, power demand is clearly lower on the weekends than it is during the week, although the evening minimum is roughly the same every day (~30,000 kW). More crucial to the issue of system design, however, is the fluctuation in power demand during the day; weekend power demand rose and fell

15% over the course of a typical day, while the variance in power consumption on weekdays was high as 40%. Keep in mind that the values presented above are hourly *averages*, meaning that variance could potentially be much higher in extreme situations. The best design scenario accounts for average variability, as illustrated here, and builds in a contingency factor to deal with additional uncertainty. The data was also organized by week and averaged to see if there was any seasonal variation in power consumption. **Figure 2** displays this data.

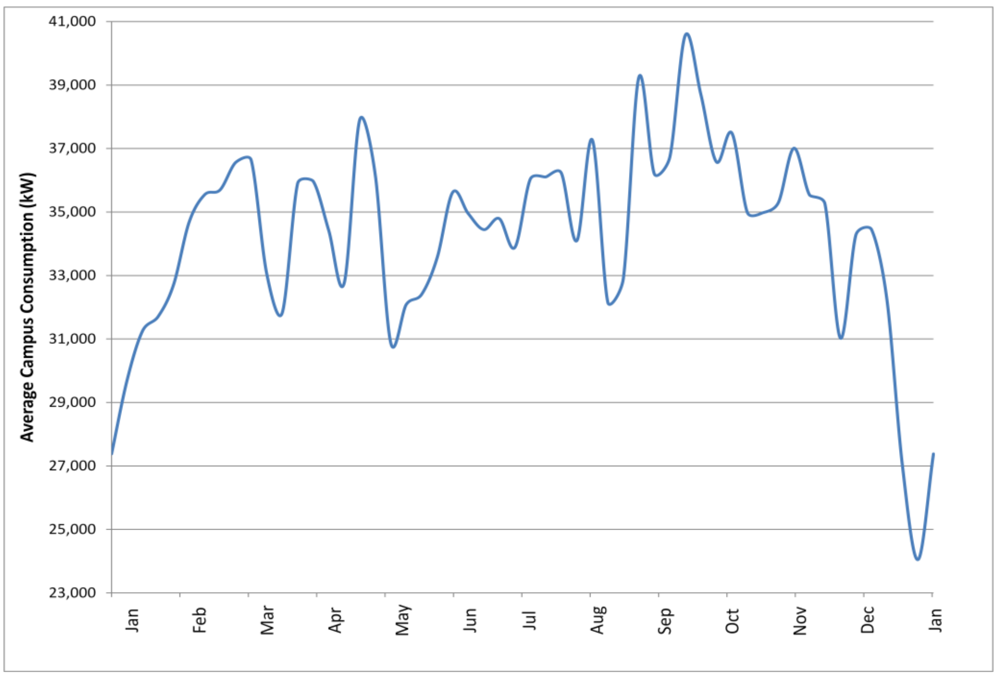


Figure 2: Standard seasonal power consumption for Texas A&M
Source Data: Borer, 2008

Here, the trends are less clear. Power demand drops off sharply in late December and early January, a consequence of the holiday break when many students are off campus. Similar drops in mid March (Spring Break), early May (break between Spring Term and Summer Term), mid August (break between Summer Term and Fall

Term), and late November (Thanksgiving) could also be attributed to students being off campus. It is interesting to note that power consumption does not noticeably drop during the summer months, suggesting that many students do remain on campus. The most important consideration, however, is this: although the average power consumption changes by more than 60% over the course of a year, there are no apparent seasonal trends in the demand profile that could be exploited.

Chapter 1: Production from Renewable Sources

Given the shrinking global supply of fossil fuels, it has become increasingly clear that long term energy policies in this country and abroad will require the extensive use of renewable energy sources. Future energy production will most likely involve a combination of renewable sources such as solar thermal, solar photovoltaic, biomass, hydroelectricity, tidal, wind, geothermal, wave, and others. Production costs account for up to 2/3 of the total cost for a renewable hydrogen power system (Levene et al., 2007). Therefore, it is especially important to determine what means of production is best suited to the particular site and application under consideration.

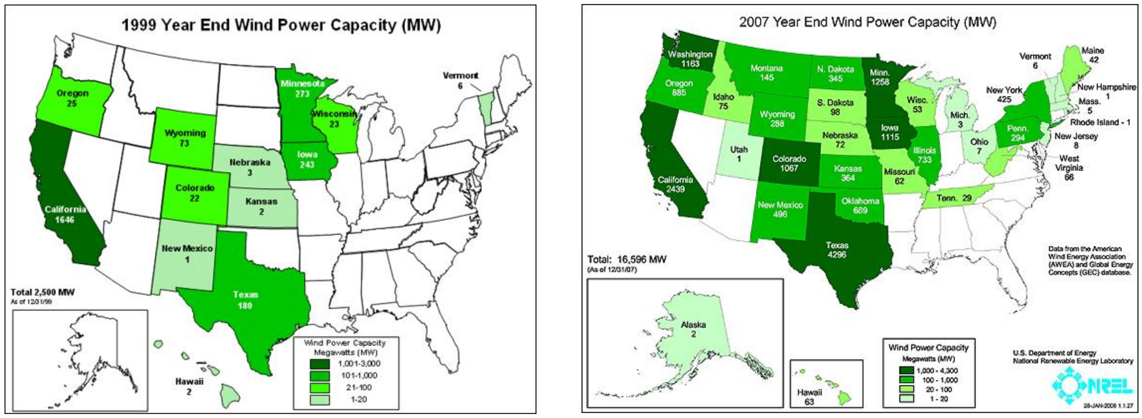
The following section evaluates wind turbine energy production in a grossly simplified model, where only one means of production is permitted. The goal here is to clearly illustrate the overwhelming potential for economical renewable energy production. The energy system used in a particular scenario will strongly depend on the geographical characteristics of the site in question. In light of this reality, it would be imprudent to suggest that the best means of production for the area considered here is the optimal system in all cases.

1.1 Introduction to Wind Energy

The technology to harvest wind energy has been around for over 4,000 years. However, the era of the modern wind turbine did not begin until the 1940's, and extensive research and development have only been going on for the past 40 years (Boyle, 2004). In response to the oil crisis of 1973, the Danish developed a new generation of wind turbines, which were initially limited to small scale applications in that country. In the late 1970's, lawmakers in California introduced tax credits to stimulate the construction of wind turbines there. Using the technology developed by the Danes several years earlier, Californian investors created the first large scale wind turbine power market in history (Boyle, 2004). Additional subsidies provided under the Public Utility Regulatory Policies Act of 1978 further stimulated development, and the dramatic rise in oil prices in the late 1970's fueled speculation that renewable sources would soon replace fossil fuels as the predominate form of energy production.

Unfortunately, the skyrocketing energy prices that Californians banked on never materialized and wind development stalled when the tax credit laws expired in the mid 1980's. The tax credits of the 1970s only provided financial incentives for installation, resulting in a wave of shoddy turbine construction. Consumers soon discovered that many of these new turbines had poor efficiencies and reliability issues (Guey-Lee, 2002). It was developments abroad that would bring about renewed interest in wind technology in the 1990s. A newly reunified Germany led the way, and by 2002 the country had expanded its own wind turbine capacity to almost 23,000 MW, compared to 4,700 MW capacity in the US (Boyle, 2004).

The recent rise in fuel costs in this country combined with renewed federal tax credits has produced a new boom in wind turbine development. In the last 5 years, US wind capacity has ballooned to 17,000 MW, and states such as Texas, Minnesota, Iowa, and Washington have joined California as US states with significant wind capacity (Woodall, 2008). In fact, Texas currently has the highest wind capacity of any US state, almost double that of California (American Wind Energy Association, 2008c). **Figure 3** shows the growth in wind energy from 1999-2007.



(a) (b)

Figure 3: The growth in US wind capacity from 1999 (a) to 2007 (b)
Source Data: US Department of Energy, 2008b

Thirty-four states provide 48 billion kWh of energy, about 1% of the total US energy supply (American Wind Energy Association, 2008a). Continued growth in wind turbine size, from 0.71 MW in 1999 to 1.60 MW in 2006 (Annual Report on US Wind Installation, 2007), combined with a boom in new turbine construction has led to global wind energy capacity growth of 30-40% annually (Boyle, 2004), as shown in **Figure 4.** Wind turbine prices have increased in the last few years due to rising material costs, a shortage of components, and the falling value of the dollar (Annual Report on US Wind Installation, 2007); nevertheless, wind-produced electricity costs have fallen almost 97% since 1980 (Kelly, 2007).

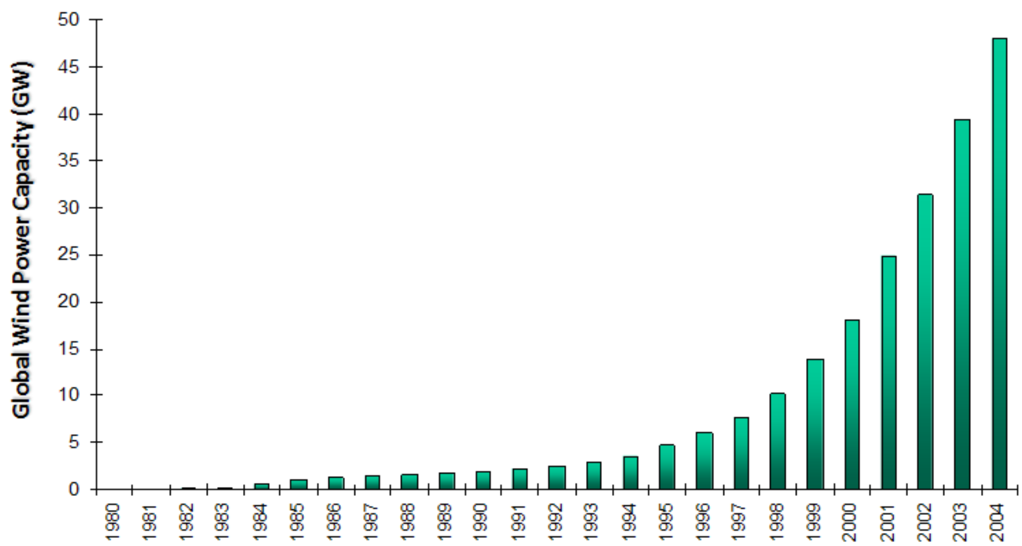


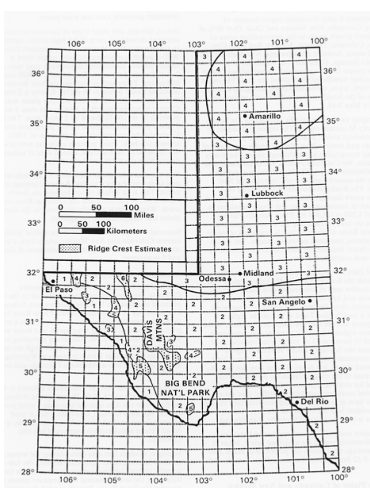
Figure 4: The growing capacity of wind energy
Source Data: Socolow, 2007

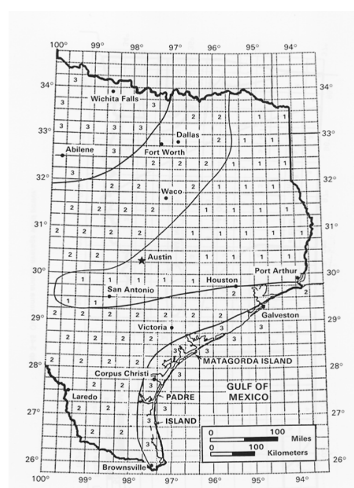
In order to evaluate the wind potential of a site, data from around the country has been incorporated into the official *US Wind Atlas* (Elliott et al., 1986)**.** The wind atlas graphically represents wind speeds, which have been grouped into seven power classes, as shown in **Table 1**. A general consensus among experts in the wind energy field is that wind energy should be economically profitable in the long term for sites with a power class of 3 or higher (Grubb & Meyer, 1993). Even if one only considers wind resources class 5 or higher, which is considered profitable with current technology, the annual wind electricity potential of North America is 42 PWh, 16 times current energy consumption for that part of the world (Succar, 2008b).

Table 1: US Wind Power Classifications (Source Data: Elliott et al., 1986)

Power Class	Power Density @ 10 m (W/m^2)	Speed @ 10 m (m/s)	Power Density @ 50 m (W/m^2)	Speed @ 50 m (m/s)
1	0-100	0-4.4	0-200	0-5.6
2	100-150	4.4-5.1	200-300	5.6-6.4
3	150-200	5.1-5.6	300-400	6.4-7.0
4	200-250	5.6-6.0	400-500	7.0-7.5
5	250-300	6.0-6.4	500-600	7.5-8.0
6	300-400	6.4-7.0	600-800	8.0-8.8
7	400-1000	7.0-9.4	800-2000	8.8-11.9

The data presented above is somewhat misleading, however, because North America has the largest wind resource of any continent (Succar, 2008b). Accommodating current global energy requirements with wind energy would require extensive transportation from North American production sites to European consumers (Grubb & Meyer, 1993). Obviously, such a system is not very reasonable, and the shortage of wind potential in Europe is a serious concern that may limit the use of wind there.





(a) (b)

Figure 5: The wind resources of West Texas (a) and East Texas (b)
Source Data: Elliott et al., 1986

It should also now be clear from the data presented in **Figure 5** that the prospective wind farm to power Texas A&M cannot be located near the campus. Instead, a metropolitan area with an excellent wind resource, Amarillo, was chosen as a production site. In reality, it is unlikely that the wind farm would be built in the Amarillo metropolitan area; any Class 4 wind site would be equally productive and costs would lower in a more rural area. However, the detailed wind data necessary to size the prospective production system was only available for metropolitan areas. The two sites, separated by about 500 miles, are shown in **Figure 6**. The question of how to transport the energy produced in Amarillo to the consumers in College Station will be addressed in detail in Chapter 3.

Figure 6: The geographic location of the production and consumption sites
Source Data: Coutsoukis, 2003

1.2 Wind Design

In designing the optimal wind farm, engineers must first decide what style of turbine to use. Wind turbine designs are generically classified as Horizontal Axis (HAWT) and Vertical Axis (VAWT). Most commercial wind designs are HAWT. VAWT designs do have certain advantages over HAWT designs: no yaw system is necessary for the turbine and controls are at ground level (Boyle, 2004). However, VAWTs are subject to serious blade fatigue, typically require heavier and more expensive equipment, and perform poorly at high wind speeds (Cavallo et al., 1993). HAWTs are generally preferred because of their improved overall performance and reliability. While HAWTs can operate at efficiencies up to 59%, VAWTs are restricted to a theoretical maximum efficiency of 15% (Gipe, 2004).

According to the theoretical model for HAWTs derived by Betz, wind power capture should have a cubic dependence on velocity (Cavallo et al., 1993). Actual rotor efficiencies range from 12-40%, rather than the 59% efficiency calculated in Betz's model. The primary cause of the observed efficiency loss is rotor inertia, although some energy is lost in the drive train itself. Operating the turbine below the rated wind velocity imposes additional losses (Gipe, 2004).

Turbine designers must also take wind speed variability into account. A common model approximates wind speed as a Rayleigh distribution:

$$p(x) = \frac{\pi x}{2} \exp\left[\frac{-\pi x^2}{4}\right]$$

where *x* is equal to *v* divided by <v>, the time averaged velocity, and *p(x)* is the probability density distribution. The value of <*v*> given in this model is typically 1.1 times the mean windspeed at a site (Grubb & Meyer, 1993). Variability introduces an additional form of efficiency loss, represented by the turbine availability, which is defined as the fraction of time when the wind speed is within turbine operating limits. This value is typically above 90%, and recent turbine designs have availabilities as high as 98% (Manwell et al., 2002). **Figure 7** shows the historical growth in wind turbine availability. Producers can best avoid variability issues by installing sufficient energy storage, which was done for the prospective wind system in Chapter 2.

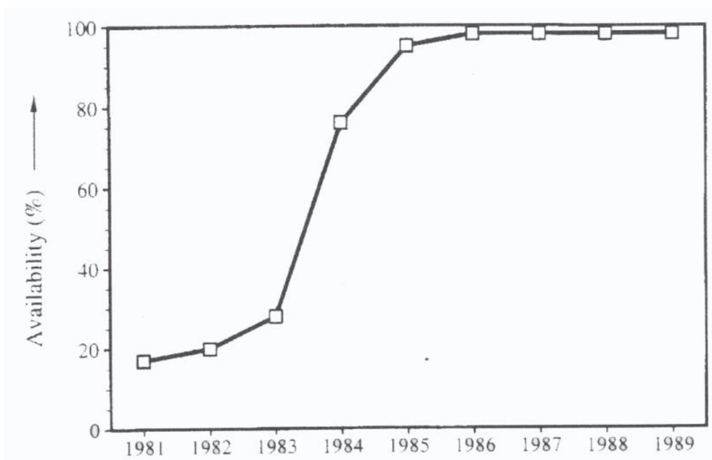


Figure 7: Improvements in wind turbine availability
Source Data: Manwell et at., 2002

Array interference can significantly reduce the available wind energy resource. Wind farm designers must take these losses into account in sizing and spacing turbines. The rate of replacement for extracted wind energy depends on the wind shear and mixing at the site, but disturbances can potentially propagate 40 diameter lengths downwind (Grubb & Meyer, 1993). As the number of turbines increases, the efficiency decreases. In the limiting case, an infinite turbine array with standard 10 diameter length spacing has an efficiency of 60% (Grubb & Meyer, 1993). However, array efficiency increases at higher windspeed, partially offsetting individual turbine losses (Grubb & Meyer, 1993). In order to minimize interference between different turbines in an array, turbines are spaced roughly 5 diameters apart and the distance between rows should be closer to 10 diameters. (Grubb & Meyer, 1993). Locations with significant economic or availability constrains on land purchases might benefit from a closer spacing than this.

The most important factor, however, in designing wind array systems is the turbine height, which determines the power available for the turbine to capture. Experimental calculations have determined that wind velocity increases with height to the 1/7 power, although the value has been found to vary from 0.07 to 0.43 depending on the land contour (Grubb & Meyer, 1993). For example, the "nocturnal jet" phenomenon in the American Great Plains allows wind farm producers there to take advantage of an elevation dependence between 0.2 and 0.3, rather than the standard 0.14 (Gipe, 2004). Standard commercial wind turbines today are 75 to 100 m tall (GE, 2007). Wind towers are typically sized with height equal to rotor diameter, allowing wind power producers to take advantage of the roughly 3/7 power law dependence of electrical power generation based on altitude. As wind technology improves, wind turbines with heights 1.5 times rotor diameter should become commonplace, leading to further improvements in power capture (Gipe, 2004).

Unfortunately, wind power faces some additional challenges, which producers must consider before investing in a project. Siting constraints, imposed by state and federal authorities to protect airspace and wildlife resources, reduce the wind potential in this country by a factor of 4, and in Europe the problem is even more severe (Grubb & Meyer, 1993). In addition, intermittent resources like wind power encounter penetration issues in systems where they account for a large proportion of electricity generation. The issue is a limit on the rate at which power can be assimilated into the grid or, in systems with storage, the rate at which power can be stored in batteries, hydrogen, etc. A study by Gonzalez et al. (2003) on the use of wind power in the Republic of Ireland found a significant decline in the value of wind energy when wind accounted for more than 20% of power production. The study recommends that wind turbine systems limit power levels to 30% of the maximum instantaneous daytime load in order to avoid significant penetration losses (Gonzalez et al., 2003).

One final issue which wind producers must address is resistance from both electric utilities and the American public. Many utility companies are naturally opposed to small scale wind energy because it could endanger long standing monopolies advantageous to their profit margin. In the 1970s, Congress intervened on behalf of consumers and introduced legislation permitting homeowners, farmers, and businesses to connect their personal wind turbines to nearby utility networks (Committee on Energy and Natural Resources, 1979). By 2003, more than 60,000 turbines had been installed as a result of this legislation (Gipe, 2004). These consumers power their homes with their own wind turbines, and the electric utility makes up the difference in cases of low production or peak demand. Excess energy can be sold back to the electric company, although the utilities typically purchase electricity back from consumers at lower wholesale rates. In some cases, utility companies have agreed to "net metering" agreements, where excess electricity is sold back to the utility and recorded as negative usage on the customer's utility meter (American Wind Energy Association, 2007b).

Concern over the visual impact and noise associated with wind turbines has also led to public opposition. Noise was a major issue in early wind turbine designs; the sound level could be distracting up to a mile away (American Wind Energy Association, 2008b). Improvements in design, turbine efficiencies, and soundproofing have largely eliminated noise problems (AWEA, 2008). Modern wind towers produce sound in the range of 35-40 dBa (Boyle, 2004), roughly equivalent to the noise level in a quiet bedroom.

Furthermore, it appears that the general public tends to support the development of wind energy. A series of surveys by the Ipsos research group between 1990 and 2002 in found that 77% of utility customers surveyed in the United Kingdom favored wind energy development, while only 9% opposed development (Simon, 1996). Perhaps most striking is the difference in public support for wind technology before and after wind turbine construction. Opinion polls conducted among homeowners in the area of several new wind farms found that while only 30-40% approved initially, support jumped to 60-90% one year after operation began (Simon, 1996). Despite the vocal nature of wind power's critics, the public drive for a cleaner environment has dominated the political forum. Subsidies and other incentives for wind power have dramatically increased in the last decade accompanied by a wave of new technological developments in the field.

There are also more minor concerns associated with wind turbines, most of which are already addressed by current siting regulations. Wind energy producers should be aware of these dangers, but it is highly unlikely that they will pose a significant barrier to wind energy development. Many wind critics complain that wind turbines are hazardous to flocks of migrating birds, although several investigative studies into the matter found that the vast majority of birds were able to see and avoid wind turbines. The number of bird fatalities that were observed was roughly comparable to the number of fatalities caused by birds flying into buildings (Boyle, 2004). In addition, certain wind tower designs can lead to electromagnetic interference with TV signals. However, this is not generally an issue with more modern turbine designs and can easily be remedied by installing a simple relay transmitter (Boyle, 2004). Finally, Boyle mentions the potential for public injury. While there are no documented cases of public injury or fatalities resulting from wind turbines, there have been several worker fatalities. Nevertheless, it is generally agreed that wind power poses no danger to public health. The external costs associated with the public health risks of fossil fuels, on the other hand, are significant and will be considered in more detail in Chapter 5.

1.3 Wind System Sizing and Cost

Turbine design is a complex art dependent on a multitude of parameters: swept area, rotor diameter, number and shape of blades, width of blade, tip speed ratio, blade pitch angle, relative wind angle, angle of attack, and others. Wind farm designers must understand the tradeoffs associated with each of these features. For example, increasing the number of blades leads to increased energy capture, but angular velocity is reduced. In general, it has been found that HAWT efficiency is maximized with 3 blades operating around 15 m/s (Cavallo et al., 1993). Above the designed wind speed, power production is limited by gearing and transmission, leading to decreased overall turbine efficiency (Gipe, 2004). Most wind turbines are designed to shut down at 25 m/s in order to prevent mechanical damage from turbulence (Cavallo et al., 1993).

Sizing and economic analysis of the potential wind turbine systems depends strongly on the particular manufacturer and model used. The rapid growth of wind turbine capacity has led to a variety of options designed to suit almost any residential or commercial application. In order to size and price a typical turbine, this study restricted the prospective Amarillo wind farm to a single medium scale commercial turbine, a General Electric 2.5 MW turbine. Specifications are listed below (**Table 2**). The turbine system contains a brake that prohibits operation at wind speeds below 3.5 m/s, where wind energy is not profitable, or above 25 m/s, where the turbine could be damaged by operation.

Table 2: 2.5 MW commercial wind turbine characteristics (Source Data: GE Energy)

Operating Data:	Rotor Data:	Tower:
Rated capacity: 2500 kW Cut in wind speed: 3.5 m/s Cut out wind speed: 25 m/s Rated wind speed: 12.5 m/s	# of blades: 3 Rotor diameter: 100 m Swept area: 7854 m^2	Hub height: 75m, 85m, 100m

National Weather Service wind speed data was compiled for the time period corresponding to the consumption data. Since these values were most likely measured around 10 meters, they were converted to metric units, then scaled to 100 meters using the 1/7 power law dependence of wind velocity on altitude. A standard daily power production plot (**Figure 8**) for the wind turbine was produced using average wind speed values and a 2.5 MW wind turbine speed-power production curve. Notice that wind power production falls in the early morning, but is highest during the day and peaks in the late afternoon. This is a fortuitous circumstance because the prospective wind system will require less storage than a system where wind production peaks in the evening (i.e. the American Great Plains and the nocturnal jet mentioned earlier). Seasonal data was also compiled but like consumption, showed no clear trend, only significant variability from week to week.

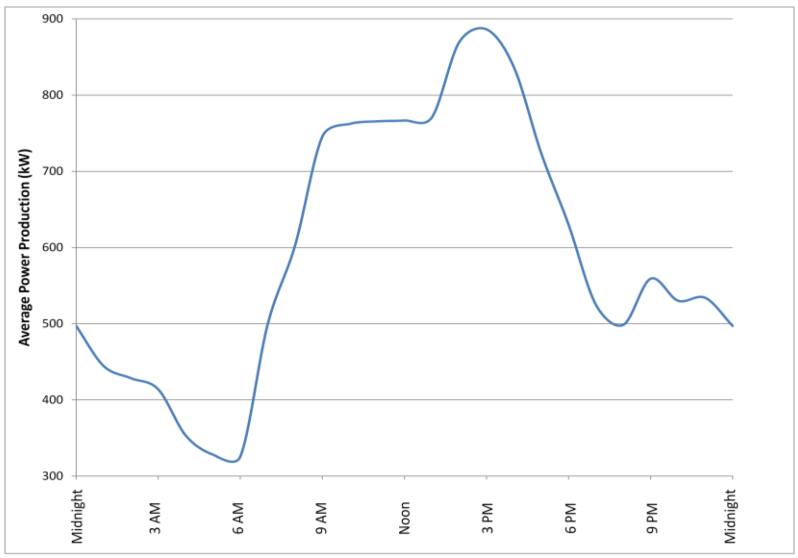


Figure 8: Average daily wind power production for Amarillo site
Source Data: National Climatic Data Center, 2008

One of these turbines operating under standard weather conditions can produce 14.3 MWh of electricity daily or 5110 MWh annually, about ¼ of the rated energy output. Even in a relatively windy location like Amarillo, wind speeds average only 6-7 m/s, while commercial wind turbines usually only achieve rated capacities at wind speeds above 10 or 15 m/s. Given the cubic dependence of power production on wind velocity, this difference significantly influences the power produced at the site. The energy consumption data provided by Texas A&M indicates that from October 2003 to October 2004 the University consumed 303,000 MWh of electricity (Borer, 2008). Assuming the Amarillo wind farm can operate for 30 years before the turbines need to be replaced (Manwell et al., 2002), construction is completed during the Fiscal Year 2009, and Texas A&M energy consumption grows at the global average of 1.5% annually (Boyle et al., 2003), the turbine array must ultimately supply 510,000 MWh of electricity annually. Such a system would nominally require 100 wind turbines. The most likely array formation would be a 10x10 plot of turbines with 5D spacing laterally and 10D spacing between rows. This farm would occupy 5500 meters by 10000 meters, or 21 square miles.

However, there are still a number of expenses to consider before investing in a potential wind farm. Boyle (2004) estimates that only 66% of the energy costs from a wind power plant come from the turbines themselves. Surveying, roads, foundations, facilities, communications, infrastructure, installation, connections, commissioning, and turnover account for the remainder of capital cost (Manwell et al., 2002). In addition, wind farms typically have substantial financing costs as well as operation and maintenance costs. Operation costs typically consist of insurance and land rental, while maintenance takes care of repairs, testing, and cleaning (Manwell et al., 2002). Then, taxes have to be paid on the electricity sold to consumers. Financing and maintenance costs are typically tax deductable, but wind turbines also have the potential to increase property taxes by increasing the appraised property value (Gipe, 2004).

Wind farm owners have to overcome several economic hurdles in the market today. Direct costs are concentrated at initial construction, which usually necessitates large amounts of debt financing for wind power projects. System integration and regulatory costs also have the potential to be significant (Manwell et al., 2002). The positive impacts of wind energy are not typically accounted for in the economic market, a factor that will be discussed in detail in Chapter 5. What is discussed here is only a brief overview of some state and federal policies designed to encourage wind power development. In addition to public funds for research and development and demonstration projects, many wind power producers receive investment subsidies, premium electricity rates, special loans and interest rates, favorable depreciation, and production tax credits (Manwell et al., 2002).

For the Amarillo site, a base case scenario is illustrated in **Table 3.**

Table 3: Base Case Scenario Inputs

Expected inflation rate: 3%
Rated capacity: 250 MW
Capital cost: $1.3 million/MW capacity[1]
Balance of system costs: 10% of capital cost[2]
Operation and maintenance: $0.01/kWh[3]
Insurance: 1% of capital cost[4]
Depreciation: Straight line for 5 years
Financing: 60% debt, 40% equity
Interest rate: 8%
Discount rate: 6%
Loan Term: 20 years
Marginal federal tax rate: 34%[5]
Tax incentive: $0.01/kWh, adjusted for inflation, for 10 years[6]

[1]Eilers, 2005; [2]Manwell et al., 2002; [3]Danish Wind Industry Association, 2003; [4]Manwell et al., 2002; [5]Rosen, 2008; [6]American Wind Energy Association, 2007a

For the base case, the final cost of electricity for the wind farm producer is 11.3 cents/kWh. **Figure 9** shows the return on investment at various electricity rates. Given that the Energy Information Administration forecasts an average cost of residential electricity price of 10.8 cents/kWh in 2009 (*Annual Energy Review 2006*, 2007), the investment in wind energy at the Amarillo site seems like a risky venture. Although the economic model presented in this study calculates the price of electricity for the wind farm at the break-even point, it is highly unlikely that any potential investor would tolerate the opportunity costs associated with a zero net return 30-year capital investment. It is important to keep in mind the uncertainty in these measurements as well as the additional costs imposed by storage and transportation requirements for wind energy. The former will be addressed in the next section, while the latter will be addressed in future chapters.

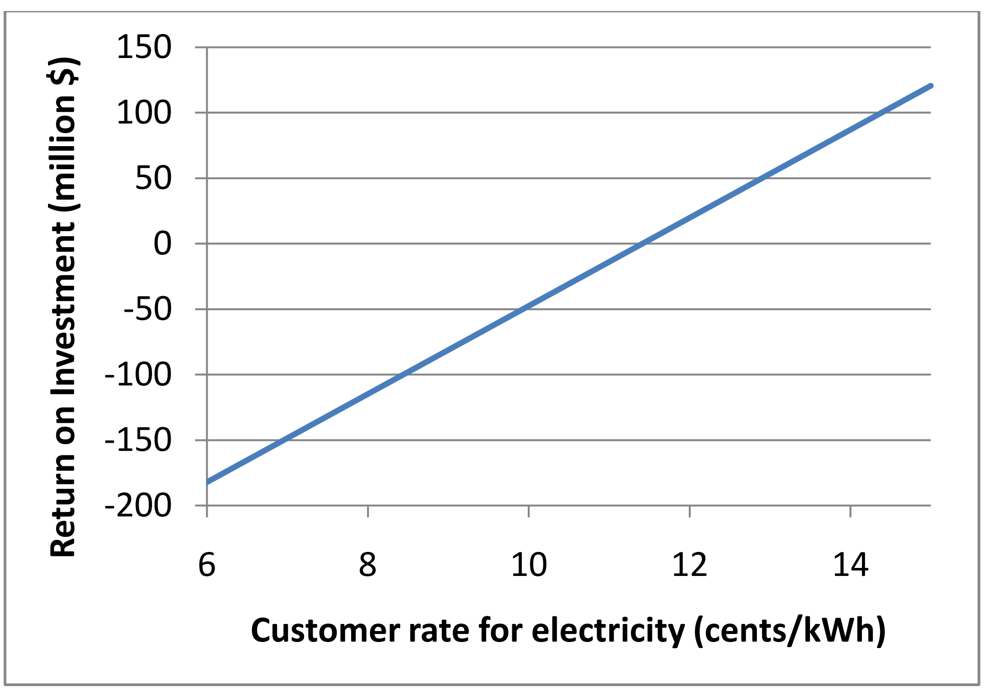


Figure 9: Return on investment versus the charge for electricity

The base case is also an excellent illustration of the lengthy payback times associated with wind turbine projects. At an electricity rate of 12.3 cents per kWh, the wind farm operator will earn $31.8 million dollars over the 30 year lifetime of the plant; however, the project is still $32.3 million dollars in debt after 15 years, and the project does not turn a profit until the 24th year. Entrepreneurs looking for ventures that will turn a profit in 10 years or less are likely to be extremely disappointed by the investment return on wind farms.

1.4 Sensitivity analysis

The base case scenario rests on a number of technological and economic assumptions, while the actual cost and revenue streams are subject to high variability. For example, the base case scenario assumes a system lifetime of 30 years, yet until recently most design studies only assumed a system lifetime of 20 years (Manwell et al., 2002). The current estimate of 30 years is reasonable today given technological advances in the last decade; system lifetimes could feasibly rise to 35 years or more in the next decade. Other sources of variability cited in the literature (Boyle, 2004; Manwell et al., 2002) are:

1. Capital cost of installation
2. Interest costs
3. Operation and maintenance costs, include insurance, leasing, etc.
4. Inflation
5. Machine availability
6. Loan repayment time
7. Interest and discount rate

Sensitivity analysis was performed on the Amarillo wind farm by varying 10 different parameters and observing the change in the cost of electricity. Results are summarized in **Table 4.**

Table 4: Sensitivity analysis based on varying 10 individual parameters

	Variable modified	Electricity Rate (cents/kWh)
Case 1	None (Base Case)	11.3
Case 2	O&M halved	10.6
Case 3	Tax incentive doubled	10.6
Case 4	Loan term halved	11.8
Case 5	35 year system lifetime	10.9
Case 6	6% inflation	12.1
Case 7	100% debt financing	11.8
Case 8	3% interest rate	12.0
Case 9	3% discount rate	9.8
Case 10	17% tax rate	9.9
Case 11	Capital costs halved	5.4

Capital, operation and maintenance, inflation, debt financing, discount rate, and tax rate increases all lead to higher electricity costs, while increases in tax incentive, loan term, system lifetime, and interest rate all reduce cost. The significant variation introduced by varying the discount rate is crucial to the cost analysis in this model, since standard discount rates vary from 2% to 10% (Bodie et al., 2004). The base case used the January 2008 prime lending rate of 6%. Some might conclude from this data that the most effective way to improve affordability would be through further capital cost reductions. However, the gains in this sector have been so great in the last 25 years that it is difficult to imagine costs falling an additional 50% anytime soon. Consequently, wind energy developers and proponents must rely on moderate improvements in efficiency and economies of scale to advance the wind industry in the coming decades.

Chapter 2: Energy Storage in Batteries and Fuel Cells

If wind power is to serve as a viable alternative for fossil fuels, producers must be able to correlate the intermittent energy supply with consumer demand for electricity. As noted in the previous chapter, a study by Gonzalez et al. (2003) found that wind energy could only supply about 1/5 of consumer electricity demand requirements without encountering variability issues. Wind power systems depend upon an appropriate means of energy storage to smooth out variations in production.

Producers must also be able to ensure that wind produced power will meet or exceed the reliability standards already in place for more conventional power sources. Current fossil fuel power plants are designed to limit lost power generation to less than 1 hour per decade. The opportunity cost of a disruption in power generation in this country is estimated at $5/kWh for residential customers; costs can be as high as $16/kWh for businesses (Grubb & Meyer, 1993). If renewable energy systems are unable to match the reliability of conventional fossil fuel power systems, they will quickly become economically unfavorable. The two primary electricity storage methods currently under consideration are battery storage and hydrogen storage. Each form of energy storage has its own advantages and disadvantages, and hybrid systems exhibit the best performance (Shakya et al., 2005). This study, however, will restrict its focus to a system exclusively dependent on either battery or hydrogen storage.

2.1 Battery Storage

One way to reduce variations in wind energy production is through the use of several secondary (rechargeable) batteries. Raymond Gaston Plante developed the first secondary battery, a lead-acid design, in 1859. Forty years later, another secondary battery design, the nickel-iron battery appeared on the market. Over the next 90 years, a series of nickel alloy batteries were introduced and improved. Although these new battery systems boasted improved performance over the original lead acid design, the high material cost of the batteries limited their use to a set of specialized niche applications (Linden & Reddy, 2002). Today, lead acid batteries still account for 68% of the $20 billion annually in secondary battery sales; nickel cadmium designs account for another 18% (Linden & Reddy, 2002). The third major category, lithium ion technology, has grown rapidly since its introduction in 1990 (Linden & Reddy, 2002). All three designs have been used for stationary power storage, although their primary applications are in other sectors. Subsequent sections will compare the performance of lead-acid, nickel-cadmium, and lithium ion batteries. The ideal secondary battery should have high power density, high discharge rate, flat discharge curves, and good performance in variable temperatures.

2.1.1 Lead acid batteries

The lead acid battery is the cheapest and most common secondary battery on the market today. The battery uses lead dioxide and metallic lead as electrodes with 37% (by weight) sulfuric acid as an electrolyte. Discharging converts both electrode components to lead sulfate in the following set of reactions:

Negative electrode: $Pb \rightarrow Pb^{2+} + 2e^-$

$$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$$

Positive electrode: $PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$

$$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$$

Overall reaction: $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$

Lead acid batteries have been commercially produced since the 1860's, and today the primary applications are SLI (starting, lighting, ignition) automotive applications, telecommunications service, and emergency power systems. Submarine and mining applications also use lead acid batteries as a power source (Salkind et al., 2002). Early batteries had very low capacities, but progress in design, manufacturing, recovery methods, production, supporting structures, and components have led to large improvements in performance and reduction in cost (Salkind et al., 2002).

Lead acid batteries are preferred because they are inexpensive, available in large quantities, efficient, easily recyclable, retain their charge, and operate at a high cell voltage (typically 2.0 Volts). The main disadvantages of lead acid batteries are their limited energy density, potential for thermal runaway, and the potential for hazardous production of stibene, and arsine (Salkind et al., 2002). Battery life varies from 200 to 1500 cycles, depending on the appplication (Srinivasan, 2006). Causes of failure include overdischarge, loss of electrolyte, corrosion, overheating, and poor cell balance in a system of batteries (Salkind et al., 2002). One safety issue in lead acid batteries is the potential for overcharge reactions, which can lead to a flammable buildup of hydrogen and oxygen in the battery cell (Salkind et al., 2002).

Typical capacities range from 1 Ah to 12,000 Ah. Cell voltage ranges from 2.40 V at full charge to 1.60 V at full discharge (Salkind et al., 2002). The largest system constructed to date operates at 2000V and 8000 A, supplying 40 MWh of stored electricity to the town of Chino, California (Salkind et al., 2002). Standard energy densities are 35 Wh/kg, with the lead content making up 60% of the battery weight (Srinivasan, 2006). One nice feature of lead acid batteries is that 100% of the lead content can be recycled, and 95% of the batteries used in this country are ultimately recycled (Srinivasan, 2006).

2.1.2 Nickel-cadmium battery

Nickel-cadmium batteries are less common than lead acid batteries, but they are favorable in high performance applications. In the cell, potassium hydroxide is used as an electrolyte with nickel oxide hydroxide and cadmium metal electrodes. The discharge reactions are listed below.

Negative electrode: $Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$

Positive electrode: $2NiO(OH) + 2H_2O + 2e^- \rightarrow 2Ni(OH)_2 + 2OH^-$

Overall reaction: $2NiO(OH) + Cd + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2$

Advantages of nickel-cadmium and other nickel alloy alkaline batteries include long durability, reliability, good charge retention, excellent long term storage, and low maintenance. Unfortunately, nickel alloy costs are still relatively high and energy densities are inferior to their lead acid counterparts but in cases where reliability and durability are crucial, nickel alloys are preferred. Nickel-cadmium batteries, the most popular alkaline battery, are used as aircraft engine starters, emergency power sources for hospitals, backup power for bank computer systems, power for railyard switches, and emergency lighting for airport runways. Other nickel alloys are used as well: nickel-zinc alloys serve as power sources for electric bikes and scooters while nickel-hydrogen batteries have found a niche in aerospace applications. Nickel-cadmium costs have a strong dependence on cell size and capacity, and initial costs are relatively high. Nevertheless, the higher lifetime of nickel-cadmium batteries sometimes makes them more attractive than lead acid batteries when a full life cycle analysis is performed (Nilsson & Baker, 2002).

Design improvements in nickel-cadmium cells have reduced the battery weight and amount of nickel required. Today, the standard specific energy of a nickel-cadmium cell ranges from 20 to 27 Wh/kg, although experimental cells have been produced up 56 Wh/kg (Nilsson & Baker, 2002). The nominal voltage of a standard cell is 1.2 V (Nilsson & Baker, 2002). Capacities range from 5 Ah to over 1200 Ah (Nilsson & Baker, 2002). Unlike lead acid cells, nickel-cadmium cells can occasionally undergo underdischarge with no detrimental effects, and the lack of a corrosive electrolyte extends the standard lifetime of these batteries to between 300 and 2000 cycles (Srinivasan, 2006; Nilsson & Baker, 2002).

2.1.3 Lithium ion batteries

In the last decade, the lithium ion battery has made great strides in capturing parts of both the lead acid and the nickel alloy battery market. Lithium ion batteries combine many of the most desirable secondary battery characteristics: high energy efficiency, high specific energy, high energy density, rapid charge capability, long shelf life, long cycle life, and minimal maintenance. The main obstacle to widespread lithium ion battery use is the cost, which has fallen rapidly in the last decade. In fact, a 2002 publication estimated that lithium ion costs would fall as much as 50% in the period from 1999 to 2005 (Ehrlich, 2002). Current costs are $0.20-0.36/Wh, and lithium ion sales doubled from 2000 to 2005 (Srinivasen, 2006).

Lithium ion batteries operate by exchanging Li^+ between the positive and negative electrodes. Liquid, gel, polymer, and ceramic materials have all been used as electrolytes, but most electrolytes incorporate some form of lithium salt. Electrodes are typically $LiCoO_2$, although more recent compounds, such as $LiMn_2O_4$ and $LiNi_{1-x}Co_xO_2$, offer better performance and reduced cost (Ehrlich, 2002). Capacities currently range from 0.1 Ah to 160 Ah, so lithium ion batteries are mostly used in electronics. Current lithium ion technology can operate at specific energies from 150 to 200 Wh/kg, meaning they outperform competing technologies by more than a factor of two (Srinivasan, 2006). Lithium ion batteries last more than 1,000 cycles (Ehrlich, 2001). Most significantly, operating voltages range from 2.5-4.2 V, which greatly reduces the number of required cells. The lithium ion reaction is illustrated below:

Negative electrode: $C + xLi^{+} + xe^{-} \rightarrow Li_{x}C$

Positive electrode: $LiCoO_{2} \rightarrow Li_{1-x}CoO_{2} + xLi^{+} + xe^{-}$

Overall: $LiCoO_{2} + C \rightarrow Li_{x}C + Li_{1-x}CoO_{2}$

Most cell phones, laptop computers, and PDAs produced today are powered by lithium ion technology. However, the lithium ion market has recently expanded into aerospace and military applications like radios, mine detectors, and thermal weapons sights. Proponents believe that the number of lithium ion applications will grow exponentially in the next 10-20 years (Ehrlich, 2002), making the technology a significant factor in the energy storage discussion.

2.2 Hydrogen storage

Instead of batteries, hydrogen can be employed as a means of energy storage. The primary methods of hydrogen production are steam methane reforming (SMR) and water electrolysis. In the SMR process, natural gas is reacted with steam at high temperature to produce hydrogen gas and carbon monoxide. The CO is subsequently converted into H_2 and CO_2 in a second step, known as the water gas shift reaction. SMR is currently the cheaper and more popular option; however, reforming does little to reduce greenhouse gases (New York State Energy Research and Development Authority, 2008). In water electrolysis, electrical energy is used to split the water molecules into component hydrogen and oxygen. This hydrogen can then be stored or transported to another site, where a fuel cell will combine it with oxygen from the atmosphere to produce energy with water as the only biproduct. Researchers are now investigating the additional possibility of a reversible fuel cell, which can serve as both an electrolyzer and a fuel cell, converting electricity to hydrogen and back. Current designs, however, typically rely on the more traditional system with separate electrolyzer and fuel cell components.

The economics of environmentally friendly hydrogen depend on efficiency improvements and capital cost reductions in the electrolysis system. The theoretical potential difference required to electrolyze water is 1.23V, but electrolyzers also have to overcome an associated overpotential created by efficiency losses in the system. Higher overpotential means less reversibility in an electricity-hydrogen-electricity conversion system. Overpotential is positively correlated with the speed of the electrolyzer (Bockris & Veziroglu, 2007); system design must balance the competing goals of speed and efficiency. Catalytic surfaces are often employed in electrolyzer systems to reduce overpotential (Ogden & Nitsch, 1993). An alternative way to improve electrolyzer efficiency is by using HBr rather than H_2O as the electrolyte, which improved reversibility and reduces cost by 25% (Bockris & Veziroglu, 2007). Advances in electrolyzer design that allow for the use of less expensive materials and accommodate higher current densities will also play a role in the improving economics of hydrogen storage systems (Ogden & Nitsch, 1993).

Before designing the electrolyzer system, the engineer must decide what type of electrolyzer to use. Electrolyzer technology relies either on proton exchange membranes (PEM) or high temperature steam (HTS) to produce hydrogen. PEM systems are used to perform electrolysis at room temperature. These systems rely on expensive platinum catalysts and high energy inputs. Efficiency increases and less energy is required for the HTS process. For example, the potential difference required to electrolyze water falls from 1.7-2.0V for room temperature electrolysis to 1.2-1.3 V for HTS electrolysis (Ogden & Nitsch, 1993). However, the temperatures present in HTS electrolysis create fabrication and material problems that have seriously constrained continued technological development and cost reductions (Ogden & Nitsch, 1993).

For the economic analysis, a model proposed by Bockris & Veziroglu (2007) was used to calculate the dollar cost of 1 MBTU of hydrogen produced by water electrolysis. The model consists of a fixed cost and variable cost term as shown below:

$$C = 2.29Ec + 3$$

Here, E is a temperature dependent constant that is 1.6 at room temperature, but falls to 1.0 at 1000° C, and c is the cost of input electricity (11.3 cents/kWh for the base case). The cost of 1 MBTU of hydrogen produced at room temperature using this model is $44.40, equivalent to $152/kWh.

2.3 Storage system sizing and cost

To maintain a reasonable amount of reliability and provide sufficient leveling in the Texas A&M system, power penetration will be limited to 25%. That is, ¼ of the power produced at the Amarillo wind farm will be fed directly into the power grid and sent to the university; the remaining ¾ will be stored in an appropriate media and dispensed in a load-following pattern. Storage systems will be sized such that they are able to meet this remaining power requirement for the lifetime of the plant. Due to the integral nature of wind technology (99.7 wind turbines are required, 100 wind turbines are constructed), 242 MWh of excess electricity are generated each week. The storage system must have a capacity of at least 273 MWh in order to ensure an adequate supply of electricity to the University at 25% penetration. Hybrid storage systems will not be considered.

Net present value analysis of each battery type was conducted over the plant lifetime using the base case conditions. Results are summarized in **Table 5**; several assumptions were made, which are summarized in **Table 6**.

Table 5: Cycle life and cost of various storage media

Battery Type	Lead acid	Nickel-cadmium	Lithium-ion
Cycle life	1000 cycles	500 cycles	1200 cycles
Cost per kWh storage capacity	$150	$300	$1200

Table 6: Life cycle cost analysis of various storage media

Storage Type	Total Lifetime Cost
Lead acid battery	$236 million
Nickel-cadmium battery	$907 million
Lithium ion battery	$1.64 billion
Hydrogen from electrolysis of water	$250 million

The current economics favor the use of a lead acid battery storage system to mitigate the variations introduced into the system by the use of intermittent electricity generation. A comparison of storage costs to production capital costs ($303 million) confirms that storage will play a large role in determining whether wind energy can be profitable at high penetration. The results also confirm the conclusion reached in the National Research Council report on the hydrogen economy mentioned earlier in this paper. That study concluded that a significant barrier to the progress of the hydrogen economy was the high cost of electrolyzer systems (Hydrogen Economy, 2004). On a more reassuring note, the report projected that electrolyzer costs would fall 75% in the next 15 to 20 years, making hydrogen energy storage much more appealing (Hydrogen Economy, 2004). One solution for the Texas A&M system is to operate on battery storage until the cost of hydrogen storage falls enough to encourage the installation of electrolyzer systems.

Chapter 3: Transportation and Storage

In some parts of the country, the development of renewable energy sources like wind turbine technology has advanced rather easily in recent years. In other areas, renewable energy is virtually nonexistent. What has prevented the expansion of renewable energy into these regions despite the falling production costs and improved storage methods? The development of future systems, like the one presented in this study, will depend upon advances in hydrogen transportation to reduce costs. Even in states with rich renewable resources, population centers may be located up to 1,000 miles away from optimal production sites.

A prime example of the wind transportation dilemma is Antarctica, a vast expanse of land where wind speeds average 44 mph for most of the year (Bockris & Veziroglu, 2007). This tremendous wind energy potential remains untapped due to the prohibitive costs associated with transporting hydrogen to consumers, most of whom are located in North America and Europe. A large scale hydrogen production and pipeline distribution network operating today would have transportation costs almost equal to production costs. Moreover, the transportation costs associated with transporting gaseous hydrogen are more than 5 times the cost of transporting the same amount of energy using natural gas (Hydrogen Economy, 2004).

Four forms of transportation are currently under consideration. One form, which appears to have the most long term potential, is to ship hydrogen in pipelines in much the same way that natural gas is commonly transported today. During the transition to a large scale hydrogen economy, however, it may be necessary to store and transport hydrogen by tanker truck. The primary issue in this case is the low energy density of gaseous hydrogen. This can be overcome either through compression, condensation, or adsorption. Each option will be assessed in turn.

3.1 Compressed Hydrogen Storage

One proposed option is to store hydrogen as a compressed gas. The US Department of Energy is currently researching compressed hydrogen tanks designed to operate at pressures between 5,000 and 10,000 psi (U.S. Department of Energy, 2008a). At atmospheric pressure, the density of hydrogen is only 0.09 kg/m^3; at high pressures, the density rises to between 25 and and 40 kg/m^3, with a corresponding increase in energy density. Compressed hydrogen is an especially promising option for hydrogen powered automobiles. Compression is less energy intensive than liquefaction but not always cheaper for hydrogen, as this study shows. Current research is focused on reducing the costs of carbon fiber, which is used for tank reinforcement (U.S. Department of Energy, 2008a).

3.2 Liquid Hydrogen Storage

Alternatively, gaseous hydrogen can be cooled to -253°C and stored in a liquid form. Although liquid hydrogen has the highest volumetric energy density of the storage possibilities considered here (70 kg/m^3), liquefaction is an energy intensive process. In comparison, liquid natural gas is shipped at -162°C, requiring a much lower energy expenditure (Boyle, 2004). If storage losses, transfer losses, and cryogenic tanker costs fall, liquid hydrogen storage could one day become a commercially successful technology (Ogden & Nitsch, 1993). Some researchers have even proposed hybrid cryocompression systems that combine the energy density advantages of compression and liquefaction (U.S. Department of Energy, 2008a). For example, hydrogen stored at -162°C and 10,000 psi has a density of 67 kg/m^3, almost equal to liquefied H_2.

3.3 Solid state storage

It is also possible to store hydrogen in an adsorbed solid state form. The materials employed are typically metallic alloys or carbon substrates, but researchers are investigating a wide variety of materials. The US Department of Energy has set a target for solid state hydrogen development, with the goal of achieving of 6 wt% solid state hydrogen storage by 2010 (Opalka et al., 2006), but only 4 wt% has been demonstrated experimentally to date (U.S. Department of Energy, 2008a). Solid state storage will not be evaluated in detail in this study because the technology is not currently competitive with the alternative transportation technologies. Issues with low hydrogen capacity, slow uptake, poor release kinetics, and cost still remain to be addressed (U.S. Department of Energy, 2008a). Although solid state technology could one day be competitive for on site storage, the relatively high weight and volume of adsorbed hydrogen are not competitive for transportation purposes (Hydrogen Economy, 2004).

3.4 Pipeline Transportation

While it is likely that compressed or liquefied hydrogen storage will lead the way in the shift toward the hydrogen economy, large scale hydrogen production will ultimately rely upon an extensive pipeline transportation network comparable to the current natural gas network, illustrated in **Figure 10**. The US already employs 700 km of pipeline for hydrogen transport, supplying an estimate 10-20 GW of power to locations throughout the country (Ogden & Nitsch, 1993; Trevisani et al., 2006). Standard pipelines range from 4 to 12 inch diameter (Remp, 2005). The cost of installing hydrogen pipelines depends strongly on the particular characteristics of the site, primarily due to highly variable right-of-way costs; current estimates range anywhere from $300 thousand to $1.4 million per mile of pipeline (Mintz et al., 2002).

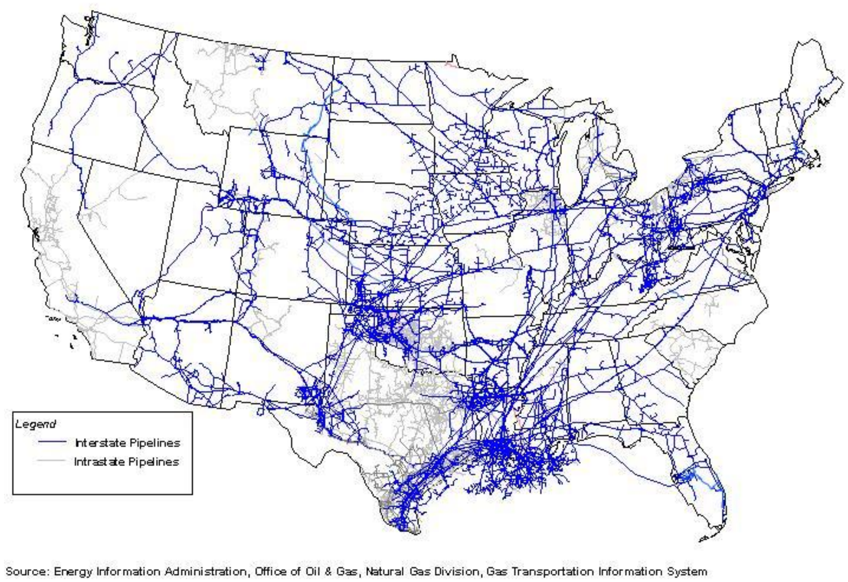


Figure 10: US natural gas pipeline network
Source Data: Energy Information Administration

Some engineers suggest that existing natural gas pipelines could be converted to hydrogen service as the energy industry transitions from fossil fuels to renewable hydrogen (Ogden & Nitsch, 1993). However, pipeline designers must take into account the reduced energy density of gaseous hydrogen (3 MJ/L) compared to natural gas (8 MJ/L) (Hydrogen Economy, 2004), which makes the cost of transmission 50% higher for hydrogen than for natural gas (Ogden & Nitsch, 1993). Ideal hydrogen pipelines are larger than current natural gas pipelines but would require fewer compressor stations (Ogden & Nitsch, 1993) . Although the gas would be under a pressure of 350 to 1900 psi (Remp, 2005), compression costs for a pipeline network would be significantly lower than compression costs for pressurized tanker transport.

Critics of such a system naturally would focus on the safety risks associated with gaseous hydrogen being used in the residential areas. Hydrogen is combustible in air at concentrations of 4-75% H_2, a broader range than natural gas or gasoline. Hydrogen also has a much lower ignition energy than comparable fossil fuels. It leaks at a rate triple that of natural gas, is odorless, and burns with a hot, almost invisible flame, making hydrogen leaks difficult to detect and extinguish. Finally, critics point to the safety hazard posed by hydrogen embrittlement, a condition in which the gas diffuses into the pipe metal, making it more susceptible to cracks (Hydrogen Economy, 2004).

Proponents counter that the lower flammability limit of 4%, which provides a better gauge of ignition risk, compares favorably with gasoline (1-3%) and is only slightly lower than natural gas (5%). An electrical spark would provide more than enough energy to ignite any competing fossil fuel or hydrogen source. Finally, they note that the risk due to hydrogen leaks is minimal. Embrittlement only becomes a risk at temperatures and pressures much higher (~500 psi) than the proposed operating conditions of the pipeline (Blencoe, 2008), and hydrogen gas disperses very quickly. Unlike gasoline, hydrogen is lighter than air, so it is unlikely to collect except in very constrained spaces (Hydrogen Economy, 2004).

3.5 Transportation system sizing and cost

Net present value analysis of each transportation method was conducted over the plant lifetime using the base case conditions. Several process specifications and assumptions from *The Hydrogen Economy* (2004) were used for the economic analysis, and are summarized in **Table 7**. Compressed and liquefied hydrogen were transported by tanker truck to the consumption site at an average speed 50 mph, rather than the 50 kph used in the study. In order to meet the penetration restrictions imposed in the previous chapter, the system stored hydrogen for transport at an average rate of 43,000 kW. The lifetime costs of each system are summarized in **Table 8**.

Table 7: Transportation system inputs (Source Data: Hydrogen Economy, 2004)

	Compressed H_2	Liquified H_2	H_2 pipeline
Undercarriage cost	$60,000	$60,000	
Cab cost	$90,000	$90,000	
Truck capacity	820 kg/truck	820 kg/truck	
Fuel economy	6 mpg	6 mpg	
Average speed	50 mph	50 mph	
Load/unload time	2 hr/trip	2 hr/trip	
Truck availability	24 hr/day	24 hr/day	
Truck utilization	80%	80%	
Driver availability	12 hr/driver	12 hr/driver	
Driver Wage	$28.75/hr	$28.75/hr	
Fuel price	$3.28/gal	$3.28/gal	
Delivery distance	500 mi	500 mi	
Electric power (per kg/h H_2)	2.3 kW	11 kW	
Compressor Cost	$3350/kW		
Liquefaction cost per kg/day H_2		$700	
Pipeline cost			$600,000/km
Storage cost (per gallon H_2)	$116	$5	
General Facilities (% of process unit cost)	20%	20%	15%
Engineering and startup (% of process unit cost)	15%	15%	25%
Contingencies ($ of process unit cost)	10%	10%	10%
Working capital, land, misc (% of process unit cost)	5%	7%	5%
Variable non-fuel O&M (% of capital cost)	1%/yr	1%/yr	1%/yr
Fixed Operating Cost (% of capital cost)	2%/yr	5%/yr	3%/yr
Capital charges (% of capital cost)	14%/yr	16%/yr	16%/yr

Table 8: Life cycle cost analysis of various transportation methods

Transportation Type	Total Lifetime Cost
Compressed hydrogen	$280 million
Liquefied hydrogen	$202 million
Hydrogen pipeline	$2.5 billion

It is clear from the data in Table 8 why many proponents of the hydrogen economy advocate the use of compressed or liquefied tanker trucks as an intermediate stage in the gradual shift toward a highly developed hydrogen infrastructure. An important caveat to keep in mind: the life cycle cost analysis was done over 30 years because that is the expected lifetime of the wind farm technology, but one would hardly expect the capital to be abandoned at the end of the project. In the case of the hydrogen pipeline, the economics improve significantly in the long term as the investment gradually recoups the $662 million in initial capital expenditure.

Chapter 4: Fuel Cell Power

In 2003, President Bush proposed a $1.2 billion Hydrogen Initiative to support the "research and development of technologies needed to support hydrogen-powered fuel cells for use in transportation and electricity generation" (*Hydrogen Fuel*, 2003). The push for commercial fuel cell development as part of a widespread renewable energy initiative is a relatively new phenomenon, but research and development of fuel cells have been underway for more than a century. The first fuel cell was invented by Sir William Grove in 1839. Grove's "gas battery" was a revolutionary development capable of converting hydrogen and oxygen gas into electricity and water, but it would take some time for efficiencies to improve enough to encourage commercial development of the fuel cell. In 1932, Dr. Francis Bacon introduced an better design for the fuel cell, which he modestly termed the "Bacon cell" (Fuel Cell Basics, 2008). The Bacon cell used less expensive electrodes and a less corrosive electrolyte than earlier fuel cell models.

The next big development in fuel cell design came in 1958, when scientists at GE constructed the first Proton Exchange Membrane (PEM) fuel cell. Shortly thereafter, Pratt and Whitney purchased the alkaline fuel cell (AFC) patents from Bacon and designed a system with even better performance than the GE PEM cell. Both the GE and the Pratt and Whitney design were successfully used as power sources onboard NASA spacecraft. Like wind turbines, fuel cells received a large research impetus in response to the energy crises of the 1970's. Improvements in design and reductions in cost led to the introduction of the first marketable fuel cell powered vehicle in 1993. Since then, the field has continued to grow rapidly on a variety of different fronts. Six general classes of fuel cells have been developed, which are distinguished by their operating temperature range. Each type of fuel cell will be introduced in turn before an optimized design is chosen. The standard modern fuel cell design is shown in **Figure 11** below

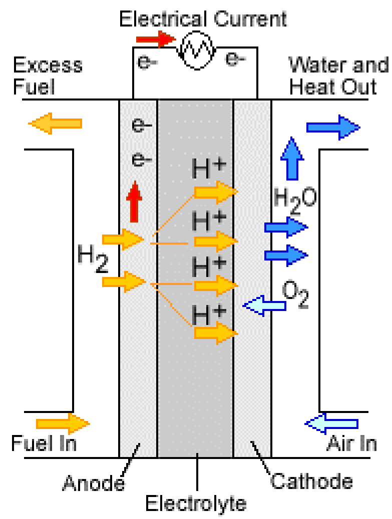


Figure 11: Basic fuel cell schematic
Source Data: US Department of Energy, 2007

4.1 Introduction to Different Fuel Cell Designs

4.1.1 Proton Exchange Membrane (PEM) Fuel Cell

PEM fuel cells were first used commercially for the NASA Gemini missions in the 1960's. One major push for commercialization of the PEM fuel cell is the potential for automotive applications (Fuel Cell Basics, 2008). The PEM fuel cell uses a fluorinated sulfonic acid polymer electrolyte in water and a platinum catalyst. Advantages of the PEM system are their low operating temperature (~85°C) and high current density, which makes them compact, lightweight, and easy to start up (Spiegel, 2007). Corrosion problems are minimal because the electrolyte is solid and not acidic, but water management is crucial for efficient performance (Fuel Cell Basics, 2008). Unfortunately, the low operating temperature of PEM cells can be a significant disadvantage. Rejected heat is not useful for cogeneration applications, and the electrocatalyst is especially subject to CO poisoning (Fuel Cell Handbook, 2005). PEM cells are marketed primarily in the 1-25 kW range (Hydrogen Economy, 2004), and average costs were around $100/kW in 2005 (Carlson et al., 2005). Experimental models have been constructed up to 750 kW, but the cost for these models can be as high as $2600/kW (Hydrogen Economy, 2004).

4.1.2 Alkaline Fuel Cell (AFC)

The alkaline fuel cell is the model constructed by Francis Bacon in the 1930's and commercialized by Pratt and Whitney in the 1960's. Alkaline fuel cells use an aqueous KOH solution as the electrolyte and operating temperatures range from 25° C to 250°C. AFCs do not require noble metal catalysts, which reduces their cost compared to other fuel cells (Spiegel, 2007). However, pure hydrogen and oxygen fuel are required in order to prevent CO_2 poisoning of the KOH electrolyte. Unfortunately, the high cost of CO_2 filtering makes AFC systems uneconomical for commercial applications (Fuel Cell Handbook, 2005).

4.1.3 Phosphoric Acid Fuel Cell (PAFC)

To date, the PAFC it is the only fuel cell technology that has been commercialized (Hydrogen Economy, 2004). The electrolyte is 100% concentrated phosphoric acid, and platinum catalysts are used. Operating temperatures range from 150°C to 205°C (Fuel Cell Handbook, 2005). Initial testing was done by the US Army in the 1960's and 1970's, but commercial development did not begin until 1991. Most PAFCs are in the 50 – 200 kW range, but plants as large as 11 MW have been constructed (Spiegel, 2007). Units currently sell at approximately $4500/kW, and operate at 99.99% reliability (Hydrogen

Economy, 2004). PAFCs are known for their high CO_2 tolerance (1.5%) and excellent cogeneration potential (Fuel Cell Handbook, 2005). Disadvantages of PAFC systems are the large size and weight and low power output (Spiegel, 2007).

4.1.4 Molten Carbonate Fuel Cell (MCFC)

Molten carbonate fuel cells were developed and tested at Texas Instruments in the late 1960s. The electrolyte is a liquid solution of lithium, sodium, or potassium carbonates retained in a ceramic matrix (Spiegel, 2007). The operating temperature range of a molten carbonate fuel cell (500°C to 700°C) means the cell is able to operate at high efficiencies and use inexpensive nickel catalysts (Hydrogen Economy, 2004). The MCFC is not subject to CO or CO_2 poisoning, and there are multiple potential cogeneration applications. However, the high temperature and corrosive electrolyte impairs system life (Fuel Cell Handbook, 2005). MCFC are marketed for 100-1000 W applications, although tests have been done at the 10 kW-2 MW level.

4.1.5 Intermediate Temperature Solid Oxide Fuel Cell (ITSOFC)

ITSOFC systems are closely related to their higher temperature counterparts, the solid oxide fuel cells, which are discussed in the following section. Operating temperatures range from 600°C to 800°C. The lower temperatures available in an ITSOFC reduce sintering and creep, relieve thermal stress, expand the range of available materials, lower balance of plant costs, and decrease heat losses (Fuel Cell Handbook, 2005). However, the cell voltage, kinetics, diffusion, and ionic conductivity are inferior to standard SOFC models (Fuel Cell Handbook, 2005).

4.1.6 Solid Oxide Fuel Cells (SOFC)

SOFCs allow users to capture high temperature efficiency without some of the issues associated with other fuel cells. SOFCs were first introduced in the late 1930s, but early designs were not very conductive, and are susceptible to many unwanted side reactions. However, many scientists believe that SOFCs have future promise for large high power applications (Spiegel, 2007). The electrolyte is a ceramic, like Y_2O_3 stabilized with ZrO_2, and perovskites are used as catalysts (Fuel Cell Handbook, 2005). SOFCs operate between 800°C and 1000°C, where CO/CO_2 poisoning is minimal and the system kinetics are very high. Current cells are subject to high internal resistance, melting, and short circuiting (Spiegel, 2007), and the high temperatures do make materials selection and fabrication difficult (Fuel Cell Handbook, 2005). Nevertheless, experimental systems have been produced at capacities of 100 kW and efficiencies of 60-85% (Spiegel, 2007). The Solid State Energy Conversion Alliance recently set a 2010 goal of 40-50% efficiency at costs around $400/kW (Hydrogen Economy, 2004).

4.2 System Design and Cost

The design of any fuel cell system must take into account the tradeoffs in efficiency present in a network of fuel cells compared to a single cell. Some system losses will inevitably be introduced during system scale up; the cause could be attributable to temperature variance from cell to cell, gas flow pattern variance from cell to cell, uneven gas flow in the plate channels, or any combination thereof (Srinivasan, 2006). Fuel cell networks also have large flow rates which create significant pressure drops, at least in series configurations. Still, fuel cell stacks generally operate at higher efficiencies than single cells. A study by the DOE National Energy Technology

Laboratory found that systems with equivalent fuel utilization, total area, and average current density increase in efficiency as the number of cells increases (Fuel Cell Handbook, 2005). The study explains that each system converts the same amount of energy, but systems with more cells operate initially at higher voltages. More electrical work and less heat is produced in these cells, so overall efficiency is improved. In theory, the inclusion of an additional fuel cell in the stack will continually increase system efficiency. However, the marginal benefit decreases with each additional fuel cell, and practical systems are usually constrained by economic, space, and design constraints (Fuel Cell Handbook, 2005).

Efficiency losses are generally caused by overpotentials in the fuel cell network (Srinivasan, 2006). Three categories of overpotentials are present in fuel cell systems. At low current density, competing electrochemical reactions and sluggish electrode kinetics lead to activation overpotential. Resistance to ion flow in the electrolyte causes to a second type, ohmic overpotential, at intermediate current densities (Fuel Cell Handbook, 2005). As current density continues to increase, concentration gradients form in the cell, leading to mass transport overpotentials (Srinivasan, 2006).

Since phosphoric acid fuel cells are the only fuel cell that has been successfully produced commercially, a PAFC system seemed like the natural choice for sizing and cost analysis. It should be noted, however, that PEM fuel cell designs are currently making large strides towards commercial development. Molten carbonate fuel cells and solid oxide fuel cells also show potential in the long term, but neither design will be economically feasible in the time frame of this project. PAFC cells were sized using the simplified design procedure proposed in *The Fuel Cell Handbook* (2005).

The annual energy production for the PAFC was calculated based on the 25% penetration requirement. Capacity was set equal to the maximum hourly stored energy demand based on the standard weekly power profile for the university. This profile yielded a capacity requirement of 54 MW and an annual energy conversion of 328 GWh. Such a system would require 80 fuel cell stacks and occupy 22,500 m^2 of space. The assumptions listed in **Table 9** were applied for economic and sizing analysis:

Table 9: PAFC system inputs (Source Data: Manwell et al., 2002)

Cell voltage	600 mV
Current density	400 mA/cm^2
Cell area	1 m^2/cell
Cells per stack	280
Capital cost	$1000/kW
O&M Cost	$20/kW-yr

Table 10: Costs associated with PAFC system

Capital cost	$54 million
Variable cost	$872 thousand/year
Total lifetime cost	$66 million

One would expect the fuel cell costs to be relatively minimal, since a PAFC system has neither the large initial capital expenditure of a wind farm nor the significant operating costs of hydrogen tanker truck shipments. The results, listed in **Table 10**, confirm that this is in fact the case. Mature PAFC technology is ready to meet the market demand for wind energy once barriers in the production, storage, and transportation stages have been addressed.

Chapter 5: Changing Economics, External Costs, and Public Policy

When summing the costs of production, storage, transportation, and fuel cell conversion found in the previous chapters, one finds the following cost breakdown for the Amarillo-Texas A&M hydrogen-supplemented wind turbine system (**Table 11**).

Table 11: The cost breakdown for Amarillo-Texas A&M wind system

Stage	Contribution to electrical costs
Wind production	11.3 cents/kWh
Electrolysis and storage	17.5 cents/kWh
Transportation	5.9 cents/kWh
Fuel cell conversion	1.6 cents/kWh
Total	**36.3 cents/kWh**

Even at a Class 4 wind site, this particular high-penetration system cannot compete economically with electricity provided by coal or natural gas power plants. A closer look at the energy market illustrates part of the issue. The coal, oil, and gas industries in this country already receive tax subsidies and rebates in the interest of lower prices for the consumer. The federal government provides direct subsidies for kerosene and diesel fuels, and regulatory policies encourage investment in large scale coal plants (Johansson et al., 1993).

Meanwhile, efforts to encourage the development of wind power in this country have been half hearted at best. The primary drive for wind energy is the production tax credit, originally enacted in 1992. In June of 1999, the credit expired; six months later, the credit was extended until the end of 2001. Since then, it has been renewed four times, but allowed to expire at the end of 2001 and 2003. These temporary fixes, which last an average of 2 years, have created boom and bust cycles in the industry that have hampered development. **Figure 12** illustrates the problem. It is especially informative to note the large and sustained growth in wind energy from 2004 to 2007, when the production tax credit was renewed prior to expiration. Many wind proponents argue that a long-term production tax credit could provide a much needed impetus to renewable energy development.

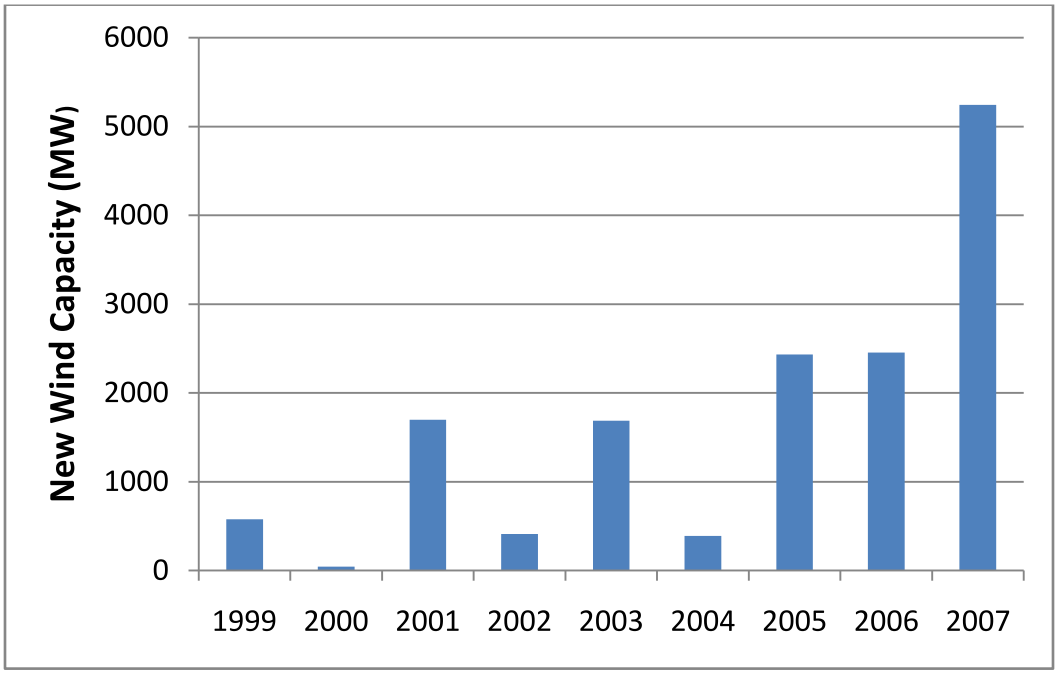


Figure 12: The boom and bust cycles generated by the temporary wind stimulus legislation
Source Data: Succar, 2008a

Of the estimated $63 billion dollars in federal energy subsidies, only 6% currently goes to wind (American Wind Energy Association, 2007a). A number of key improvements in public policy would assist in the expansion of wind and other renewables. The government could remove conventional fuel subsidies, internalize environmental and other external costs (through a carbon tax), increase support for research and development of renewable energy, toughen emissions requirements, mandate net metering agreements, establish renewable energy contracts, require utilities to produce a set fraction of energy from renewables, and offer premium prices for renewable energy (Johansson et al., 1993; Boyle, 2004; Gipe, 2004). These are just a few of the initiatives proposed by wind proponents in the last decade.

5.1 The External Costs of Fossil Fuels

Part of the impediment to wind energy development is the failure of economic markets to take into account the environmental benefits of renewable resource electricity production. A typical internal combustion engine releases approximately 3.0kg of carbon into the atmosphere for every gallon of gasoline consumed (Hydrogen Economy, 2004), and the resulting environmental damage could cost as much as half of the gasoline pump price to repair (Bockris & Veziroglu, 2007). Internal combustion engines also release nitrogen-oxygen compounds (a source of acid rain), carbon monoxide (a poison), volatile organic compounds (a carcinogen), and particulates (a cause of respiratory problems).

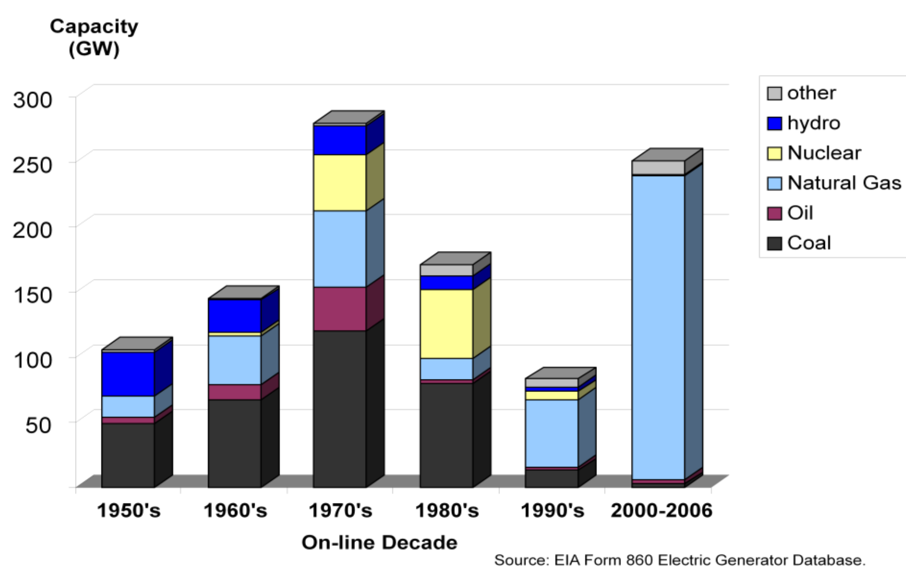


Figure 13: Electrical capacity additions by fuel type
Source Data: Annual Electric Generator Report, 2006

But utilities play a significant role as well; 40% of carbon dioxide and other greenhouse gases are generated by electricity production (Hydrogen Economy, 2004). Coal fired plants generate sulfur dioxide, another source of acid rain. Using natural gas has a less detrimental effect on the environment due to the reduced carbon content of the fuel, but proponents of coal point to the dangers of relying heavily on a natural resource that must be imported (Boyle, 2003). In recent years, most US electrical investment has gone toward natural gas plants (see **Figure 13**); however, rising oil and gas costs are currently shifting the momentum back toward coal. The economics of large scale power production are currently at odds with efforts to reduce greenhouse gases because a push for domestically generated electricity is by definition a push for coal power (see **Figure 14**).

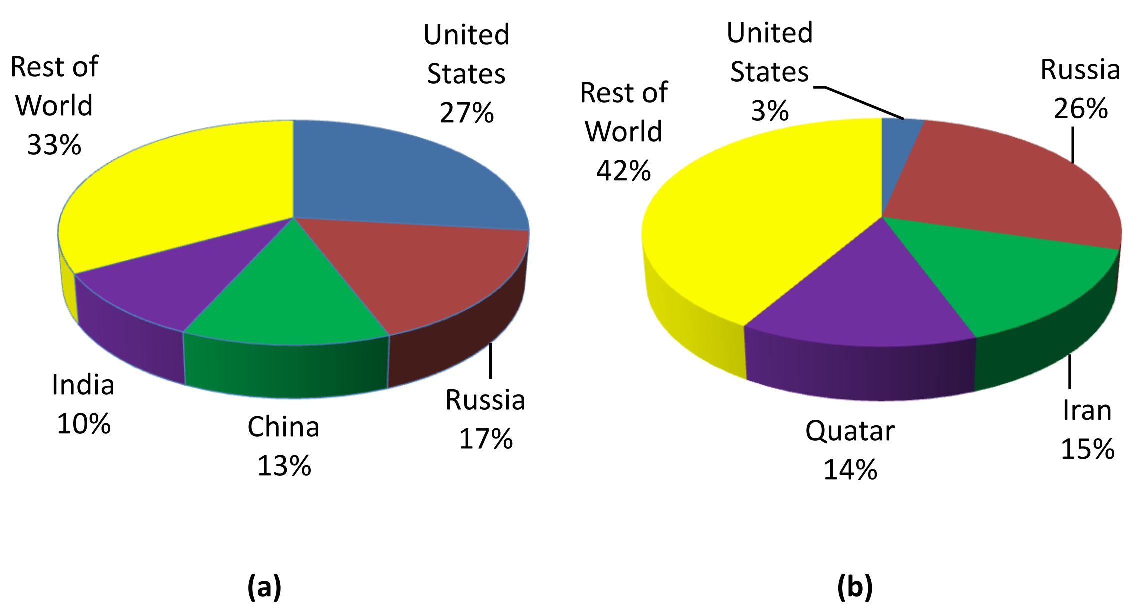


Figure 14: World coal (a) and natural gas (b) reserves by country
Source: International Energy Annual, 2005

The exact cost of fossil fuel emissions is difficult to quantify and estimates vary widely. Producing 1 MWh of electricity using natural gas releases about 800 lbs of CO_2 into the atmosphere; the same amount of electricity produced at a coal fired plant releases 2,200 lbs of CO_2 (Romm, 2004). But how to price the amount of environmental damage caused by these emissions is another matter. Pricing must take into account the potential for work-related as well as public health hazards, shown in **Table 12**. Wind turbine use has resulted in about 20 worker deaths, but no known injuries to the public, meaning the externalities associated with wind energy are minimal (Boyle, 2003). In addition, increased wind energy development has positive effects, such as economic progress, land restoration, energy supply diversity, and domestic power resource development (Cavallo et al., 1993; Boyle, 2003), to name a few. Despite the appeals of renewable energy sources like wind, the current situation is highly discriminatory and extremely effective at preserving the present domination of fossil fuels in the energy industry.

Table 12: Estimated deaths from power generation per GWh of output (Source Data: Gipe, 2004)

Fuel	Occupational Accidents	Occupational Disease	Public
Coal	0.46	0.13-8.7	0-320
Oil	1.63		0-130
Gas	0.21		

One proposal for change is a carbon tax, similar to those already in place in several Scandinavian countries. Denmark's carbon tax of $14 per ton of carbon dioxide, for example, has resulted in a decrease of 15% in carbon emissions from 1990 to 2005 (Carbon Tax Center, 2008). Some advocacy groups and scientists in the United States are calling for a carbon tax of $30-50 per ton of carbon dioxide in an effort to fight global warming (Carbon Tax Center, 2008; Hydrogen Economy, 2004). While most of the options on the table call for a tax on power production, some alternative proposals place a tax on consumption in the form of a gas tax (Carbon Tax Center, 2008).

A multitude of studies have been commissioned to determine when the price of renewable hydrogen will fall enough to become competitive with fossil fuels but very few authors have taken the time to consider if and when fossil fuel prices might rise enough to make hydrogen competitive. As **Figure 15** shows, oil and natural gas prices have been rising steadily in the last decade, enhancing the economic incentives for renewable alternatives in both the automotive and stationary electricity production sectors. For example, a study into the feasibility of the hydrogen economy 5 years ago based its entire economic analysis on the national average of $1.27/gal for gasoline (Hydrogen Economy, 2004). Today, the national average stands at $3.61/gal (Gas Buddy, 2008), and renewable energy is looking more appealing than ever before.

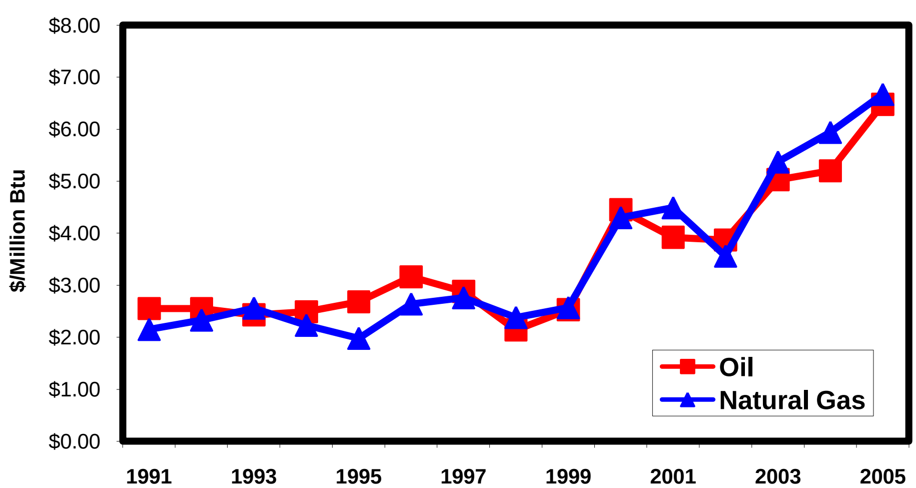


Figure 15: The rising average cost of fossil fuel electricity
Source Data: Cunningham, 2007

5.2 Long term outlook: A best case scenario

It is debatable whether the external costs of fossil fuels are large enough to really make a difference. Would a federal carbon emissions tax coupled with rising fuel prices really be strong enough to reduce fossil fuel's hegemony in the energy industry? Consider a best case scenario: impose not only a generous carbon tax of $50/ton CO_2, but assume as well that residential electricity prices continue to rise at their current 10-year average of 2% annually (Energy Information Administration, 2007), electrolyzer costs fall by 11% annually (Bockris & Veziroglu, 2007; Hydrogen Economy, 2004), fuel cell capital costs fall by 10% annually (Fuel Cell Handbook, 2005), and a hydrogen pipeline infrastructure is already present. In this highly idealistic scenario, the Amarillo-Texas A&M system would be able to profitably produce electricity in the year 2029 at a cost of 18.1 cents/kWh.

5.3 Conclusions and suggestions for further research

Rather than try to determine when the transition to the hydrogen economy will occur, this study focused more specifically on the economic potential of one renewable energy technology, wind energy, to completely service the electricity needs of a small metropolitan area. Although the prospective Amarillo wind farm was able to operate close to profitability in a competitive market, the costs of storage and transportation made the proposed Amarillo-Texas A&M power grid economically infeasible. The primary difficulties associated with such a system center around the inherent variability of wind power production at high penetration levels and the lack of hydrogen pipeline infrastructure. In the future, reduced electrolyzer, pipeline, and fuel cell costs coupled with rising natural gas prices and carbon tax policy initiatives could one day make this and similar systems economically profitable. But the necessary changes are unlikely to come anytime soon. Even the most optimistic scenarios predict that it will take more than twenty years for a high penetration wind system to succeed, even in regions with excellent wind resources.

But proponents of wind and other renewable energy sources should not be disheartened. Future research may one day show that an Amarillo-Texas A&M power grid can be commercially successful. One possibility is to try implementing the same system in a different location. Transportation costs could be reduced by designing a system to service the city of Amarillo itself or more proximate universities (like Texas Tech in Lubbock). The initial goal in this study was to consider a system like this, but difficulties in obtaining consumption data restricted research to servicing Texas A&M. Alternatively, researchers could consider meeting campus demand with a hybrid portfolio of production, storage, and transportation systems designed to maximize profitability along several avenues. This sort of analysis was deemed too complex for the restrictive nature of this study. One final proposal would be to consider at a more detailed level the extent to which variability impacts the sizing and pricing of equipment in the Amarillo-Texas A&M system. In this study, a standard energy profile was used and a contingency percentage was added to approximate the extra storage and transportation capacity necessary to meet extreme fluctuations in supply. A more thorough examination of variability would require extensive supply and demand information, neither of which was available for this paper.

Policy makers and advocacy groups would do well to consider the perspective of engineers and economists on this issue. The urgent problem of greenhouse gas emissions and global warming necessitates drastic action, but there is no renewable cure-all for pressing climate change issues. Even today, there are powerful economic forces maintaining the dominance of cheap, environmentally unfriendly fuels in the market, and they show no signs of retreating in the face of rising costs. The best course of action, then, is to continue to improve renewable energy systems, employing greenhouse reducing technologies where they are already profitable and searching for the next best alternative where they are not.

References

American Wind Energy Association. Another Record Year for New Wind Installations. http://www.awea.org/pubs/factsheets/2008_Market_Update.pdf (accessed April 2, 2008), 2008a.

American Wind Energy Association. Facts About Wind Energy and Noise. http://www.awea.org/pubs/factsheets/WE_Noise.pdf (accessed April 13, 2008), 2008b.

American Wind Energy Association. U.S. Wind Energy Projects. http://www.awea.org/projects/ (accessed April 2, 2008), 2008c.

American Wind Energy Association. Wind Energy and U.S. Energy Subsidies. http://www.ifnotwind.org/pdf/Subsidy_updated_Jan_07.pdf (accessed Mar 29, 2008), 2007a.

American Wind Energy Association. Wind Energy FAQ.. http://www.awea.org/faq/netbdef.html (accessed Apr 8, 2008), 2007b.

Annual Electric Generator Report 2006; DOE/EIA-860; Department of Energy, Washington, DC, 2007.

Annual Energy Review 2006; DOE/EIA-0384; Department of Energy; Washington, DC, 2007.

Annual Report on US Wind Power Installation, Cost, and Performance Trends; DOE/GO-102007-2433; Department of Energy; Washington, DC, 2007.

Blencoe, Greg. Twelve Hydrogen Facts. http://hydrogendiscoveries.wordpress.com/category/hydrogen-pipelines/ (accessed May 5, 2008), 2008.

Bockris, J.; Veziroglu, T.N.. Estimates of the Price the Hydrogen as a medium for Wind and Solar Sources. *International Journal of Hydrogen Energy.* **2007**, *32*, 1605-1610.

Bodie, Z.; Kane, A.; Marcus, A. *Investments*; McGraw-Hill: New York, 2004.

Borer, E.T. Princeton University, Princeton, NJ. Personal communication, 2008.

Boyle, G., Ed. *Renewable Energy: Power for a Sustainable Future*; Oxford University Press: New York, 2004.

Boyle, G.; Everett, B.; Ramage, J., Eds. *Energy Systems and Sustainability*; Oxford University Press: New York, 2003.

Carbon Tax Center. www.carbontax.org (accessed Mar 29, 2008).

Carlson, E.; Kopf, P.; Sinha, J.; Sriramulu, S.; Yang, Y. PEM Fuel Cell Cost Status-2005. http://fuelcellseminar.com/pdf/2005/Thursday-Nov17/Carlson_Eric_392.PDF (accessed Mar 25, 2008).

Cavallo, A.J.; Hock, S.M.; Smith, D.R. Wind Energy: Technology and Economics. In *Renewable Energy: Sources for Fuels and Electricity*; Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H.; Island Press: Washington, D.C., 1993.

Cole, R. Green Hydrogen Cash Flow Improvements. Presented at Energy Center Hydrogen Initiative Symposium, West Lafayette, IN, April 5-6, 2006.

Committee on Energy and Natural Resources. Public Utility Regulatory Policies Act of 1978, Public Law 95-617. *National Energy Act*; US Government Printing Office: Washington, DC, 1979; 277-395.

Coutsoukis, Photius. Texas Quick Maps. http://www.geographic.org/maps/new2/ texas_maps.html (accessed Apr 14, 2008), 2003.

Cunningham, D. Electrical Power Generation and the Environment. MAE 328: Energy for a Greenhouse Constrained Environment, Princeton, NJ, Mar 6, 2007 .

Danish Wind Industry Association. Operation and Maintenance Cost for Wind Turbines. http://www.windpower.org/en/tour/econ/oandm.htm (accessed Apr 14, 2008), 2003.

Ehrlich, G.M. Lithium-ion Batteries. In *Handbook of Batteries,* 3rd ed.; McGraw-Hill: New York, 2001.

Eilers, M. Current Status of Wind: Market Update in the Context of the Economics of Wind. Presented at U.S. DOE Regional Wind Conference, Brookings, SD, Sep 11-13, 2005.

Elliot, D.L.; Windell, L.L.; Gower, G.L. *An Assessment of the Available Wind Land Area and Wind Potential in the Contiguous United States; PNL-7789;* Pacific Northwest Laboratory, Golden, CO, 1991.

Energy Information Administration. About US Natural Gas Pipelines. http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ ngpipeline/ (accessed Apr 14, 2008), 2008.

Energy Information Administration. Average Retail Price of Electricity to Ultimate Customers by End Use Sector. http://www.eia.doe.gov/cneaf/electricity/ epa/epat7p4.html (accessed Apr 14, 2008), 2007.

Fuel Cell Basics. U.S. Department of Defense. http://www.fctec.com/ftec_basic.asp (accessed Mar 25, 2008), 2008.

Fuel Cell Handbook: National Energy Technology Laboratory; Department of Energy, University Press of the Pacific: Honolulu, HI, 2005.

Fuel Cell Origins. http://americanhistory.si.edu/fuelcells/origins/orig1.htm (accessed Mar 25, 2008).

Gas Buddy Home Page. www.gasbuddy.com (accessed May 6, 2008).

GE Energy: 2.5 MW Wind Turbine. http://gepower.com/businesses/ge_wind_energy/ en/index.htm (accessed Mar 25, 2008), 2008.

Gipe, P. *Wind Power: Renewable Energy for Home, Farm, and Business*; Chelsea Green Publishing: White River Junction, VT, 2004.

Gonzalez, A.; McKeogh, E.; Gallachoir, B.O. The role of hydrogen in high wind energy penetration electricity systems: The Irish case. *Renewable Energy*. **2003**, *29*, 471-489.

Grubb, M.J.; Meyer, N.I. Wind Energy: Resources, Systems and Regional Strategies. In *Renewable Energy: Sources for Fuels and Electricity*; Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H.; Island Press: Washington, D.C., 1993.

Guey-Lee, L. Wind Energy Development: Incentives in Selected Countries. http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/windart.html (accessed Feb 13, 2008), 2002.

The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. National Research Council, National Academy Press: Washington, DC, 2004.

Hydrogen Fuel: A Clean and Secure Energy Future; The White House. http://www.whitehouse.gov/news/releases/2003/01/20030128-25.html (accessed Apr 14, 2008), 2003.

International Energy Annual, 2005. Energy Information Association. http://www.eia.doe.gov/iea/ (accessed Apr 13, 2008), 2007.

Johansson, T. B.; Kelly, H.; Reddy, A. K. N.; Williams, R. H. Eds. Renewable Fuels and Electricity for a Growing World Economy. In *Renewable Energy: Sources for Fuels and Electricity;* Island Press: Washington, D.C., 1993.

Kelly, M. *Wind Energy and Economic Development.* Presented in Golden, CO, Jun 8, 2007.

Levene, I.L.; Mann, M.K.; Margolis, R.M; Milbrandt, A. An analysis of hydrogen production from renewable electricity sources. *Solar Energy*. **2007**, *81,* 773-780.

Linden, D.; Reddy, T. Eds. Secondary Batteries-Introduction. In *Handbook of Batteries,* 3rd ed.; McGraw-Hill: New York, 2001.

Manwell, J. F.; McGowan, J. G.; Rogers, A. L. *Wind Energy Explained: Theory, Design and Application*; John Wiley and Sons: New York, 2002.

Mintz, M.; Folga, S.; Molburg, J.; Gillette, J. Cost of Some Hydrogen Fuel Infrastructure Options. Presented at Transportation Research Board, Jan 16, 2002.

National Climatic Data Center. Unedited Local Climatological Data for Amarillo Rick Husband International Airport. http://cdo.ncdc.noaa.gov/ulcd/ULCD?state=TX&callsign=AMA (accessed Apr 14, 2008), 2008.

New York State Energy Research and Development Authority. Hydrogen Production – Steam Methane Reforming (SMR). http://www.getenergysmart.org/Files/HydrogenEducation/6HydrogenProductionSteamMethaneReforming.pdf (accessed Apr 8, 2008), 2008.

Nilsson, A.O.; Baker, C.A. Industrial and Aerospace Nickel-Cadmium Batteries. In *Handbook of Batteries,* 3rd ed.; McGraw-Hill: New York, 2001.

Ogden, J.M; Nitsch, J. Solar Hydrogen. In *Renewable Energy: Sources for Fuels and Electricity*; Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H.; Island Press: Washington, D.C., 1993.

Opalka, S. M.; Qui, C.; Lovvik, O. M. In First Principles Contributions to the Thermodynamic Assessment of Solid State Metal Hydride and Complex Hydride Phases. Presented at DOE Theory Focus Session on Hydrogen Storage Materials, Crystal City, VA, May 18, 2006.

Remp, L. H. Hydrogen Pipeline Experience. Presented at DOE Hydrogen Pipeline Working Group Workshop, Augusta, GA, Aug 31, 2005.

Romm, J. The Hype about Hydrogen. *Issues in Science and Technology*. **2004**.

Rosen, H.S. Princeton University, Princeton, NJ. Personal communication, 2008.

Salking, A.J.; Cannone, A.G.; Trumbure, F.A. Lead-Acid Batteries. In *Handbook of Batteries,* 3rd ed.; McGraw-Hill: New York, 2001.

Shakya, B.D.; Aye, L.; Musgrave, P. Technical feasibility and financial analysis of hybrid wind-photovoltaic system with hydrogen storage for Cooma. *International Journal of Hydrogen Energy*. **2005**, *30*, 9-20.

Simon, A. A Summary of Research Conducted into Attitudes to Wind Power from 1990-1996. http://www.bwea.com/ref/surveys-90-96.html (accessed Feb 19, 2008), 1996.

Socolow, R. Hydropower and Wind: Renewable Energy Naturally Amplified [2007 Lecture 18]. MAE 328: Energy for a Greenhouse Constrained Environment, Princeton, NJ, 2007.

Spiegel, C. *Designing and Building Fuel Cells*; McGraw-Hill: New York, 2007.

Srinivasan, S. *Fuel Cells: From Fundamentals to Applications*; Spring Science: New York, 2006.

Succar, S. Global Prospects for Wind Energy, Par 1: Fundamentals, Trends, and Resources. MAE 328: Energy for a Greenhouse Constrained Environment, Princeton, NJ, Apr 1, 2008a.

Succar, S. Global Prospects for Wind Energy, Part 2: Exploiting New Resources and Mitigating Intermittency. MAE 328: Energy for a Greenhouse Constrained Environment, Princeton, NJ, Apr 3, 2008b.

Texas A&M Office of Institutional Studies and Planning. Enrollment Profile: Spring 2006. http:www.tamu.edu/opir/reports/ep/epsp2006_certified.pdf (accessed Mar 28, 2008), 2006.

Trevisani, L.; Fabbri, M.; Negrini, F. Long-term scenarios for energy and environment: Energy from the desert with very large solar plants using liquid hydrogen and superconducting technologies. *Fuel Processing Technology*. **2006**, *87*, 157-161.

U.S. Department of Energy. Gaseous and Liquid Hydrogen Storage. http://www1.eere.energy.gov/hydrogenandfuelcells/storage/hydrogen_storage.html (accessed Apr 13, 2008), 2008a.

U.S. Department of Energy. Installed US Wind Capacity and Wind Project Locations. http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_installed_capacity.asp (accessed Apr 14, 2008), 2008b.

U.S. Department of Energy. Today's Hydrogen Production Industry. http://www.fossil.energy.gov/programs/fuels/hydrogen/currenttechnology.html (accessed Apr 14, 2008), 2005.

U.S. Department of Energy. Types of Fuel Cells. http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html (accessed Apr 14, 2008), 2007.

Woodall, B. U.S. Wind Power Grew 45 Percent in 2007: AWEA. *Reuters.* http://www.reuters.com/article/bondsNews/idUSN1637365420080117 (accessed Feb 13, 2008), 2008.

Appendix

	Case 1	Case 2	Case 3	Case 4	Case 5
Expected inflation	0.03	0.03	0.03	0.03	0.03
# of Turbines	100	100	100	100	100
Electricity supplied (kWh)	302,892,922	302,892,922	302,892,922	302,892,922	302,892,922
Rated capacity (MW)	250	250	250	250	250
Capital cost	$325,000,000	$325,000,000	$325,000,000	$325,000,000	$325,000,000
Balance of system costs	$32,500,000	$32,500,000	$32,500,000	$32,500,000	$32,500,000
Operation and maintainance (cents/kWh)	1	0.5	1	1	1
Insurance Percent	0.01	0.01	0.01	0.01	0.01
Depreciation Term (yrs)	5	5	5	5	5
Debt Ratio	0.6	0.6	0.6	0.6	0.6
Interest rate	0.06	0.06	0.06	0.06	0.06
Discount rate	0.06	0.06	0.06	0.06	0.06
Loan Term (yrs)	20	20	20	10	20
Federal Tax Rate	0.34	0.34	0.34	0.34	0.34
Tax incentive (cents/kWh)	1	1	2	1	1
Electricity rate (cents/kWh)	**11.3**	**10.6**	**10.6**	**11.8**	**10.9**
Total Mortgage Amount	$214,500,000	$214,500,000	$214,500,000	$214,500,000	$214,500,000
Total Equity Amount	$143,000,000	$143,000,000	$143,000,000	$143,000,000	$143,000,000
System Lifetime	30 years	30 years	30 years	30 years	35 years
NPV	$0	$0	$0	$0	$0

	Case 6	Case 7	Case 8	Case 9	Case 10
Expected inflation	0.06	0.03	0.03	0.03	0.03
# of Turbines	100	100	100	100	100
Electricity supplied (kWh)	302,892,922	302,892,922	302,892,922	302,892,922	302,892,922
Rated capacity (MW)	250	250	250	250	250
Capital cost	$325,000,000	$325,000,000	$325,000,000	$325,000,000	$325,000,000
Balance of system costs	$32,500,000	$32,500,000	$32,500,000	$32,500,000	$32,500,000
Operation and maintainance (cents/kWh)	1	1	1	1	1
Insurance Percent	0.01	0.01	0.01	0.01	0.01
Depreciation Term (yrs)	5	5	5	5	5
Debt Ratio	0.6	1	0.6	0.6	0.6
Interest rate	0.06	0.06	0.03	0.06	0.06
Discount rate	0.06	0.06	0.06	0.03	0.06
Loan Term (yrs)	20	20	20	20	20
Federal Tax Rate	0.34	0.34	0.34	0.34	0.17
Tax incentive (cents/kWh)	1	1	1	1	1
Electricity rate (cents/kWh)	**12.1**	**11.8**	**12.0**	**9.8**	**9.9**
Total Mortgage Amount	$214,500,000	$357,500,000	$214,500,000	$214,500,000	$214,500,000
Total Equity Amount	$143,000,000	$0	$143,000,000	$143,000,000	$143,000,000
System Lifetime	30 years	30 years	30 years	30 years	30 years
NPV	$0	$0	$0	$0	$0

	Case 11	Case 1 w/ S	Case 1 w/ S+T	Case 1 w/ S+T+F	Best Case Scenario
Expected inflation	0.03	0.03	0.03	0.03	0.03
# of Turbines	100	100	100	100	100
Electricity supplied (kWh)	302,892,922	302,892,922	302,892,922	302,892,922	302,892,922
Rated capacity (MW)	250	250	250	250	250
Capital cost	$162,500,000	$325,000,000	$325,000,000	$325,000,000	$325,000,000
Balance of system costs	$16,250,000	$32,500,000	$32,500,000	$32,500,000	$32,500,000
Operation and maintainance (cents/kWh)	1	1	1	1	1
Insurance Percent	0.01	0.01	0.01	0.01	0.01
Depreciation Term (yrs)	5	5	5	5	5
Debt Ratio	0.6	0.6	0.6	0.6	0.6
Interest rate	0.06	0.06	0.06	0.06	0.06
Discount rate	0.06	0.06	0.06	0.06	0.06
Loan Term (yrs)	20	20	20	20	20
Federal Tax Rate	0.2	0.34	0.34	0.34	0.34
Tax incentive (cents/kWh)	1	1	1	1	1
Electricity rate (cents/kWh)	**5.4**	**28.8**	**34.7**	**36.3**	**18.1**
Total Mortgage Amount	$107,250,000	$214,500,000	$214,500,000	$214,500,000	$214,500,000
Total Equity Amount	$71,500,000	$143,000,000	$143,000,000	$143,000,000	$143,000,000
System Lifetime	30 years	30 years	30 years	30 years	30 years
NPV	$0	$0	$0	$0	$0

Case 1

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0	$0	$143,000,000	$0	$0
1	$34,345,217	$3,028,929	$3,250,000	$21,631,000	$121,369,000	$0	$0
2	$34,860,395	$3,074,363	$3,347,500	$22,499,390	$98,869,610	$0	$0
3	$35,383,301	$3,120,479	$3,447,925	$23,397,293	$75,472,317	$0	$0
4	$35,914,051	$3,167,286	$3,551,363	$24,326,168	$51,146,150	$0	$0
5	$36,452,762	$3,214,795	$3,657,904	$25,287,560	$25,858,590	$0	$0
6	$36,999,553	$3,263,017	$3,767,641	$25,858,590	$0	$424,513	$144,334
7	$37,554,546	$3,311,962	$3,880,670	$0	$0	$27,314,525	$9,286,939
8	$38,117,864	$3,361,642	$3,997,090	$0	$0	$28,383,658	$9,650,444
9	$38,689,632	$3,412,066	$4,117,003	$0	$0	$29,492,438	$10,027,429
10	$39,269,977	$3,463,247	$4,240,513	$0	$0	$30,642,916	$10,418,591
11	$39,859,027	$3,515,196	$4,367,728	$0	$0	$31,837,264	$10,824,670
12	$40,456,912	$3,567,924	$4,498,760	$0	$0	$33,077,781	$11,246,446
13	$41,063,766	$3,621,443	$4,633,723	$0	$0	$34,366,903	$11,684,747
14	$41,679,722	$3,675,764	$4,772,735	$0	$0	$35,707,208	$12,140,451
15	$42,304,918	$3,730,901	$4,915,917	$0	$0	$37,101,429	$12,614,486
16	$42,939,492	$3,786,864	$5,063,394	$0	$0	$38,552,459	$13,107,836
17	$43,583,584	$3,843,667	$5,215,296	$0	$0	$40,063,366	$13,621,544
18	$44,237,338	$3,901,322	$5,371,755	$0	$0	$41,637,397	$14,156,715
19	$44,900,898	$3,959,842	$5,532,907	$0	$0	$43,277,994	$14,714,518
20	$45,574,411	$4,019,240	$5,698,895	$0	$0	$44,988,807	$15,296,194
21	$46,258,028	$4,079,528	$5,869,862	$0	$0	$46,258,028	$15,727,729
22	$46,951,898	$4,140,721	$6,045,957	$0	$0	$46,951,898	$15,963,645
23	$47,656,176	$4,202,832	$6,227,336	$0	$0	$47,656,177	$16,203,100
24	$48,371,019	$4,265,875	$6,414,156	$0	$0	$48,371,019	$16,446,146
25	$49,096,584	$4,329,863	$6,606,581	$0	$0	$49,096,584	$16,692,839
26	$49,833,033	$4,394,811	$6,804,778	$0	$0	$49,833,033	$16,943,231
27	$50,580,529	$4,460,733	$7,008,922	$0	$0	$50,580,529	$17,197,380
28	$51,339,237	$4,527,644	$7,219,189	$0	$0	$51,339,237	$17,455,340
29	$52,109,325	$4,595,559	$7,435,765	$0	$0	$52,109,325	$17,717,171
30	$52,890,965	$4,664,492	$7,658,838	$0	$0	$52,890,965	$17,982,928

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0	$0	$143,000,000	$143,000,000
1	$3,028,929	$12,714,217	$5,726,718	$18,440,935	$12,654,282	$11,938,002	$131,061,998
2	$3,119,797	$12,361,006	$6,079,930	$18,440,935	$13,117,394	$11,674,434	$119,387,565
3	$3,213,391	$11,986,009	$6,454,927	$18,440,935	$13,587,353	$11,408,204	$107,979,361
4	$3,309,793	$11,587,883	$6,853,052	$18,440,935	$14,064,260	$11,140,211	$96,839,150
5	$3,409,087	$11,165,202	$7,275,734	$18,440,935	$14,548,214	$10,871,272	$85,967,878
6	$3,511,359	$10,716,450	$7,724,485	$18,440,935	$14,894,985	$10,500,376	$75,467,502
7	$3,616,700	$10,240,021	$8,200,914	$18,440,935	$6,250,740	$4,157,099	$71,310,403
8	$3,725,201	$9,734,207	$8,706,729	$18,440,935	$6,392,955	$4,011,019	$67,299,384
9	$3,836,957	$9,197,195	$9,243,741	$18,440,935	$6,529,156	$3,864,597	$63,434,787
10	$3,952,066	$8,627,061	$9,813,875	$18,440,935	$6,658,755	$3,718,214	$59,716,572
11	$0	$8,021,763	$10,419,173	$18,440,935	$2,710,497	$1,427,856	$58,288,716
12	$0	$7,379,131	$11,061,805	$18,440,935	$2,702,847	$1,343,232	$56,945,484
13	$0	$6,696,863	$11,744,073	$18,440,935	$2,682,918	$1,257,856	$55,687,628
14	$0	$5,972,514	$12,468,421	$18,440,935	$2,649,837	$1,172,025	$54,515,602
15	$0	$5,203,489	$13,237,446	$18,440,935	$2,602,679	$1,086,007	$53,429,595
16	$0	$4,387,033	$14,053,903	$18,440,935	$2,540,462	$1,000,043	$52,429,552
17	$0	$3,520,219	$14,920,717	$18,440,935	$2,462,141	$914,352	$51,515,200
18	$0	$2,599,941	$15,840,994	$18,440,935	$2,366,610	$829,127	$50,686,073
19	$0	$1,622,904	$16,818,032	$18,440,935	$2,252,695	$744,545	$49,941,528
20	$0	$585,604	$17,855,332	$18,440,936	$2,119,147	$660,760	$49,280,768
21	$0	$0	$0	$0	$20,580,908	$6,053,985	$43,226,783
22	$0	$0	$0	$0	$20,801,574	$5,772,543	$37,454,240
23	$0	$0	$0	$0	$21,022,908	$5,503,740	$31,950,500
24	$0	$0	$0	$0	$21,244,842	$5,247,020	$26,703,480
25	$0	$0	$0	$0	$21,467,302	$5,001,852	$21,701,628
26	$0	$0	$0	$0	$21,690,213	$4,767,726	$16,933,902
27	$0	$0	$0	$0	$21,913,494	$4,544,156	$12,389,745
28	$0	$0	$0	$0	$22,137,063	$4,330,677	$8,059,068
29	$0	$0	$0	$0	$22,360,831	$4,126,842	$3,932,226
30	$0	$0	$0	$0	$22,584,707	$3,932,226	$0

Case 2

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	$0
1	$32,117,410	$1,514,465	$3,250,000	$19,403,193	$123,596,807	$0	$0
2	$32,599,171	$1,537,182	$3,347,500	$20,238,166	$103,358,641	$0	$0
3	$33,088,159	$1,560,239	$3,447,925	$21,102,150	$82,256,490	$0	$0
4	$33,584,481	$1,583,643	$3,551,363	$21,996,598	$60,259,892	$0	$0
5	$34,088,249	$1,607,398	$3,657,904	$22,923,047	$37,336,845	$0	$0
6	$34,599,572	$1,631,508	$3,767,641	$23,883,122	$13,453,723	$0	$0
7	$35,118,566	$1,655,981	$3,880,670	$13,453,723	$0	$11,424,822	$3,884,439
8	$35,645,344	$1,680,821	$3,997,090	$0	$0	$25,911,138	$8,809,787
9	$36,180,025	$1,706,033	$4,117,003	$0	$0	$26,982,830	$9,174,162
10	$36,722,725	$1,731,624	$4,240,513	$0	$0	$28,095,664	$9,552,526
11	$37,273,566	$1,757,598	$4,367,728	$0	$0	$29,251,803	$9,945,613
12	$37,832,669	$1,783,962	$4,498,760	$0	$0	$30,453,539	$10,354,203
13	$38,400,159	$1,810,721	$4,633,723	$0	$0	$31,703,297	$10,779,121
14	$38,976,162	$1,837,882	$4,772,735	$0	$0	$33,003,648	$11,221,240
15	$39,560,804	$1,865,450	$4,915,917	$0	$0	$34,357,315	$11,681,487
16	$40,154,216	$1,893,432	$5,063,394	$0	$0	$35,767,184	$12,160,842
17	$40,756,530	$1,921,834	$5,215,296	$0	$0	$37,236,311	$12,660,346
18	$41,367,877	$1,950,661	$5,371,755	$0	$0	$38,767,936	$13,181,098
19	$41,988,396	$1,979,921	$5,532,907	$0	$0	$40,365,492	$13,724,267
20	$42,618,222	$2,009,620	$5,698,895	$0	$0	$42,032,617	$14,291,090
21	$43,257,495	$2,039,764	$5,869,862	$0	$0	$43,257,495	$14,707,548
22	$43,906,357	$2,070,361	$6,045,957	$0	$0	$43,906,357	$14,928,161
23	$44,564,953	$2,101,416	$6,227,336	$0	$0	$44,564,953	$15,152,084
24	$45,233,427	$2,132,937	$6,414,156	$0	$0	$45,233,427	$15,379,365
25	$45,911,928	$2,164,931	$6,606,581	$0	$0	$45,911,928	$15,610,056
26	$46,600,607	$2,197,405	$6,804,778	$0	$0	$46,600,607	$15,844,206
27	$47,299,616	$2,230,366	$7,008,922	$0	$0	$47,299,616	$16,081,870
28	$48,009,111	$2,263,822	$7,219,189	$0	$0	$48,009,111	$16,323,098
29	$48,729,247	$2,297,779	$7,435,765	$0	$0	$48,729,247	$16,567,944
30	$49,460,186	$2,332,246	$7,658,838	$0	$0	$49,460,186	$16,816,463

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0	$0	$143,000,000	$143,000,000
1	$3,028,929	$12,714,217	$5,726,718	$18,440,935	$11,940,939	$11,265,037	$131,734,963
2	$3,119,797	$12,361,006	$6,079,930	$18,440,935	$12,393,352	$11,030,039	$120,704,924
3	$3,213,391	$11,986,009	$6,454,927	$18,440,935	$12,852,450	$10,791,165	$109,913,759
4	$3,309,793	$11,587,883	$6,853,052	$18,440,935	$13,318,333	$10,549,367	$99,364,392
5	$3,409,087	$11,165,202	$7,275,734	$18,440,935	$13,791,099	$10,305,511	$89,058,881
6	$3,511,359	$10,716,450	$7,724,485	$18,440,935	$14,270,847	$10,060,384	$78,998,497
7	$3,616,700	$10,240,021	$8,200,914	$18,440,935	$10,873,240	$7,231,326	$71,767,171
8	$3,725,201	$9,734,207	$8,706,729	$18,440,935	$6,441,912	$4,041,735	$67,725,436
9	$3,836,957	$9,197,195	$9,243,741	$18,440,935	$6,578,848	$3,894,010	$63,831,426
10	$3,952,066	$8,627,061	$9,813,875	$18,440,935	$6,709,193	$3,746,378	$60,085,048
11	$0	$8,021,763	$10,419,173	$18,440,935	$2,761,691	$1,454,824	$58,630,223
12	$0	$7,379,131	$11,061,805	$18,440,935	$2,754,809	$1,369,056	$57,261,168
13	$0	$6,696,863	$11,744,073	$18,440,935	$2,735,659	$1,282,584	$55,978,584
14	$0	$5,972,514	$12,468,421	$18,440,935	$2,703,369	$1,195,703	$54,782,881
15	$0	$5,203,489	$13,237,446	$18,440,935	$2,657,015	$1,108,679	$53,674,202
16	$0	$4,387,033	$14,053,903	$18,440,935	$2,595,612	$1,021,753	$52,652,449
17	$0	$3,520,219	$14,920,717	$18,440,935	$2,518,119	$935,140	$51,717,309
18	$0	$2,599,941	$15,840,994	$18,440,935	$2,423,428	$849,033	$50,868,276
19	$0	$1,622,904	$16,818,032	$18,440,935	$2,310,364	$763,605	$50,104,671
20	$0	$585,604	$17,855,332	$18,440,936	$2,177,681	$679,011	$49,425,659
21	$0	$0	$0	$0	$20,640,321	$6,071,462	$43,354,197
22	$0	$0	$0	$0	$20,861,878	$5,789,277	$37,564,920
23	$0	$0	$0	$0	$21,084,117	$5,519,764	$32,045,156
24	$0	$0	$0	$0	$21,306,968	$5,262,364	$26,782,792
25	$0	$0	$0	$0	$21,530,360	$5,016,544	$21,766,247
26	$0	$0	$0	$0	$21,754,217	$4,781,795	$16,984,452
27	$0	$0	$0	$0	$21,978,459	$4,557,628	$12,426,824
28	$0	$0	$0	$0	$22,203,002	$4,343,576	$8,083,248
29	$0	$0	$0	$0	$22,427,759	$4,139,194	$3,944,054
30	$0	$0	$0	$0	$22,652,639	$3,944,054	$0

Case 3

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	
1	$32,053,637	$3,028,929	$3,250,000	$19,339,420	$123,660,580	$0	$0
2	$32,534,442	$3,074,363	$3,347,500	$20,173,436	$103,487,144	$0	$0
3	$33,022,458	$3,120,479	$3,447,925	$21,036,449	$82,450,695	$0	$0
4	$33,517,795	$3,167,286	$3,551,363	$21,929,912	$60,520,783	$0	$0
5	$34,020,562	$3,214,795	$3,657,904	$22,855,360	$37,665,422	$0	$0
6	$34,530,870	$3,263,017	$3,767,641	$23,814,420	$13,851,002	$0	$0
7	$35,048,833	$3,311,962	$3,880,670	$13,851,002	$0	$10,957,810	$3,725,655
8	$35,574,566	$3,361,642	$3,997,090	$0	$0	$25,840,359	$8,785,722
9	$36,108,184	$3,412,066	$4,117,003	$0	$0	$26,910,990	$9,149,737
10	$36,649,807	$3,463,247	$4,240,513	$0	$0	$28,022,746	$9,527,734
11	$37,199,554	$3,515,196	$4,367,728	$0	$0	$29,177,792	$9,920,449
12	$37,757,548	$3,567,924	$4,498,760	$0	$0	$30,378,417	$10,328,662
13	$38,323,911	$3,621,443	$4,633,723	$0	$0	$31,627,048	$10,753,196
14	$38,898,769	$3,675,764	$4,772,735	$0	$0	$32,926,255	$11,194,927
15	$39,482,251	$3,730,901	$4,915,917	$0	$0	$34,278,762	$11,654,779
16	$40,074,485	$3,786,864	$5,063,394	$0	$0	$35,687,452	$12,133,734
17	$40,675,602	$3,843,667	$5,215,296	$0	$0	$37,155,384	$12,632,830
18	$41,285,736	$3,901,322	$5,371,755	$0	$0	$38,685,795	$13,153,170
19	$41,905,022	$3,959,842	$5,532,907	$0	$0	$40,282,119	$13,695,920
20	$42,533,597	$4,019,240	$5,698,895	$0	$0	$41,947,993	$14,262,318
21	$43,171,601	$4,079,528	$5,869,862	$0	$0	$43,171,601	$14,678,344
22	$43,819,175	$4,140,721	$6,045,957	$0	$0	$43,819,175	$14,898,520
23	$44,476,463	$4,202,832	$6,227,336	$0	$0	$44,476,463	$15,121,997
24	$45,143,610	$4,265,875	$6,414,156	$0	$0	$45,143,610	$15,348,827
25	$45,820,764	$4,329,863	$6,606,581	$0	$0	$45,820,764	$15,579,060
26	$46,508,076	$4,394,811	$6,804,778	$0	$0	$46,508,076	$15,812,746
27	$47,205,697	$4,460,733	$7,008,922	$0	$0	$47,205,697	$16,049,937
28	$47,913,782	$4,527,644	$7,219,189	$0	$0	$47,913,782	$16,290,686
29	$48,632,489	$4,595,559	$7,435,765	$0	$0	$48,632,489	$16,535,046
30	$49,361,976	$4,664,492	$7,658,838	$0	$0	$49,361,976	$16,783,072

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0					$143,000,000	$143,000,000
1	$6,057,858	$12,714,217	$5,726,718	$18,440,935	$13,391,631	$12,633,614	$130,366,386
2	$6,239,594	$12,361,006	$6,079,930	$18,440,935	$13,911,237	$12,380,951	$117,985,435
3	$6,426,782	$11,986,009	$6,454,927	$18,440,935	$14,439,901	$12,124,019	$105,861,415
4	$6,619,585	$11,587,883	$6,853,052	$18,440,935	$14,977,797	$11,863,818	$93,997,598
5	$6,818,173	$11,165,202	$7,275,734	$18,440,935	$15,525,101	$11,601,258	$82,396,339
6	$7,022,718	$10,716,450	$7,724,485	$18,440,935	$16,081,995	$11,337,172	$71,059,167
7	$7,233,400	$10,240,021	$8,200,914	$18,440,935	$12,923,010	$8,594,540	$62,464,627
8	$7,450,402	$9,734,207	$8,706,729	$18,440,935	$8,439,578	$5,295,096	$57,169,531
9	$7,673,914	$9,197,195	$9,243,741	$18,440,935	$8,662,357	$5,127,236	$52,042,295
10	$7,904,131	$8,627,061	$9,813,875	$18,440,935	$8,881,509	$4,959,388	$47,082,907
11	$0	$8,021,763	$10,419,173	$18,440,935	$955,245	$503,211	$46,579,696
12	$0	$7,379,131	$11,061,805	$18,440,935	$921,266	$457,841	$46,121,854
13	$0	$6,696,863	$11,744,073	$18,440,935	$874,613	$410,053	$45,711,802
14	$0	$5,972,514	$12,468,421	$18,440,935	$814,408	$360,214	$45,351,588
15	$0	$5,203,489	$13,237,446	$18,440,935	$739,719	$308,659	$45,042,929
16	$0	$4,387,033	$14,053,903	$18,440,935	$649,557	$255,696	$44,787,233
17	$0	$3,520,219	$14,920,717	$18,440,935	$542,873	$201,604	$44,585,630
18	$0	$2,599,941	$15,840,994	$18,440,935	$418,553	$146,638	$44,438,992
19	$0	$1,622,904	$16,818,032	$18,440,935	$275,417	$91,029	$44,347,963
20	$0	$585,604	$17,855,332	$18,440,936	$112,210	$34,987	$44,312,976
21	$0	$0	$0	$0	$18,543,867	$5,454,779	$38,858,197
22	$0	$0	$0	$0	$18,733,977	$5,198,774	$33,659,423
23	$0	$0	$0	$0	$18,924,297	$4,954,329	$28,705,094
24	$0	$0	$0	$0	$19,114,752	$4,720,934	$23,984,160
25	$0	$0	$0	$0	$19,305,261	$4,498,099	$19,486,061
26	$0	$0	$0	$0	$19,495,741	$4,285,359	$15,200,702
27	$0	$0	$0	$0	$19,686,105	$4,082,267	$11,118,434
28	$0	$0	$0	$0	$19,876,263	$3,888,396	$7,230,038
29	$0	$0	$0	$0	$20,066,119	$3,703,338	$3,526,701
30	$0	$0	$0	$0	$20,255,574	$3,526,701	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	
1	$35,610,671	$3,028,929	$3,250,000	$23,179,885	$119,820,115	$0	$0
2	$36,144,831	$3,074,363	$3,347,500	$24,709,888	$95,110,227	$0	$0
3	$36,687,003	$3,120,479	$3,447,925	$26,309,325	$68,800,902	$0	$0
4	$37,237,308	$3,167,286	$3,551,363	$27,982,105	$40,818,797	$0	$0
5	$37,795,868	$3,214,795	$3,657,904	$29,732,371	$11,086,427	$0	$0
6	$38,362,806	$3,263,017	$3,767,641	$11,086,427	$0	$20,478,090	$6,962,550
7	$38,938,248	$3,311,962	$3,880,670	$0	$0	$33,483,202	$11,384,289
8	$39,522,322	$3,361,642	$3,997,090	$0	$0	$35,493,367	$12,067,745
9	$40,115,156	$3,412,066	$4,117,003	$0	$0	$37,600,252	$12,784,086
10	$40,716,884	$3,463,247	$4,240,513	$0	$0	$39,809,413	$13,535,200
11	$41,327,637	$3,515,196	$4,367,728	$0	$0	$41,327,637	$14,051,397
12	$41,947,552	$3,567,924	$4,498,760	$0	$0	$41,947,552	$14,262,168
13	$42,576,765	$3,621,443	$4,633,723	$0	$0	$42,576,765	$14,476,100
14	$43,215,416	$3,675,764	$4,772,735	$0	$0	$43,215,416	$14,693,242
15	$43,863,648	$3,730,901	$4,915,917	$0	$0	$43,863,648	$14,913,640
16	$44,521,602	$3,786,864	$5,063,394	$0	$0	$44,521,602	$15,137,345
17	$45,189,426	$3,843,667	$5,215,296	$0	$0	$45,189,426	$15,364,405
18	$45,867,268	$3,901,322	$5,371,755	$0	$0	$45,867,268	$15,594,871
19	$46,555,277	$3,959,842	$5,532,907	$0	$0	$46,555,277	$15,828,794
20	$47,253,606	$4,019,240	$5,698,895	$0	$0	$47,253,606	$16,066,226
21	$47,962,410	$4,079,528	$5,869,862	$0	$0	$47,962,410	$16,307,219
22	$48,681,846	$4,140,721	$6,045,957	$0	$0	$48,681,846	$16,551,828
23	$49,412,074	$4,202,832	$6,227,336	$0	$0	$49,412,074	$16,800,105
24	$50,153,255	$4,265,875	$6,414,156	$0	$0	$50,153,255	$17,052,107
25	$50,905,554	$4,329,863	$6,606,581	$0	$0	$50,905,554	$17,307,888
26	$51,669,137	$4,394,811	$6,804,778	$0	$0	$51,669,137	$17,567,507
27	$52,444,174	$4,460,733	$7,008,922	$0	$0	$52,444,174	$17,831,019
28	$53,230,837	$4,527,644	$7,219,189	$0	$0	$53,230,837	$18,098,484
29	$54,029,299	$4,595,559	$7,435,765	$0	$0	$54,029,299	$18,369,962
30	$54,839,739	$4,664,492	$7,658,838	$0	$0	$54,839,739	$18,645,511

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0					$143,000,000	$143,000,000
1	$3,028,929	$12,430,786	$16,145,891	$28,576,677	$3,783,993	$3,569,805	$139,430,195
2	$3,119,797	$11,434,943	$17,141,735	$28,576,677	$4,266,087	$3,796,803	$135,633,392
3	$3,213,391	$10,377,678	$18,198,999	$28,576,677	$4,755,313	$3,992,653	$131,640,740
4	$3,309,793	$9,255,203	$19,321,474	$28,576,677	$5,251,775	$4,159,898	$127,480,842
5	$3,409,087	$8,063,497	$20,513,180	$28,576,677	$5,755,578	$4,300,903	$123,179,939
6	$3,511,359	$6,798,289	$21,778,388	$28,576,677	$695,721	$490,456	$123,670,395
7	$3,616,700	$5,455,046	$23,121,631	$28,576,677	$4,598,650	$3,058,365	$126,728,760
8	$3,725,201	$4,028,954	$24,547,723	$28,576,677	$4,755,631	$2,983,742	$129,712,502
9	$3,836,957	$2,514,904	$26,061,773	$28,576,677	$4,937,719	$2,922,628	$132,635,130
10	$3,952,066	$907,471	$27,669,205	$28,576,677	$5,146,688	$2,873,884	$135,509,014
11	$0	$0	$0	$0	$19,393,316	$10,216,157	$125,292,857
12	$0	$0	$0	$0	$19,618,700	$9,749,893	$115,542,964
13	$0	$0	$0	$0	$19,845,499	$9,304,344	$106,238,619
14	$0	$0	$0	$0	$20,073,676	$8,878,606	$97,360,013
15	$0	$0	$0	$0	$20,303,190	$8,471,812	$88,888,201
16	$0	$0	$0	$0	$20,533,999	$8,083,132	$80,805,069
17	$0	$0	$0	$0	$20,766,058	$7,711,775	$73,093,294
18	$0	$0	$0	$0	$20,999,319	$7,356,981	$65,736,313
19	$0	$0	$0	$0	$21,233,733	$7,018,025	$58,718,288
20	$0	$0	$0	$0	$21,469,245	$6,694,212	$52,024,076
21	$0	$0	$0	$0	$21,705,801	$6,384,879	$45,639,197
22	$0	$0	$0	$0	$21,943,340	$6,089,389	$39,549,809
23	$0	$0	$0	$0	$22,181,800	$5,807,135	$33,742,674
24	$0	$0	$0	$0	$22,421,117	$5,537,535	$28,205,139
25	$0	$0	$0	$0	$22,661,222	$5,280,034	$22,925,105
26	$0	$0	$0	$0	$22,902,041	$5,034,098	$17,891,007
27	$0	$0	$0	$0	$23,143,500	$4,799,220	$13,091,787
28	$0	$0	$0	$0	$23,385,519	$4,574,912	$8,516,874
29	$0	$0	$0	$0	$23,628,014	$4,360,709	$4,156,165
30	$0	$0	$0	$0	$23,870,898	$4,156,165	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	
1	$32,898,010	$3,028,929	$3,250,000	$20,183,793	$122,816,207	$0	$0
2	$33,391,480	$3,074,363	$3,347,500	$21,030,474	$101,785,733	$0	$0
3	$33,892,352	$3,120,479	$3,447,925	$21,906,343	$79,879,389	$0	$0
4	$34,400,737	$3,167,286	$3,551,363	$22,812,854	$57,066,535	$0	$0
5	$34,916,748	$3,214,795	$3,657,904	$23,751,547	$33,314,988	$0	$0
6	$35,440,500	$3,263,017	$3,767,641	$24,724,049	$8,590,939	$0	$0
7	$35,972,107	$3,311,962	$3,880,670	$8,590,939	$0	$17,141,147	$5,827,990
8	$36,511,689	$3,361,642	$3,997,090	$0	$0	$26,777,482	$9,104,344
9	$37,059,364	$3,412,066	$4,117,003	$0	$0	$27,862,170	$9,473,138
10	$37,615,255	$3,463,247	$4,240,513	$0	$0	$28,988,194	$9,855,986
11	$38,179,483	$3,515,196	$4,367,728	$0	$0	$30,157,721	$10,253,625
12	$38,752,176	$3,567,924	$4,498,760	$0	$0	$31,373,045	$10,666,835
13	$39,333,458	$3,621,443	$4,633,723	$0	$0	$32,636,595	$11,096,442
14	$39,923,460	$3,675,764	$4,772,735	$0	$0	$33,950,946	$11,543,322
15	$40,522,312	$3,730,901	$4,915,917	$0	$0	$35,318,823	$12,008,400
16	$41,130,147	$3,786,864	$5,063,394	$0	$0	$36,743,114	$12,492,659
17	$41,747,099	$3,843,667	$5,215,296	$0	$0	$38,226,880	$12,997,139
18	$42,373,305	$3,901,322	$5,371,755	$0	$0	$39,773,364	$13,522,944
19	$43,008,905	$3,959,842	$5,532,907	$0	$0	$41,386,002	$14,071,241
20	$43,654,039	$4,019,240	$5,698,895	$0	$0	$43,068,435	$14,643,268
21	$44,308,849	$4,079,528	$5,869,862	$0	$0	$44,308,849	$15,065,009
22	$44,973,482	$4,140,721	$6,045,957	$0	$0	$44,973,482	$15,290,984
23	$45,648,084	$4,202,832	$6,227,336	$0	$0	$45,648,084	$15,520,349
24	$46,332,805	$4,265,875	$6,414,156	$0	$0	$46,332,805	$15,753,154
25	$47,027,798	$4,329,863	$6,606,581	$0	$0	$47,027,798	$15,989,451
26	$47,733,214	$4,394,811	$6,804,778	$0	$0	$47,733,215	$16,229,293
27	$48,449,213	$4,460,733	$7,008,922	$0	$0	$48,449,213	$16,472,732
28	$49,175,951	$4,527,644	$7,219,189	$0	$0	$49,175,951	$16,719,823
29	$49,913,590	$4,595,559	$7,435,765	$0	$0	$49,913,590	$16,970,621
30	$50,662,294	$4,664,492	$7,658,838	$0	$0	$50,662,294	$17,225,180
31	$51,422,228	$4,734,459	$7,888,603	$0	$0	$51,422,228	$17,483,558
32	$52,193,562	$4,805,476	$8,125,261	$0	$0	$52,193,562	$17,745,811
33	$52,976,465	$4,877,558	$8,369,019	$0	$0	$52,976,465	$18,011,998
34	$53,771,112	$4,950,722	$8,620,090	$0	$0	$53,771,112	$18,282,178
35	$54,577,679	$5,024,983	$8,878,692	$0	$0	$54,577,679	$18,556,411

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0					$143,000,000	$143,000,000
1	$3,028,929	$12,714,217	$5,726,718	$18,440,935	$11,207,074	$10,572,712	$132,427,288
2	$3,119,797	$12,361,006	$6,079,930	$18,440,935	$11,648,478	$10,367,104	$122,060,184
3	$3,213,391	$11,986,009	$6,454,927	$18,440,935	$12,096,404	$10,156,374	$111,903,810
4	$3,309,793	$11,587,883	$6,853,052	$18,440,935	$12,550,946	$9,941,525	$101,962,285
5	$3,409,087	$11,165,202	$7,275,734	$18,440,935	$13,012,201	$9,723,473	$92,238,811
6	$3,511,359	$10,716,450	$7,724,485	$18,440,935	$13,480,266	$9,503,055	$82,735,756
7	$3,616,700	$10,240,021	$8,200,914	$18,440,935	$8,127,249	$5,405,085	$77,330,671
8	$3,725,201	$9,734,207	$8,706,729	$18,440,935	$5,332,879	$3,345,914	$73,984,757
9	$3,836,957	$9,197,195	$9,243,741	$18,440,935	$5,453,179	$3,227,728	$70,757,029
10	$3,952,066	$8,627,061	$9,813,875	$18,440,935	$5,566,639	$3,108,382	$67,648,647
11	$0	$8,021,763	$10,419,173	$18,440,935	$1,601,999	$843,913	$66,804,734
12	$0	$7,379,131	$11,061,805	$18,440,935	$1,577,721	$784,079	$66,020,655
13	$0	$6,696,863	$11,744,073	$18,440,935	$1,540,915	$722,441	$65,298,214
14	$0	$5,972,514	$12,468,421	$18,440,935	$1,490,704	$659,340	$64,638,874
15	$0	$5,203,489	$13,237,446	$18,440,935	$1,426,159	$595,086	$64,043,788
16	$0	$4,387,033	$14,053,903	$18,440,935	$1,346,294	$529,964	$63,513,824
17	$0	$3,520,219	$14,920,717	$18,440,935	$1,250,061	$464,228	$63,049,596
18	$0	$2,599,941	$15,840,994	$18,440,935	$1,136,349	$398,113	$62,651,483
19	$0	$1,622,904	$16,818,032	$18,440,935	$1,003,979	$331,828	$62,319,655
20	$0	$585,604	$17,855,332	$18,440,936	$851,701	$265,564	$62,054,091
21	$0	$0	$0	$0	$19,294,450	$5,675,567	$56,378,524
22	$0	$0	$0	$0	$19,495,819	$5,410,189	$50,968,335
23	$0	$0	$0	$0	$19,697,567	$5,156,769	$45,811,565
24	$0	$0	$0	$0	$19,899,621	$4,914,779	$40,896,786
25	$0	$0	$0	$0	$20,101,903	$4,683,716	$36,213,070
26	$0	$0	$0	$0	$20,304,332	$4,463,096	$31,749,974
27	$0	$0	$0	$0	$20,506,826	$4,252,458	$27,497,516
28	$0	$0	$0	$0	$20,709,294	$4,051,362	$23,446,154
29	$0	$0	$0	$0	$20,911,646	$3,859,385	$19,586,768
30	$0	$0	$0	$0	$21,113,784	$3,676,124	$15,910,645
31	$0	$0	$0	$0	$21,315,608	$3,501,192	$12,409,453
32	$0	$0	$0	$0	$21,517,013	$3,334,220	$9,075,232
33	$0	$0	$0	$0	$21,717,890	$3,174,856	$5,900,376
34	$0	$0	$0	$0	$21,918,123	$3,022,762	$2,877,614
35	$0	$0	$0	$0	$22,117,593	$2,877,614	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	$0
1	$36,732,438	$3,028,929	$3,250,000	$24,018,221	$118,981,779	$0	$0
2	$37,283,424	$3,074,363	$3,445,000	$24,922,419	$94,059,361	$0	$0
3	$37,842,676	$3,120,479	$3,651,700	$25,856,667	$68,202,694	$0	$0
4	$38,410,316	$3,167,286	$3,870,802	$26,822,433	$41,380,261	$0	$0
5	$38,986,470	$3,214,795	$4,103,050	$27,821,269	$13,558,992	$0	$0
6	$39,571,267	$3,263,017	$4,349,233	$13,558,992	$0	$15,295,825	$5,200,580
7	$40,164,836	$3,311,962	$4,610,187	$0	$0	$29,924,815	$10,174,437
8	$40,767,309	$3,361,642	$4,886,798	$0	$0	$31,033,103	$10,551,255
9	$41,378,819	$3,412,066	$5,180,006	$0	$0	$32,181,624	$10,941,752
10	$41,999,501	$3,463,247	$5,490,807	$0	$0	$33,372,440	$11,346,630
11	$42,629,493	$3,515,196	$5,820,255	$0	$0	$34,607,731	$11,766,629
12	$43,268,936	$3,567,924	$6,169,470	$0	$0	$35,889,805	$12,202,534
13	$43,917,970	$3,621,443	$6,539,639	$0	$0	$37,221,107	$12,655,176
14	$44,576,739	$3,675,764	$6,932,017	$0	$0	$38,604,225	$13,125,437
15	$45,245,391	$3,730,901	$7,347,938	$0	$0	$40,041,901	$13,614,246
16	$45,924,071	$3,786,864	$7,788,814	$0	$0	$41,537,039	$14,122,593
17	$46,612,932	$3,843,667	$8,256,143	$0	$0	$43,092,714	$14,651,523
18	$47,312,126	$3,901,322	$8,751,512	$0	$0	$44,712,185	$15,202,143
19	$48,021,808	$3,959,842	$9,276,602	$0	$0	$46,398,905	$15,775,628
20	$48,742,135	$4,019,240	$9,833,198	$0	$0	$48,156,531	$16,373,221
21	$49,473,268	$4,079,528	$10,423,190	$0	$0	$49,473,268	$16,820,911
22	$50,215,367	$4,140,721	$11,048,582	$0	$0	$50,215,367	$17,073,225
23	$50,968,597	$4,202,832	$11,711,497	$0	$0	$50,968,597	$17,329,323
24	$51,733,126	$4,265,875	$12,414,186	$0	$0	$51,733,126	$17,589,263
25	$52,509,123	$4,329,863	$13,159,038	$0	$0	$52,509,123	$17,853,102
26	$53,296,760	$4,394,811	$13,948,580	$0	$0	$53,296,760	$18,120,898
27	$54,096,211	$4,460,733	$14,785,495	$0	$0	$54,096,211	$18,392,712
28	$54,907,654	$4,527,644	$15,672,624	$0	$0	$54,907,654	$18,668,602
29	$55,731,269	$4,595,559	$16,612,982	$0	$0	$55,731,269	$18,948,631
30	$56,567,238	$4,664,492	$17,609,761	$0	$0	$56,567,238	$19,232,861

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0		$143,000,000	$143,000,000
1	$3,028,929	$12,714,217	$5,726,718	$18,440,935	$15,041,502	$14,190,096	$128,809,904
2	$3,210,665	$12,361,006	$6,079,930	$18,440,935	$15,533,791	$13,825,018	$114,984,885
3	$3,403,305	$11,986,009	$6,454,927	$18,440,935	$16,032,866	$13,461,504	$101,523,382
4	$3,607,503	$11,587,883	$6,853,052	$18,440,935	$16,538,796	$13,100,275	$88,423,106
5	$3,823,953	$11,165,202	$7,275,734	$18,440,935	$17,051,643	$12,741,980	$75,681,127
6	$4,053,391	$10,716,450	$7,724,485	$18,440,935	$12,370,892	$8,720,991	$66,960,136
7	$4,296,594	$10,240,021	$8,200,914	$18,440,935	$7,923,908	$5,269,852	$61,690,284
8	$4,554,390	$9,734,207	$8,706,729	$18,440,935	$8,081,068	$5,070,162	$56,620,122
9	$4,827,653	$9,197,195	$9,243,741	$18,440,935	$8,231,711	$4,872,337	$51,747,785
10	$5,117,312	$8,627,061	$9,813,875	$18,440,935	$8,375,194	$4,676,665	$47,071,120
11	$0	$8,021,763	$10,419,173	$18,440,935	$3,086,478	$1,625,918	$45,445,202
12	$0	$7,379,131	$11,061,805	$18,440,935	$2,888,072	$1,435,284	$44,009,918
13	$0	$6,696,863	$11,744,073	$18,440,935	$2,660,777	$1,247,476	$42,762,442
14	$0	$5,972,514	$12,468,421	$18,440,935	$2,402,586	$1,062,666	$41,699,776
15	$0	$5,203,489	$13,237,446	$18,440,935	$2,111,370	$881,001	$40,818,775
16	$0	$4,387,033	$14,053,903	$18,440,935	$1,784,864	$702,605	$40,116,170
17	$0	$3,520,219	$14,920,717	$18,440,935	$1,420,664	$527,584	$39,588,586
18	$0	$2,599,941	$15,840,994	$18,440,935	$1,016,214	$356,024	$39,232,562
19	$0	$1,622,904	$16,818,032	$18,440,935	$568,801	$187,996	$39,044,565
20	$0	$585,604	$17,855,332	$18,440,936	$75,541	$23,554	$39,021,011
21	$0	$0	$0	$0	$18,149,638	$5,338,814	$33,682,197
22	$0	$0	$0	$0	$17,952,839	$4,982,004	$28,700,193
23	$0	$0	$0	$0	$17,724,945	$4,640,342	$24,059,851
24	$0	$0	$0	$0	$17,463,802	$4,313,184	$19,746,667
25	$0	$0	$0	$0	$17,167,121	$3,999,916	$15,746,751
26	$0	$0	$0	$0	$16,832,471	$3,699,946	$12,046,805
27	$0	$0	$0	$0	$16,457,272	$3,412,711	$8,634,094
28	$0	$0	$0	$0	$16,038,784	$3,137,670	$5,496,425
29	$0	$0	$0	$0	$15,574,097	$2,874,305	$2,622,120
30	$0	$0	$0	$0	$15,060,125	$2,622,120	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$0	$0	$0		$0	$0	$0
1	$35,706,350	$3,028,929	$3,250,000	$0	$0	$14,515,988	$4,935,436
2	$36,241,945	$3,074,363	$3,347,500	$0	$0	$15,640,269	$5,317,691
3	$36,785,574	$3,120,479	$3,447,925	$0	$0	$16,808,893	$5,715,024
4	$37,337,358	$3,167,286	$3,551,363	$0	$0	$18,024,219	$6,128,235
5	$37,897,418	$3,214,795	$3,657,904	$0	$0	$19,288,749	$6,558,174
6	$38,465,879	$3,263,017	$3,767,641	$0	$0	$20,605,129	$7,005,744
7	$39,042,867	$3,311,962	$3,880,670	$0	$0	$21,976,166	$7,471,896
8	$39,628,511	$3,361,642	$3,997,090	$0	$0	$23,404,833	$7,957,643
9	$40,222,938	$3,412,066	$4,117,003	$0	$0	$24,894,281	$8,464,055
10	$40,826,282	$3,463,247	$4,240,513	$0	$0	$26,447,847	$8,992,268
11	$41,438,676	$3,515,196	$4,367,728	$0	$0	$28,069,072	$9,543,485
12	$42,060,257	$3,567,924	$4,498,760	$0	$0	$29,761,705	$10,118,980
13	$42,691,160	$3,621,443	$4,633,723	$0	$0	$31,529,722	$10,720,106
14	$43,331,528	$3,675,764	$4,772,735	$0	$0	$33,377,338	$11,348,295
15	$43,981,501	$3,730,901	$4,915,917	$0	$0	$35,309,019	$12,005,066
16	$44,641,223	$3,786,864	$5,063,394	$0	$0	$37,329,502	$12,692,031
17	$45,310,842	$3,843,667	$5,215,296	$0	$0	$39,443,811	$13,410,896
18	$45,990,504	$3,901,322	$5,371,755	$0	$0	$41,657,269	$14,163,471
19	$46,680,362	$3,959,842	$5,532,907	$0	$0	$43,975,523	$14,951,678
20	$47,380,567	$4,019,240	$5,698,895	$0	$0	$46,404,560	$15,777,551
21	$48,091,276	$4,079,528	$5,869,862	$0	$0	$48,091,276	$16,351,034
22	$48,812,645	$4,140,721	$6,045,957	$0	$0	$48,812,645	$16,596,299
23	$49,544,835	$4,202,832	$6,227,336	$0	$0	$49,544,835	$16,845,244
24	$50,288,007	$4,265,875	$6,414,156	$0	$0	$50,288,007	$17,097,922
25	$51,042,327	$4,329,863	$6,606,581	$0	$0	$51,042,327	$17,354,391
26	$51,807,962	$4,394,811	$6,804,778	$0	$0	$51,807,962	$17,614,707
27	$52,585,082	$4,460,733	$7,008,922	$0	$0	$52,585,082	$17,878,928
28	$53,373,858	$4,527,644	$7,219,189	$0	$0	$53,373,858	$18,147,112
29	$54,174,466	$4,595,559	$7,435,765	$0	$0	$54,174,466	$18,419,318
30	$54,987,083	$4,664,492	$7,658,838	$0	$0	$54,987,083	$18,695,608

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0		$0	$0
1	$3,028,929	$21,190,362	$9,544,531	$30,734,892	$3,213,979	$3,032,055	$3,032,055
2	$3,119,797	$20,601,676	$10,133,216	$30,734,892	$3,112,705	$2,770,296	$5,802,352
3	$3,213,391	$19,976,681	$10,758,211	$30,734,892	$3,019,354	$2,535,108	$8,337,460
4	$3,309,793	$19,313,138	$11,421,754	$30,734,892	$2,934,625	$2,324,498	$10,661,958
5	$3,409,087	$18,608,670	$12,126,223	$30,734,892	$2,859,261	$2,136,606	$12,798,564
6	$3,511,359	$17,860,751	$12,874,142	$30,734,892	$2,794,055	$1,969,699	$14,768,263
7	$3,616,700	$17,066,702	$13,668,191	$30,734,892	$2,739,854	$1,822,159	$16,590,422
8	$3,725,201	$16,223,678	$14,511,215	$30,734,892	$2,697,556	$1,692,480	$18,282,902
9	$3,836,957	$15,328,658	$15,406,235	$30,734,892	$2,668,122	$1,579,257	$19,862,159
10	$3,952,066	$14,378,435	$16,356,458	$30,734,892	$2,652,573	$1,481,183	$21,343,342
11	$0	$13,369,604	$17,365,288	$30,734,892	$6,722,625	$3,541,395	$24,884,737
12	$0	$12,298,551	$18,436,341	$30,734,892	$6,860,300	$3,409,359	$28,294,095
13	$0	$11,161,438	$19,573,454	$30,734,892	$7,019,003	$3,290,783	$31,584,878
14	$0	$9,954,190	$20,780,702	$30,734,892	$7,200,158	$3,184,637	$34,769,515
15	$0	$8,672,482	$22,062,410	$30,734,892	$7,405,275	$3,089,963	$37,859,478
16	$0	$7,311,721	$23,423,171	$30,734,892	$7,635,958	$3,005,867	$40,865,344
17	$0	$5,867,031	$24,867,861	$30,734,892	$7,893,910	$2,931,517	$43,796,861
18	$0	$4,333,236	$26,401,657	$30,734,892	$8,180,937	$2,866,140	$46,663,002
19	$0	$2,704,839	$28,030,053	$30,734,892	$8,498,958	$2,809,016	$49,472,018
20	$0	$976,007	$29,758,887	$30,734,894	$8,850,012	$2,759,476	$52,231,493
21	$0	$0	$0	$0	$21,790,852	$6,409,897	$45,821,597
22	$0	$0	$0	$0	$22,029,667	$6,113,345	$39,708,252
23	$0	$0	$0	$0	$22,269,423	$5,830,074	$33,878,178
24	$0	$0	$0	$0	$22,510,054	$5,559,500	$28,318,678
25	$0	$0	$0	$0	$22,751,492	$5,301,067	$23,017,611
26	$0	$0	$0	$0	$22,993,666	$5,054,238	$17,963,373
27	$0	$0	$0	$0	$23,236,499	$4,818,505	$13,144,867
28	$0	$0	$0	$0	$23,479,913	$4,593,379	$8,551,489
29	$0	$0	$0	$0	$23,723,824	$4,378,392	$4,173,097
30	$0	$0	$0	$0	$23,968,145	$4,173,097	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	$0
1	$36,468,709	$3,028,929	$3,250,000	$19,472,555	$123,527,445	$0	$0
2	$37,015,739	$3,074,363	$3,347,500	$20,395,890	$103,131,554	$0	$0
3	$37,570,975	$3,120,479	$3,447,925	$21,358,664	$81,772,890	$0	$0
4	$38,134,540	$3,167,286	$3,551,363	$22,363,591	$59,409,299	$0	$0
5	$38,706,558	$3,214,795	$3,657,904	$23,413,605	$35,995,693	$0	$0
6	$39,287,156	$3,263,017	$3,767,641	$24,511,873	$11,483,821	$0	$0
7	$39,876,464	$3,311,962	$3,880,670	$11,483,821	$0	$14,177,995	$4,820,518
8	$40,474,611	$3,361,642	$3,997,090	$0	$0	$26,867,130	$9,134,824
9	$41,081,730	$3,412,066	$4,117,003	$0	$0	$28,131,812	$9,564,816
10	$41,697,956	$3,463,247	$4,240,513	$0	$0	$29,460,178	$10,016,460
11	$42,323,425	$3,515,196	$4,367,728	$0	$0	$30,856,894	$10,491,344
12	$42,958,277	$3,567,924	$4,498,760	$0	$0	$32,327,006	$10,991,182
13	$43,602,651	$3,621,443	$4,633,723	$0	$0	$33,875,967	$11,517,829
14	$44,256,691	$3,675,764	$4,772,735	$0	$0	$35,509,673	$12,073,289
15	$44,920,541	$3,730,901	$4,915,917	$0	$0	$37,234,502	$12,659,731
16	$45,594,349	$3,786,864	$5,063,394	$0	$0	$39,057,349	$13,279,499
17	$46,278,264	$3,843,667	$5,215,296	$0	$0	$40,985,674	$13,935,129
18	$46,972,438	$3,901,322	$5,371,755	$0	$0	$43,027,542	$14,629,364
19	$47,677,025	$3,959,842	$5,532,907	$0	$0	$45,191,680	$15,365,171
20	$48,392,180	$4,019,240	$5,698,895	$0	$0	$47,487,530	$16,145,760
21	$49,118,063	$4,079,528	$5,869,862	$0	$0	$49,118,063	$16,700,141
22	$49,854,834	$4,140,721	$6,045,957	$0	$0	$49,854,834	$16,950,643
23	$50,602,656	$4,202,832	$6,227,336	$0	$0	$50,602,656	$17,204,903
24	$51,361,696	$4,265,875	$6,414,156	$0	$0	$51,361,696	$17,462,977
25	$52,132,122	$4,329,863	$6,606,581	$0	$0	$52,132,122	$17,724,921
26	$52,914,103	$4,394,811	$6,804,778	$0	$0	$52,914,103	$17,990,795
27	$53,707,815	$4,460,733	$7,008,922	$0	$0	$53,707,815	$18,260,657
28	$54,513,432	$4,527,644	$7,219,189	$0	$0	$54,513,432	$18,534,567
29	$55,331,134	$4,595,559	$7,435,765	$0	$0	$55,331,134	$18,812,585
30	$56,161,101	$4,664,492	$7,658,838	$0	$0	$56,161,101	$19,094,774

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0		$143,000,000	$143,000,000
1	$3,028,929	$16,996,153	$4,533,814	$21,529,967	$11,688,741	$11,027,114	$131,972,886
2	$3,119,797	$16,619,849	$4,910,119	$21,529,967	$12,183,706	$10,843,455	$121,129,431
3	$3,213,391	$16,212,311	$5,317,656	$21,529,967	$12,685,995	$10,651,406	$110,478,024
4	$3,309,793	$15,770,949	$5,759,019	$21,529,967	$13,195,717	$10,452,244	$100,025,781
5	$3,409,087	$15,292,953	$6,237,015	$21,529,967	$13,712,979	$10,247,135	$89,778,645
6	$3,511,359	$14,775,284	$6,754,684	$21,529,967	$14,237,890	$10,037,151	$79,741,494
7	$3,616,700	$14,214,648	$7,315,319	$21,529,967	$9,950,046	$6,617,349	$73,124,146
8	$3,725,201	$13,607,480	$7,922,487	$21,529,967	$6,176,288	$3,875,080	$69,249,066
9	$3,836,957	$12,949,918	$8,580,049	$21,529,967	$6,294,834	$3,725,903	$65,523,163
10	$3,952,066	$12,237,778	$9,292,189	$21,529,967	$6,399,833	$3,573,634	$61,949,530
11	$0	$11,466,531	$10,063,436	$21,529,967	$2,419,190	$1,274,399	$60,675,131
12	$0	$10,631,271	$10,898,697	$21,529,967	$2,370,443	$1,178,038	$59,497,093
13	$0	$9,726,684	$11,803,283	$21,529,967	$2,299,689	$1,078,184	$58,418,909
14	$0	$8,747,017	$12,782,950	$21,529,967	$2,204,935	$975,245	$57,443,664
15	$0	$7,686,039	$13,843,928	$21,529,967	$2,084,025	$869,591	$56,574,073
16	$0	$6,537,000	$14,992,968	$21,529,967	$1,934,624	$761,558	$55,812,516
17	$0	$5,292,591	$16,237,377	$21,529,967	$1,754,205	$651,449	$55,161,067
18	$0	$3,944,897	$17,585,071	$21,529,967	$1,540,029	$539,540	$54,621,527
19	$0	$2,485,344	$19,044,623	$21,529,967	$1,289,136	$426,076	$54,195,450
20	$0	$904,650	$20,625,316	$21,529,966	$998,319	$311,281	$53,884,170
21	$0	$0	$0	$0	$22,468,531	$6,609,240	$47,274,930
22	$0	$0	$0	$0	$22,717,512	$6,304,225	$40,970,705
23	$0	$0	$0	$0	$22,967,585	$6,012,851	$34,957,854
24	$0	$0	$0	$0	$23,218,689	$5,734,518	$29,223,336
25	$0	$0	$0	$0	$23,470,757	$5,468,654	$23,754,682
26	$0	$0	$0	$0	$23,723,719	$5,214,711	$18,539,970
27	$0	$0	$0	$0	$23,977,503	$4,972,166	$13,567,805
28	$0	$0	$0	$0	$24,232,032	$4,740,516	$8,827,289
29	$0	$0	$0	$0	$24,487,225	$4,519,282	$4,308,006
30	$0	$0	$0	$0	$24,742,997	$4,308,006	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	$0
1	$29,686,531	$3,028,929	$3,250,000	$16,972,314	$126,027,686	$0	$0
2	$30,131,829	$3,074,363	$3,347,500	$17,770,824	$108,256,862	$0	$0
3	$30,583,807	$3,120,479	$3,447,925	$18,597,798	$89,659,064	$0	$0
4	$31,042,564	$3,167,286	$3,551,363	$19,454,681	$70,204,383	$0	$0
5	$31,508,202	$3,214,795	$3,657,904	$20,343,001	$49,861,383	$0	$0
6	$31,980,825	$3,263,017	$3,767,641	$21,264,375	$28,597,008	$0	$0
7	$32,460,538	$3,311,962	$3,880,670	$22,220,517	$6,376,491	$0	$0
8	$32,947,446	$3,361,642	$3,997,090	$23,213,239	$16,836,748	$0	$0
9	$33,441,657	$3,412,066	$4,117,003	$0	$16,836,748	$24,244,463	$8,243,117
10	$33,943,282	$3,463,247	$4,240,513	$0	$16,836,748	$25,316,221	$8,607,515
11	$34,452,431	$3,515,196	$4,367,728	$0	$16,836,748	$26,430,669	$8,986,427
12	$34,969,218	$3,567,924	$4,498,760	$0	$16,836,748	$27,590,087	$9,380,630
13	$35,493,756	$3,621,443	$4,633,723	$0	$16,836,748	$28,796,893	$9,790,944
14	$36,026,163	$3,675,764	$4,772,735	$0	$16,836,748	$30,053,648	$10,218,240
15	$36,566,555	$3,730,901	$4,915,917	$0	$16,836,748	$31,363,066	$10,663,442
16	$37,115,053	$3,786,864	$5,063,394	$0	$16,836,748	$32,728,021	$11,127,527
17	$37,671,779	$3,843,667	$5,215,296	$0	$16,836,748	$34,151,561	$11,611,531
18	$38,236,856	$3,901,322	$5,371,755	$0	$16,836,748	$35,636,914	$12,116,551
19	$38,810,409	$3,959,842	$5,532,907	$0	$16,836,748	$37,187,505	$12,643,752
20	$39,392,565	$4,019,240	$5,698,895	$0	$16,836,748	$38,806,961	$13,194,367
21	$39,983,453	$4,079,528	$5,869,862	$0	$16,836,748	$39,983,453	$13,594,374
22	$40,583,205	$4,140,721	$6,045,957	$0	$16,836,748	$40,583,205	$13,798,290
23	$41,191,953	$4,202,832	$6,227,336	$0	$16,836,748	$41,191,953	$14,005,264
24	$41,809,832	$4,265,875	$6,414,156	$0	$16,836,748	$41,809,832	$14,215,343
25	$42,436,980	$4,329,863	$6,606,581	$0	$16,836,748	$42,436,980	$14,428,573
26	$43,073,535	$4,394,811	$6,804,778	$0	$16,836,748	$43,073,535	$14,645,002
27	$43,719,638	$4,460,733	$7,008,922	$0	$16,836,748	$43,719,638	$14,864,677
28	$44,375,432	$4,527,644	$7,219,189	$0	$16,836,748	$44,375,432	$15,087,647
29	$45,041,064	$4,595,559	$7,435,765	$0	$16,836,748	$45,041,064	$15,313,962
30	$45,716,680	$4,664,492	$7,658,838	$0	$16,836,748	$45,716,680	$15,543,671

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0		$143,000,000	$143,000,000
1	$3,028,929	$12,714,217	$5,726,718	$18,440,935	$7,995,596	$7,762,714	$135,237,286
2	$3,119,797	$12,361,006	$6,079,930	$18,440,935	$8,388,828	$7,907,275	$127,330,011
3	$3,213,391	$11,986,009	$6,454,927	$18,440,935	$8,787,859	$8,042,136	$119,287,875
4	$3,309,793	$11,587,883	$6,853,052	$18,440,935	$9,192,773	$8,167,659	$111,120,216
5	$3,409,087	$11,165,202	$7,275,734	$18,440,935	$9,603,655	$8,284,197	$102,836,019
6	$3,511,359	$10,716,450	$7,724,485	$18,440,935	$10,020,591	$8,392,087	$94,443,932
7	$3,616,700	$10,240,021	$8,200,914	$18,440,935	$10,443,670	$8,491,659	$85,952,273
8	$3,725,201	$9,734,207	$8,706,729	$18,440,935	$10,872,979	$8,583,230	$77,369,042
9	$3,836,957	$9,197,195	$9,243,741	$18,440,935	$3,065,492	$2,349,445	$75,019,598
10	$3,952,066	$8,627,061	$9,813,875	$18,440,935	$3,143,137	$2,338,789	$72,680,808
11	$0	$8,021,763	$10,419,173	$18,440,935	$857,856	$619,733	$73,300,542
12	$0	$7,379,131	$11,061,805	$18,440,935	$919,031	$644,590	$73,945,132
13	$0	$6,696,863	$11,744,073	$18,440,935	$993,289	$676,381	$74,621,513
14	$0	$5,972,514	$12,468,421	$18,440,935	$1,081,512	$715,007	$75,336,520
15	$0	$5,203,489	$13,237,446	$18,440,935	$1,184,640	$760,376	$76,096,895
16	$0	$4,387,033	$14,053,903	$18,440,935	$1,303,668	$812,403	$76,909,298
17	$0	$3,520,219	$14,920,717	$18,440,935	$1,439,650	$871,012	$77,780,310
18	$0	$2,599,941	$15,840,994	$18,440,935	$1,593,708	$936,135	$78,716,445
19	$0	$1,622,904	$16,818,032	$18,440,935	$1,767,028	$1,007,712	$79,724,157
20	$0	$585,604	$17,855,332	$18,440,936	$1,960,872	$1,085,687	$80,809,844
21	$0	$0	$0	$0	$16,439,689	$8,837,143	$71,972,701
22	$0	$0	$0	$0	$16,598,237	$8,662,495	$63,310,206
23	$0	$0	$0	$0	$16,756,521	$8,490,391	$54,819,815
24	$0	$0	$0	$0	$16,914,459	$8,320,793	$46,499,023
25	$0	$0	$0	$0	$17,071,963	$8,153,665	$38,345,358
26	$0	$0	$0	$0	$17,228,944	$7,988,970	$30,356,387
27	$0	$0	$0	$0	$17,385,306	$7,826,675	$22,529,713
28	$0	$0	$0	$0	$17,540,952	$7,666,742	$14,862,971
29	$0	$0	$0	$0	$17,695,778	$7,509,139	$7,353,831
30	$0	$0	$0	$0	$17,849,679	$7,353,831	$0

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Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	$0
1	$29,976,122	$3,028,929	$3,250,000	$17,261,905	$125,738,095	$0	$0
2	$30,425,763	$3,074,363	$3,347,500	$18,064,758	$107,673,337	$0	$0
3	$30,882,150	$3,120,479	$3,447,925	$18,896,141	$88,777,196	$0	$0
4	$31,345,382	$3,167,286	$3,551,363	$19,757,499	$69,019,697	$0	$0
5	$31,815,563	$3,214,795	$3,657,904	$20,650,361	$48,369,336	$0	$0
6	$32,292,796	$3,263,017	$3,767,641	$21,576,346	$26,792,990	$0	$0
7	$32,777,188	$3,311,962	$3,880,670	$22,537,167	$4,255,823	$0	$0
8	$33,268,846	$3,361,642	$3,997,090	$23,534,639	$19,278,817	$0	$0
9	$33,767,879	$3,412,066	$4,117,003	$0	$19,278,817	$24,570,684	$4,177,016
10	$34,274,397	$3,463,247	$4,240,513	$0	$19,278,817	$25,647,336	$4,360,047
11	$34,788,513	$3,515,196	$4,367,728	$0	$19,278,817	$26,766,750	$4,550,348
12	$35,310,341	$3,567,924	$4,498,760	$0	$19,278,817	$27,931,210	$4,748,306
13	$35,839,996	$3,621,443	$4,633,723	$0	$19,278,817	$29,143,133	$4,954,333
14	$36,377,596	$3,675,764	$4,772,735	$0	$19,278,817	$30,405,082	$5,168,864
15	$36,923,260	$3,730,901	$4,915,917	$0	$19,278,817	$31,719,770	$5,392,361
16	$37,477,108	$3,786,864	$5,063,394	$0	$19,278,817	$33,090,076	$5,625,313
17	$38,039,265	$3,843,667	$5,215,296	$0	$19,278,817	$34,519,047	$5,868,238
18	$38,609,854	$3,901,322	$5,371,755	$0	$19,278,817	$36,009,913	$6,121,685
19	$39,189,002	$3,959,842	$5,532,907	$0	$19,278,817	$37,566,098	$6,386,237
20	$39,776,837	$4,019,240	$5,698,895	$0	$19,278,817	$39,191,233	$6,662,510
21	$40,373,489	$4,079,528	$5,869,862	$0	$19,278,817	$40,373,490	$6,863,493
22	$40,979,092	$4,140,721	$6,045,957	$0	$19,278,817	$40,979,092	$6,966,446
23	$41,593,778	$4,202,832	$6,227,336	$0	$19,278,817	$41,593,778	$7,070,942
24	$42,217,685	$4,265,875	$6,414,156	$0	$19,278,817	$42,217,685	$7,177,006
25	$42,850,950	$4,329,863	$6,606,581	$0	$19,278,817	$42,850,950	$7,284,662
26	$43,493,714	$4,394,811	$6,804,778	$0	$19,278,817	$43,493,714	$7,393,931
27	$44,146,120	$4,460,733	$7,008,922	$0	$19,278,817	$44,146,120	$7,504,840
28	$44,808,312	$4,527,644	$7,219,189	$0	$19,278,817	$44,808,312	$7,617,413
29	$45,480,437	$4,595,559	$7,435,765	$0	$19,278,817	$45,480,437	$7,731,674
30	$46,162,643	$4,664,492	$7,658,838	$0	$19,278,817	$46,162,643	$7,847,649

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0		$143,000,000	$143,000,000
1	$3,028,929	$12,714,217	$5,726,718	$18,440,935	$8,285,186	$7,816,213	$135,183,787
2	$3,119,797	$12,361,006	$6,079,930	$18,440,935	$8,682,762	$7,727,627	$127,456,159
3	$3,213,391	$11,986,009	$6,454,927	$18,440,935	$9,086,202	$7,628,950	$119,827,209
4	$3,309,793	$11,587,883	$6,853,052	$18,440,935	$9,495,591	$7,521,397	$112,305,812
5	$3,409,087	$11,165,202	$7,275,734	$18,440,935	$9,911,015	$7,406,087	$104,899,725
6	$3,511,359	$10,716,450	$7,724,485	$18,440,935	$10,332,562	$7,284,049	$97,615,676
7	$3,616,700	$10,240,021	$8,200,914	$18,440,935	$10,760,320	$7,156,228	$90,459,448
8	$3,725,201	$9,734,207	$8,706,729	$18,440,935	$11,194,380	$7,023,492	$83,435,956
9	$3,836,957	$9,197,195	$9,243,741	$18,440,935	$7,457,815	$4,414,269	$79,021,687
10	$3,952,066	$8,627,061	$9,813,875	$18,440,935	$7,721,720	$4,311,768	$74,709,919
11	$0	$8,021,763	$10,419,173	$18,440,935	$3,914,306	$2,062,007	$72,647,911
12	$0	$7,379,131	$11,061,805	$18,440,935	$4,054,415	$2,014,920	$70,632,991
13	$0	$6,696,863	$11,744,073	$18,440,935	$4,189,562	$1,964,230	$68,668,761
14	$0	$5,972,514	$12,468,421	$18,440,935	$4,319,297	$1,910,429	$66,758,332
15	$0	$5,203,489	$13,237,446	$18,440,935	$4,443,146	$1,853,969	$64,904,362
16	$0	$4,387,033	$14,053,903	$18,440,935	$4,560,602	$1,795,264	$63,109,098
17	$0	$3,520,219	$14,920,717	$18,440,935	$4,671,128	$1,734,691	$61,374,407
18	$0	$2,599,941	$15,840,994	$18,440,935	$4,774,156	$1,672,596	$59,701,811
19	$0	$1,622,904	$16,818,032	$18,440,935	$4,869,080	$1,609,294	$58,092,517
20	$0	$585,604	$17,855,332	$18,440,936	$4,955,257	$1,545,073	$56,547,444
21	$0	$0	$0	$0	$23,560,606	$6,930,480	$49,616,965
22	$0	$0	$0	$0	$23,825,967	$6,611,827	$43,005,137
23	$0	$0	$0	$0	$24,092,668	$6,307,394	$36,697,743
24	$0	$0	$0	$0	$24,360,648	$6,016,557	$30,681,186
25	$0	$0	$0	$0	$24,629,845	$5,738,720	$24,942,466
26	$0	$0	$0	$0	$24,900,194	$5,473,312	$19,469,153
27	$0	$0	$0	$0	$25,171,625	$5,219,788	$14,249,365
28	$0	$0	$0	$0	$25,444,066	$4,977,626	$9,271,739
29	$0	$0	$0	$0	$25,717,439	$4,746,327	$4,525,412
30	$0	$0	$0	$0	$25,991,664	$4,525,412	$0

Case 11

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$71,500,000	$0	$0		$71,500,000	$0	$0
1	$16,280,719	$3,028,929	$1,625,000	$9,923,611	$61,576,389	$0	$0
2	$16,524,930	$3,074,363	$1,673,750	$10,344,427	$51,231,962	$0	$0
3	$16,772,804	$3,120,479	$1,723,963	$10,779,800	$40,452,162	$0	$0
4	$17,024,396	$3,167,286	$1,775,681	$11,230,455	$29,221,708	$0	$0
5	$17,279,762	$3,214,795	$1,828,952	$11,697,161	$17,524,547	$0	$0
6	$17,538,958	$3,263,017	$1,883,820	$12,180,733	$5,343,814	$0	$0
7	$17,802,043	$3,311,962	$1,940,335	$5,343,814	$0	$7,338,219	$1,467,644
8	$18,069,073	$3,361,642	$1,998,545	$0	$0	$13,201,970	$2,640,394
9	$18,340,110	$3,412,066	$2,058,501	$0	$0	$13,741,512	$2,748,302
10	$18,615,211	$3,463,247	$2,120,256	$0	$0	$14,301,681	$2,860,336
11	$18,894,439	$3,515,196	$2,183,864	$0	$0	$14,883,558	$2,976,712
12	$19,177,856	$3,567,924	$2,249,380	$0	$0	$15,488,291	$3,097,658
13	$19,465,524	$3,621,443	$2,316,861	$0	$0	$16,117,092	$3,223,418
14	$19,757,507	$3,675,764	$2,386,367	$0	$0	$16,771,250	$3,354,250
15	$20,053,869	$3,730,901	$2,457,958	$0	$0	$17,452,125	$3,490,425
16	$20,354,677	$3,786,864	$2,531,697	$0	$0	$18,161,161	$3,632,232
17	$20,659,997	$3,843,667	$2,607,648	$0	$0	$18,899,888	$3,779,978
18	$20,969,897	$3,901,322	$2,685,877	$0	$0	$19,669,927	$3,933,985
19	$21,284,446	$3,959,842	$2,766,454	$0	$0	$20,472,994	$4,094,599
20	$21,603,713	$4,019,240	$2,849,447	$0	$0	$21,310,910	$4,262,182
21	$21,927,768	$4,079,528	$2,934,931	$0	$0	$21,927,768	$4,385,554
22	$22,256,685	$4,140,721	$3,022,979	$0	$0	$22,256,685	$4,451,337
23	$22,590,535	$4,202,832	$3,113,668	$0	$0	$22,590,535	$4,518,107
24	$22,929,393	$4,265,875	$3,207,078	$0	$0	$22,929,393	$4,585,879
25	$23,273,334	$4,329,863	$3,303,290	$0	$0	$23,273,334	$4,654,667
26	$23,622,434	$4,394,811	$3,402,389	$0	$0	$23,622,434	$4,724,487
27	$23,976,770	$4,460,733	$3,504,461	$0	$0	$23,976,770	$4,795,354
28	$24,336,422	$4,527,644	$3,609,595	$0	$0	$24,336,422	$4,867,284
29	$24,701,468	$4,595,559	$3,717,882	$0	$0	$24,701,468	$4,940,294
30	$25,071,990	$4,664,492	$3,829,419	$0	$0	$25,071,990	$5,014,398

Year	Tax Credit	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue
0	$0	$0	$0	$0		$71,500,000	$71,500,000
1	$3,028,929	$6,357,108	$2,863,359	$9,220,468	$5,435,252	$5,127,596	$66,372,404
2	$3,119,797	$6,180,503	$3,039,965	$9,220,468	$5,676,146	$5,051,750	$61,320,654
3	$3,213,391	$5,993,004	$3,227,463	$9,220,468	$5,921,286	$4,971,626	$56,349,028
4	$3,309,793	$5,793,941	$3,426,526	$9,220,468	$6,170,754	$4,887,815	$51,461,213
5	$3,409,087	$5,582,601	$3,637,867	$9,220,468	$6,424,634	$4,800,860	$46,660,353
6	$3,511,359	$5,358,225	$3,862,243	$9,220,468	$6,683,012	$4,711,260	$41,949,093
7	$3,616,700	$5,120,011	$4,100,457	$9,220,468	$5,478,334	$3,643,405	$38,305,688
8	$3,725,201	$4,867,103	$4,353,364	$9,220,468	$4,573,226	$2,869,298	$35,436,390
9	$3,836,957	$4,598,597	$4,621,870	$9,220,468	$4,737,729	$2,804,254	$32,632,135
10	$3,952,066	$4,313,530	$4,906,937	$9,220,468	$4,902,969	$2,737,792	$29,894,343
11	$0	$4,010,881	$5,209,586	$9,220,468	$998,200	$525,839	$29,368,504
12	$0	$3,689,565	$5,530,902	$9,220,468	$1,042,426	$518,054	$28,850,450
13	$0	$3,348,431	$5,872,036	$9,220,468	$1,083,333	$507,909	$28,342,541
14	$0	$2,986,257	$6,234,211	$9,220,468	$1,120,657	$495,668	$27,846,873
15	$0	$2,601,745	$6,618,723	$9,220,468	$1,154,117	$481,573	$27,365,300
16	$0	$2,193,516	$7,026,951	$9,220,468	$1,183,416	$465,847	$26,899,453
17	$0	$1,760,109	$7,460,358	$9,220,468	$1,208,237	$448,696	$26,450,757
18	$0	$1,299,971	$7,920,497	$9,220,468	$1,228,244	$430,308	$26,020,449
19	$0	$811,452	$8,409,016	$9,220,468	$1,243,083	$410,855	$25,609,594
20	$0	$292,802	$8,927,666	$9,220,468	$1,252,375	$390,497	$25,219,097
21	$0	$0	$0	$0	$10,527,755	$3,096,796	$22,122,301
22	$0	$0	$0	$0	$10,641,648	$2,953,111	$19,169,190
23	$0	$0	$0	$0	$10,755,928	$2,815,872	$16,353,317
24	$0	$0	$0	$0	$10,870,562	$2,684,796	$13,668,522
25	$0	$0	$0	$0	$10,985,514	$2,559,610	$11,108,912
26	$0	$0	$0	$0	$11,100,747	$2,440,056	$8,668,857
27	$0	$0	$0	$0	$11,216,223	$2,325,885	$6,342,971
28	$0	$0	$0	$0	$11,331,899	$2,216,861	$4,126,110
29	$0	$0	$0	$0	$11,447,734	$2,112,756	$2,013,354
30	$0	$0	$0	$0	$11,563,681	$2,013,354	$0

Case 1 with Storage

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax
0	$143,000,000	$0	$0		$143,000,000	$0	$0
1	$87,258,044	$3,028,929	$3,250,000	$65,000,000	$78,000,000	$9,543,827	$3,244,901
2	$88,566,914	$3,074,363	$3,347,500	$65,000,000	$13,000,000	$11,205,909	$3,810,009
3	$89,895,418	$3,120,479	$3,447,925	$13,000,000	$0	$64,909,409	$22,069,199
4	$91,243,849	$3,167,286	$3,551,363	$0	$0	$79,655,966	$27,083,029
5	$92,612,507	$3,214,795	$3,657,904	$0	$0	$81,447,306	$27,692,084
6	$94,001,695	$3,263,017	$3,767,641	$0	$0	$83,285,244	$28,316,983
7	$95,411,720	$3,311,962	$3,880,670	$0	$0	$85,171,699	$28,958,378
8	$96,842,896	$3,361,642	$3,997,090	$0	$0	$87,108,689	$29,616,954
9	$98,295,539	$3,412,066	$4,117,003	$0	$0	$89,098,345	$30,293,437
10	$99,769,973	$3,463,247	$4,240,513	$0	$0	$91,142,912	$30,988,590
11	$101,266,522	$3,515,196	$4,367,728	$0	$0	$93,244,760	$31,703,218
12	$102,785,520	$3,567,924	$4,498,760	$0	$0	$95,406,389	$32,438,172
13	$104,327,303	$3,621,443	$4,633,723	$0	$0	$97,630,440	$33,194,350
14	$105,892,212	$3,675,764	$4,772,735	$0	$0	$99,919,698	$33,972,697
15	$107,480,595	$3,730,901	$4,915,917	$0	$0	$102,277,106	$34,774,216
16	$109,092,804	$3,786,864	$5,063,394	$0	$0	$104,705,772	$35,599,962
17	$110,729,196	$3,843,667	$5,215,296	$0	$0	$107,208,978	$36,451,052
18	$112,390,134	$3,901,322	$5,371,755	$0	$0	$109,790,193	$37,328,666
19	$114,075,986	$3,959,842	$5,532,907	$0	$0	$112,453,083	$38,234,048
20	$115,787,126	$4,019,240	$5,698,895	$0	$0	$115,201,522	$39,168,518
21	$117,523,933	$4,079,528	$5,869,862	$0	$0	$117,523,933	$39,958,137
22	$119,286,792	$4,140,721	$6,045,957	$0	$0	$119,286,792	$40,557,509
23	$121,076,094	$4,202,832	$6,227,336	$0	$0	$121,076,094	$41,165,872
24	$122,892,235	$4,265,875	$6,414,156	$0	$0	$122,892,235	$41,783,360
25	$124,735,619	$4,329,863	$6,606,581	$0	$0	$124,735,619	$42,410,110
26	$126,606,653	$4,394,811	$6,804,778	$0	$0	$126,606,653	$43,046,262
27	$128,505,753	$4,460,733	$7,008,922	$0	$0	$128,505,753	$43,691,956
28	$130,433,339	$4,527,644	$7,219,189	$0	$0	$130,433,339	$44,347,335
29	$132,389,839	$4,595,559	$7,435,765	$0	$0	$132,389,839	$45,012,545
30	$134,375,687	$4,664,492	$7,658,838	$0	$0	$134,375,687	$45,687,734

Year	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue	Storage Cost
0	$0	$0	$0		$143,000,000	$143,000,000	
1	$12,714,217	$5,726,718	$18,440,935	$20,949,942	$19,764,097	$123,235,903	$41,372,265
2	$12,361,006	$6,079,930	$18,440,935	$21,641,639	$19,260,982	$103,974,922	$41,372,265
3	$11,986,009	$6,454,927	$18,440,935	$4,658,006	$3,910,952	$100,063,970	$41,372,265
4	$11,587,883	$6,853,052	$18,440,935	$938,765	$743,590	$99,320,380	$41,372,265
5	$11,165,202	$7,275,734	$18,440,935	$1,643,611	$1,228,202	$98,092,179	$41,372,265
6	$10,716,450	$7,724,485	$18,440,935	$2,352,213	$1,658,217	$96,433,962	$41,372,265
7	$10,240,021	$8,200,914	$18,440,935	$3,064,210	$2,037,875	$94,396,087	$41,372,265
8	$9,734,207	$8,706,729	$18,440,935	$3,779,210	$2,371,123	$92,024,964	$41,372,265
9	$9,197,195	$9,243,741	$18,440,935	$4,496,790	$2,661,643	$89,363,321	$41,372,265
10	$8,627,061	$9,813,875	$18,440,935	$5,216,488	$2,912,860	$86,450,461	$41,372,265
11	$8,021,763	$10,419,173	$18,440,935	$1,867,179	$983,607	$85,466,854	$41,372,265
12	$7,379,131	$11,061,805	$18,440,935	$2,467,463	$1,226,254	$84,240,601	$41,372,265
13	$6,696,863	$11,744,073	$18,440,935	$3,064,587	$1,436,798	$82,803,803	$41,372,265
14	$5,972,514	$12,468,421	$18,440,935	$3,657,816	$1,617,855	$81,185,947	$41,372,265
15	$5,203,489	$13,237,446	$18,440,935	$4,246,362	$1,771,858	$79,414,089	$41,372,265
16	$4,387,033	$14,053,903	$18,440,935	$4,829,383	$1,901,069	$77,513,020	$41,372,265
17	$3,520,219	$14,920,717	$18,440,935	$5,405,980	$2,007,589	$75,505,432	$41,372,265
18	$2,599,941	$15,840,994	$18,440,935	$5,975,191	$2,093,371	$73,412,060	$41,372,265
19	$1,622,904	$16,818,032	$18,440,935	$6,535,988	$2,160,229	$71,251,831	$41,372,265
20	$585,604	$17,855,332	$18,440,936	$7,087,274	$2,209,845	$69,041,986	$41,372,265
21	$0	$0	$0	$26,244,141	$7,719,856	$61,322,130	$41,372,265
22	$0	$0	$0	$27,170,339	$7,539,908	$53,782,222	$41,372,265
23	$0	$0	$0	$28,107,789	$7,358,542	$46,423,680	$41,372,265
24	$0	$0	$0	$29,056,580	$7,176,352	$39,247,328	$41,372,265
25	$0	$0	$0	$30,016,800	$6,993,873	$32,253,455	$41,372,265
26	$0	$0	$0	$30,988,537	$6,811,591	$25,441,864	$41,372,265
27	$0	$0	$0	$31,971,878	$6,629,943	$18,811,921	$41,372,265
28	$0	$0	$0	$32,966,906	$6,449,321	$12,362,600	$41,372,265
29	$0	$0	$0	$33,973,706	$6,270,076	$6,092,524	$41,372,265
30	$0	$0	$0	$34,992,359	$6,092,524	$0	$41,372,265

Case 1 with Storage and Transportation

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax	Tax Credit
0	$143,000,000	$0	$0		$182,723,816	$0	$0	$0
1	$105,073,471	$3,028,929	$3,250,000	$65,000,000	$117,723,816	$27,359,254	$9,302,146	$3,028,929
2	$106,649,573	$3,074,363	$3,347,500	$65,000,000	$52,723,816	$29,288,567	$9,958,113	$3,119,797
3	$108,249,316	$3,120,479	$3,447,925	$52,723,816	$0	$43,539,491	$14,803,427	$3,213,391
4	$109,873,056	$3,167,286	$3,551,363	$0	$0	$98,285,173	$33,416,959	$3,309,793
5	$111,521,152	$3,214,795	$3,657,904	$0	$0	$100,355,950	$34,121,023	$3,409,087
6	$113,193,969	$3,263,017	$3,767,641	$0	$0	$102,477,519	$34,842,356	$3,511,359
7	$114,891,879	$3,311,962	$3,880,670	$0	$0	$104,651,858	$35,581,632	$3,616,700
8	$116,615,257	$3,361,642	$3,997,090	$0	$0	$106,881,050	$36,339,557	$3,725,201
9	$118,364,486	$3,412,066	$4,117,003	$0	$0	$109,167,291	$37,116,879	$3,836,957
10	$120,139,953	$3,463,247	$4,240,513	$0	$0	$111,512,892	$37,914,383	$3,952,066
11	$121,942,052	$3,515,196	$4,367,728	$0	$0	$113,920,290	$38,732,898	$0
12	$123,771,183	$3,567,924	$4,498,760	$0	$0	$116,392,052	$39,573,298	$0
13	$125,627,751	$3,621,443	$4,633,723	$0	$0	$118,930,888	$40,436,502	$0
14	$127,512,167	$3,675,764	$4,772,735	$0	$0	$121,539,653	$41,323,482	$0
15	$129,424,850	$3,730,901	$4,915,917	$0	$0	$124,221,360	$42,235,263	$0
16	$131,366,222	$3,786,864	$5,063,394	$0	$0	$126,979,190	$43,172,925	$0
17	$133,336,716	$3,843,667	$5,215,296	$0	$0	$129,816,497	$44,137,609	$0
18	$135,336,766	$3,901,322	$5,371,755	$0	$0	$132,736,825	$45,130,521	$0
19	$137,366,818	$3,959,842	$5,532,907	$0	$0	$135,743,914	$46,152,931	$0
20	$139,427,320	$4,019,240	$5,698,895	$0	$0	$138,841,716	$47,206,183	$0
21	$141,518,730	$4,079,528	$5,869,862	$0	$0	$141,518,730	$48,116,368	$0
22	$143,641,511	$4,140,721	$6,045,957	$0	$0	$143,641,511	$48,838,114	$0
23	$145,796,134	$4,202,832	$6,227,336	$0	$0	$145,796,134	$49,570,685	$0
24	$147,983,076	$4,265,875	$6,414,156	$0	$0	$147,983,076	$50,314,246	$0
25	$150,202,822	$4,329,863	$6,606,581	$0	$0	$150,202,822	$51,068,959	$0
26	$152,455,864	$4,394,811	$6,804,778	$0	$0	$152,455,864	$51,834,994	$0
27	$154,742,702	$4,460,733	$7,008,922	$0	$0	$154,742,702	$52,612,519	$0
28	$157,063,843	$4,527,644	$7,219,189	$0	$0	$157,063,843	$53,401,706	$0
29	$159,419,800	$4,595,559	$7,435,765	$0	$0	$159,419,800	$54,202,732	$0
30	$161,811,097	$4,664,492	$7,658,838	$0	$0	$161,811,097	$55,015,773	$0

Year	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue	Storage Cost	Transportation Cost
0	$0	$0	$0		$182,723,816	$182,723,816		$39,723,816
1	$12,714,217	$5,726,718	$18,440,935	$20,953,623	$19,767,569	$162,956,247	$41,372,265	$11,754,501
2	$12,361,006	$6,079,930	$18,440,935	$21,821,693	$19,421,229	$143,535,018	$41,372,265	$11,754,501
3	$11,986,009	$6,454,927	$18,440,935	$18,523,176	$15,552,416	$127,982,603	$41,372,265	$11,754,501
4	$11,587,883	$6,853,052	$18,440,935	$1,479,540	$1,171,935	$126,810,668	$41,372,265	$11,754,501
5	$11,165,202	$7,275,734	$18,440,935	$2,368,816	$1,770,117	$125,040,551	$41,372,265	$11,754,501
6	$10,716,450	$7,724,485	$18,440,935	$3,264,613	$2,301,423	$122,739,128	$41,372,265	$11,754,501
7	$10,240,021	$8,200,914	$18,440,935	$4,166,614	$2,771,036	$119,968,091	$41,372,265	$11,754,501
8	$9,734,207	$8,706,729	$18,440,935	$5,074,468	$3,183,784	$116,784,307	$41,372,265	$11,754,501
9	$9,197,195	$9,243,741	$18,440,935	$5,987,794	$3,544,166	$113,240,142	$41,372,265	$11,754,501
10	$8,627,061	$9,813,875	$18,440,935	$6,906,174	$3,856,372	$109,383,770	$41,372,265	$11,754,501
11	$8,021,763	$10,419,173	$18,440,935	$3,758,529	$1,979,946	$107,403,824	$41,372,265	$11,754,501
12	$7,379,131	$11,061,805	$18,440,935	$4,563,500	$2,267,920	$105,135,904	$41,372,265	$11,754,501
13	$6,696,863	$11,744,073	$18,440,935	$5,368,382	$2,516,907	$102,618,997	$41,372,265	$11,754,501
14	$5,972,514	$12,468,421	$18,440,935	$6,172,485	$2,730,096	$99,888,901	$41,372,265	$11,754,501
15	$5,203,489	$13,237,446	$18,440,935	$6,975,069	$2,910,452	$96,978,448	$41,372,265	$11,754,501
16	$4,387,033	$14,053,903	$18,440,935	$7,775,338	$3,060,733	$93,917,715	$41,372,265	$11,754,501
17	$3,520,219	$14,920,717	$18,440,935	$8,572,442	$3,183,500	$90,734,215	$41,372,265	$11,754,501
18	$2,599,941	$15,840,994	$18,440,935	$9,365,468	$3,281,133	$87,453,082	$41,372,265	$11,754,501
19	$1,622,904	$16,818,032	$18,440,935	$10,153,436	$3,355,843	$84,097,239	$41,372,265	$11,754,501
20	$585,604	$17,855,332	$18,440,936	$10,935,301	$3,409,679	$80,687,561	$41,372,265	$11,754,501
21	$0	$0	$0	$30,326,206	$8,920,617	$71,766,943	$41,372,265	$11,754,501
22	$0	$0	$0	$31,489,953	$8,738,622	$63,028,321	$41,372,265	$11,754,501
23	$0	$0	$0	$32,668,514	$8,552,528	$54,475,793	$41,372,265	$11,754,501
24	$0	$0	$0	$33,862,034	$8,363,196	$46,112,597	$41,372,265	$11,754,501
25	$0	$0	$0	$35,070,653	$8,171,414	$37,941,183	$41,372,265	$11,754,501
26	$0	$0	$0	$36,294,516	$7,977,899	$29,963,284	$41,372,265	$11,754,501
27	$0	$0	$0	$37,533,763	$7,783,300	$22,179,985	$41,372,265	$11,754,501
28	$0	$0	$0	$38,788,537	$7,588,207	$14,591,778	$41,372,265	$11,754,501
29	$0	$0	$0	$40,058,979	$7,393,155	$7,198,623	$41,372,265	$11,754,501
30	$0	$0	$0	$41,345,229	$7,198,623	$0	$41,372,265	$11,754,501

Case 1 with Storage and Transportation and Fuel Cells

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax	Tax Credit	Loan Interest
0	$143,000,000	$0	$0		$236,723,816	$0	$0	$0	$0
1	$109,875,802	$3,028,929	$3,250,000	$65,000,000	$171,723,816	$32,161,585	$10,934,939	$3,028,929	$12,714,217
2	$111,523,939	$3,074,363	$3,347,500	$65,000,000	$106,723,816	$34,162,934	$11,615,397	$3,119,797	$12,361,006
3	$113,196,798	$3,120,479	$3,447,925	$65,000,000	$41,723,816	$36,210,789	$12,311,668	$3,213,391	$11,986,009
4	$114,894,750	$3,167,286	$3,551,363	$41,723,816	$0	$61,583,051	$20,938,237	$3,309,793	$11,587,883
5	$116,618,171	$3,214,795	$3,657,904	$0	$0	$105,452,970	$35,854,010	$3,409,087	$11,165,202
6	$118,367,444	$3,263,017	$3,767,641	$0	$0	$107,650,994	$36,601,338	$3,511,359	$10,716,450
7	$120,142,956	$3,311,962	$3,880,670	$0	$0	$109,902,935	$37,366,998	$3,616,700	$10,240,021
8	$121,945,100	$3,361,642	$3,997,090	$0	$0	$112,210,893	$38,151,704	$3,725,201	$9,734,207
9	$123,774,276	$3,412,066	$4,117,003	$0	$0	$114,577,082	$38,956,208	$3,836,957	$9,197,195
10	$125,630,891	$3,463,247	$4,240,513	$0	$0	$117,003,830	$39,781,302	$3,952,066	$8,627,061
11	$127,515,354	$3,515,196	$4,367,728	$0	$0	$119,493,591	$40,627,821	$0	$8,021,763
12	$129,428,084	$3,567,924	$4,498,760	$0	$0	$122,048,953	$41,496,644	$0	$7,379,131
13	$131,369,505	$3,621,443	$4,633,723	$0	$0	$124,672,643	$42,388,698	$0	$6,696,863
14	$133,340,048	$3,675,764	$4,772,735	$0	$0	$127,367,534	$43,304,962	$0	$5,972,514
15	$135,340,149	$3,730,901	$4,915,917	$0	$0	$130,136,660	$44,246,464	$0	$5,203,489
16	$137,370,251	$3,786,864	$5,063,394	$0	$0	$132,983,218	$45,214,294	$0	$4,387,033
17	$139,430,805	$3,843,667	$5,215,296	$0	$0	$135,910,586	$46,209,599	$0	$3,520,219
18	$141,522,267	$3,901,322	$5,371,755	$0	$0	$138,922,326	$47,233,591	$0	$2,599,941
19	$143,645,101	$3,959,842	$5,532,907	$0	$0	$142,022,197	$48,287,547	$0	$1,622,904
20	$145,799,777	$4,019,240	$5,698,895	$0	$0	$145,214,173	$49,372,819	$0	$585,604
21	$147,986,774	$4,079,528	$5,869,862	$0	$0	$147,986,774	$50,315,503	$0	$0
22	$150,206,576	$4,140,721	$6,045,957	$0	$0	$150,206,576	$51,070,236	$0	$0
23	$152,459,674	$4,202,832	$6,227,336	$0	$0	$152,459,674	$51,836,289	$0	$0
24	$154,746,569	$4,265,875	$6,414,156	$0	$0	$154,746,569	$52,613,834	$0	$0
25	$157,067,768	$4,329,863	$6,606,581	$0	$0	$157,067,768	$53,403,041	$0	$0
26	$159,423,784	$4,394,811	$6,804,778	$0	$0	$159,423,784	$54,204,087	$0	$0
27	$161,815,141	$4,460,733	$7,008,922	$0	$0	$161,815,141	$55,017,148	$0	$0
28	$164,242,368	$4,527,644	$7,219,189	$0	$0	$164,242,368	$55,842,405	$0	$0
29	$166,706,004	$4,595,559	$7,435,765	$0	$0	$166,706,004	$56,680,041	$0	$0
30	$169,206,594	$4,664,492	$7,658,838	$0	$0	$169,206,594	$57,530,242	$0	$0

Year	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue	Storage Cost	Transportation Cost	FC Cost
0	$0	$0	$0		$236,723,816	$236,723,816		$39,723,816	$54,000,000
1	$12,714,217	$5,726,718	$18,440,935	$23,250,876	$21,934,789	$214,789,027	$41,372,265	$11,754,501	$872,286
2	$12,361,006	$6,079,930	$18,440,935	$24,166,489	$21,508,089	$193,280,939	$41,372,265	$11,754,501	$872,286
3	$11,986,009	$6,454,927	$18,440,935	$25,090,130	$21,066,157	$172,214,781	$41,372,265	$11,754,501	$872,286
4	$11,587,883	$6,853,052	$18,440,935	$18,107,670	$14,342,971	$157,871,811	$41,372,265	$11,754,501	$872,286
5	$11,165,202	$7,275,734	$18,440,935	$4,860,563	$3,632,095	$154,239,715	$41,372,265	$11,754,501	$872,286
6	$10,716,450	$7,724,485	$18,440,935	$5,806,821	$4,093,579	$150,146,136	$41,372,265	$11,754,501	$872,286
7	$10,240,021	$8,200,914	$18,440,935	$6,760,039	$4,495,812	$145,650,324	$41,372,265	$11,754,501	$872,286
8	$9,734,207	$8,706,729	$18,440,935	$7,719,878	$4,843,547	$140,806,777	$41,372,265	$11,754,501	$872,286
9	$9,197,195	$9,243,741	$18,440,935	$8,685,970	$5,141,212	$135,665,565	$41,372,265	$11,754,501	$872,286
10	$8,627,061	$9,813,875	$18,440,935	$9,657,907	$5,392,925	$130,272,640	$41,372,265	$11,754,501	$872,286
11	$8,021,763	$10,419,173	$18,440,935	$6,564,622	$3,458,161	$126,814,479	$41,372,265	$11,754,501	$872,286
12	$7,379,131	$11,061,805	$18,440,935	$7,424,769	$3,689,883	$123,124,596	$41,372,265	$11,754,501	$872,286
13	$6,696,863	$11,744,073	$18,440,935	$8,285,654	$3,884,638	$119,239,958	$41,372,265	$11,754,501	$872,286
14	$5,972,514	$12,468,421	$18,440,935	$9,146,601	$4,045,550	$115,194,408	$41,372,265	$11,754,501	$872,286
15	$5,203,489	$13,237,446	$18,440,935	$10,006,880	$4,175,521	$111,018,886	$41,372,265	$11,754,501	$872,286
16	$4,387,033	$14,053,903	$18,440,935	$10,865,711	$4,277,247	$106,741,640	$41,372,265	$11,754,501	$872,286
17	$3,520,219	$14,920,717	$18,440,935	$11,722,255	$4,353,229	$102,388,411	$41,372,265	$11,754,501	$872,286
18	$2,599,941	$15,840,994	$18,440,935	$12,575,612	$4,405,788	$97,982,623	$41,372,265	$11,754,501	$872,286
19	$1,622,904	$16,818,032	$18,440,935	$13,424,817	$4,437,077	$93,545,547	$41,372,265	$11,754,501	$872,286
20	$585,604	$17,855,332	$18,440,936	$14,268,837	$4,449,091	$89,096,456	$41,372,265	$11,754,501	$872,286
21	$0	$0	$0	$33,722,829	$9,919,752	$79,176,703	$41,372,265	$11,754,501	$872,286
22	$0	$0	$0	$34,950,610	$9,698,972	$69,477,731	$41,372,265	$11,754,501	$872,286
23	$0	$0	$0	$36,194,165	$9,475,533	$60,002,198	$41,372,265	$11,754,501	$872,286
24	$0	$0	$0	$37,453,654	$9,250,249	$50,751,949	$41,372,265	$11,754,501	$872,286
25	$0	$0	$0	$38,729,232	$9,023,858	$41,728,091	$41,372,265	$11,754,501	$872,286
26	$0	$0	$0	$40,021,057	$8,797,030	$32,931,061	$41,372,265	$11,754,501	$872,286
27	$0	$0	$0	$41,329,287	$8,570,370	$24,360,691	$41,372,265	$11,754,501	$872,286
28	$0	$0	$0	$42,654,078	$8,344,423	$16,016,268	$41,372,265	$11,754,501	$872,286
29	$0	$0	$0	$43,995,588	$8,119,682	$7,896,586	$41,372,265	$11,754,501	$872,286
30	$0	$0	$0	$45,353,971	$7,896,586	$0	$41,372,265	$11,754,501	$872,286

Best Case Scenario

Year	Gross Revenue	O&M	Insurance	Depreciation	Depreciation remaining	Taxable Income	Income Tax	Tax Credit	Loan Interest
0	$143,000,000	$0	$0		$149,438,413	$0	$0	$0	$0
1	$54,849,275	$3,028,929	$3,250,000	$42,135,058	$107,303,354	$0	$0	$3,028,929	$12,714,217
2	$55,672,015	$3,074,363	$3,347,500	$43,311,009	$63,992,345	$0	$0	$3,119,797	$12,361,006
3	$56,507,095	$3,120,479	$3,447,925	$44,521,086	$19,471,259	$0	$0	$3,213,391	$11,986,009
4	$57,354,701	$3,167,286	$3,551,363	$19,471,259	$0	$26,295,559	$8,940,490	$3,309,793	$11,587,883
5	$58,215,022	$3,214,795	$3,657,904	$0	$0	$47,049,820	$15,996,939	$3,409,087	$11,165,202
6	$59,088,247	$3,263,017	$3,767,641	$0	$0	$48,371,797	$16,446,411	$3,511,359	$10,716,450
7	$59,974,571	$3,311,962	$3,880,670	$0	$0	$49,734,550	$16,909,747	$3,616,700	$10,240,021
8	$60,874,189	$3,361,642	$3,997,090	$0	$0	$51,139,983	$17,387,594	$3,725,201	$9,734,207
9	$61,787,302	$3,412,066	$4,117,003	$0	$0	$52,590,108	$17,880,637	$3,836,957	$9,197,195
10	$62,714,112	$3,463,247	$4,240,513	$0	$0	$54,087,051	$18,389,597	$3,952,066	$8,627,061
11	$63,654,823	$3,515,196	$4,367,728	$0	$0	$55,633,061	$18,915,241	$0	$8,021,763
12	$64,609,646	$3,567,924	$4,498,760	$0	$0	$57,230,515	$19,458,375	$0	$7,379,131
13	$65,578,790	$3,621,443	$4,633,723	$0	$0	$58,881,928	$20,019,855	$0	$6,696,863
14	$66,562,472	$3,675,764	$4,772,735	$0	$0	$60,589,958	$20,600,586	$0	$5,972,514
15	$67,560,909	$3,730,901	$4,915,917	$0	$0	$62,357,420	$21,201,523	$0	$5,203,489
16	$68,574,323	$3,786,864	$5,063,394	$0	$0	$64,187,290	$21,823,679	$0	$4,387,033
17	$69,602,938	$3,843,667	$5,215,296	$0	$0	$66,082,719	$22,468,125	$0	$3,520,219
18	$70,646,982	$3,901,322	$5,371,755	$0	$0	$68,047,041	$23,135,994	$0	$2,599,941
19	$71,706,687	$3,959,842	$5,532,907	$0	$0	$70,083,783	$23,828,486	$0	$1,622,904
20	$72,782,287	$4,019,240	$5,698,895	$0	$0	$72,196,683	$24,546,872	$0	$585,604
21	$73,874,021	$4,079,528	$5,869,862	$0	$0	$73,874,021	$25,117,167	$0	$0
22	$74,982,131	$4,140,721	$6,045,957	$0	$0	$74,982,132	$25,493,925	$0	$0
23	$76,106,863	$4,202,832	$6,227,336	$0	$0	$76,106,863	$25,876,334	$0	$0
24	$77,248,466	$4,265,875	$6,414,156	$0	$0	$77,248,466	$26,264,479	$0	$0
25	$78,407,193	$4,329,863	$6,606,581	$0	$0	$78,407,193	$26,658,446	$0	$0
26	$79,583,301	$4,394,811	$6,804,778	$0	$0	$79,583,301	$27,058,322	$0	$0
27	$80,777,051	$4,460,733	$7,008,922	$0	$0	$80,777,051	$27,464,197	$0	$0
28	$81,988,707	$4,527,644	$7,219,189	$0	$0	$81,988,707	$27,876,160	$0	$0
29	$83,218,537	$4,595,559	$7,435,765	$0	$0	$83,218,537	$28,294,303	$0	$0
30	$84,466,815	$4,664,492	$7,658,838	$0	$0	$84,466,815	$28,718,717	$0	$0

Year	Loan Interest	Loan Principal	Total Loan Payment	Revenue	Discounted Revenue	Net Total Revenue	Storage Cost	Transportation Cost	FC Cost
0	$0	$0	$0		$148,908,625	$148,908,625	$41,372,265	$0	$5,908,625
1	$12,714,217	$5,726,718	$18,440,935	$17,441,196	$16,453,958	$132,454,667	$3,580,135	$11,754,501	$872,286
2	$12,361,006	$6,079,930	$18,440,935	$18,219,215	$16,215,037	$116,239,631	$3,580,135	$11,754,501	$872,286
3	$11,986,009	$6,454,927	$18,440,935	$19,008,806	$15,960,160	$100,279,471	$3,580,135	$11,754,501	$872,286
4	$11,587,883	$6,853,052	$18,440,935	$10,008,285	$7,927,499	$92,351,971	$3,580,135	$11,754,501	$872,286
5	$11,165,202	$7,275,734	$18,440,935	$4,449,702	$3,325,077	$89,026,895	$3,580,135	$11,754,501	$872,286
6	$10,716,450	$7,724,485	$18,440,935	$4,822,916	$3,399,965	$85,626,930	$3,580,135	$11,754,501	$872,286
7	$10,240,021	$8,200,914	$18,440,935	$5,194,493	$3,454,635	$82,172,295	$3,580,135	$11,754,501	$872,286
8	$9,734,207	$8,706,729	$18,440,935	$5,563,968	$3,490,902	$78,681,393	$3,580,135	$11,754,501	$872,286
9	$9,197,195	$9,243,741	$18,440,935	$5,930,838	$3,510,454	$75,170,939	$3,580,135	$11,754,501	$872,286
10	$8,627,061	$9,813,875	$18,440,935	$6,294,567	$3,514,853	$71,656,085	$3,580,135	$11,754,501	$872,286
11	$8,021,763	$10,419,173	$18,440,935	$2,583,950	$1,361,192	$70,294,893	$3,580,135	$11,754,501	$872,286
12	$7,379,131	$11,061,805	$18,440,935	$2,817,505	$1,400,214	$68,894,679	$3,580,135	$11,754,501	$872,286
13	$6,696,863	$11,744,073	$18,440,935	$3,042,399	$1,426,396	$67,468,284	$3,580,135	$11,754,501	$872,286
14	$5,972,514	$12,468,421	$18,440,935	$3,257,815	$1,440,935	$66,027,349	$3,580,135	$11,754,501	$872,286
15	$5,203,489	$13,237,446	$18,440,935	$3,462,881	$1,444,939	$64,582,410	$3,580,135	$11,754,501	$872,286
16	$4,387,033	$14,053,903	$18,440,935	$3,656,670	$1,439,434	$63,142,976	$3,580,135	$11,754,501	$872,286
17	$3,520,219	$14,920,717	$18,440,935	$3,838,196	$1,425,369	$61,717,606	$3,580,135	$11,754,501	$872,286
18	$2,599,941	$15,840,994	$18,440,935	$4,006,410	$1,403,621	$60,313,985	$3,580,135	$11,754,501	$872,286
19	$1,622,904	$16,818,032	$18,440,935	$4,160,195	$1,374,999	$58,938,987	$3,580,135	$11,754,501	$872,286
20	$585,604	$17,855,332	$18,440,936	$4,298,364	$1,340,250	$57,598,737	$3,580,135	$11,754,501	$872,286
21	$0	$0	$0	$23,035,917	$6,776,139	$50,822,597	$3,580,135	$11,754,501	$872,286
22	$0	$0	$0	$23,536,512	$6,531,502	$44,291,095	$3,580,135	$11,754,501	$872,286
23	$0	$0	$0	$24,041,974	$6,294,123	$37,996,972	$3,580,135	$11,754,501	$872,286
24	$0	$0	$0	$24,552,297	$6,063,891	$31,933,081	$3,580,135	$11,754,501	$872,286
25	$0	$0	$0	$25,067,473	$5,840,687	$26,092,394	$3,580,135	$11,754,501	$872,286
26	$0	$0	$0	$25,587,491	$5,624,387	$20,468,007	$3,580,135	$11,754,501	$872,286
27	$0	$0	$0	$26,112,335	$5,414,861	$15,053,146	$3,580,135	$11,754,501	$872,286
28	$0	$0	$0	$26,641,990	$5,211,976	$9,841,170	$3,580,135	$11,754,501	$872,286
29	$0	$0	$0	$27,176,436	$5,015,594	$4,825,575	$3,580,135	$11,754,501	$872,286
30	$0	$0	$0	$27,715,650	$4,825,575	$0	$3,580,135	$11,754,501	$872,286

Date and Time	Average Campus Consumption (kW)	Average Production per Turbine (kW)	Average Array Production (kW)	Campus Consumption in 2038 (kW)	25% Penetration Limit (kW)	Production to Storage (kW)	Production from Storage (kW)	Cumulative Storage (kWh)	Shifted Storage (kWh)
Sun 0:00	30,156	497	49,706	50,779	12,695	37,012	38,435	-1,423	66,287
Sun 1:00	29,323	445	44,462	49,377	12,344	32,118	37,089	-6,394	61,316
Sun 2:00	29,190	428	42,846	49,152	12,288	30,558	36,938	-12,774	54,936
Sun 3:00	29,014	414	41,383	48,856	12,214	29,169	36,544	-20,149	47,561
Sun 4:00	29,246	353	35,347	49,247	12,312	23,035	36,907	-34,021	33,689
Sun 5:00	29,314	328	32,813	49,361	12,340	20,472	36,950	-50,499	17,212
Sun 6:00	29,482	326	32,553	49,644	12,411	20,142	37,354	-67,711	0
Sun 7:00	29,194	499	49,887	49,159	12,290	37,598	36,717	-66,830	881
Sun 8:00	29,556	602	60,239	49,769	12,442	47,797	37,035	-56,069	11,642
Sun 9:00	30,247	746	74,559	50,933	12,733	61,825	38,055	-32,298	35,412
Sun 10:00	30,592	762	76,222	51,513	12,878	63,344	38,482	-7,436	60,274
Sun 11:00	30,954	766	76,562	52,123	13,031	63,531	38,894	17,200	84,911
Sun 12:00	31,424	767	76,669	52,914	13,229	63,440	39,513	41,127	108,838
Sun 13:00	31,833	771	77,061	53,603	13,401	63,660	40,141	64,646	132,357
Sun 14:00	31,978	869	86,934	53,847	13,462	73,473	40,331	97,788	165,498
Sun 15:00	32,106	886	88,637	54,063	13,516	75,121	40,602	132,307	200,018
Sun 16:00	31,976	837	83,680	53,844	13,461	70,219	40,359	162,167	229,878
Sun 17:00	32,034	724	72,384	53,941	13,485	58,899	40,451	180,615	248,325
Sun 18:00	32,044	630	63,005	53,959	13,490	49,515	40,425	189,705	257,415
Sun 19:00	32,148	525	52,486	54,134	13,534	38,952	40,558	188,099	255,809
Sun 20:00	32,249	498	49,842	54,304	13,576	36,266	40,749	183,616	251,327
Sun 21:00	32,199	559	55,898	54,220	13,555	42,343	40,902	185,057	252,768
Sun 22:00	31,636	530	53,015	53,271	13,318	39,697	40,445	184,310	252,020
Sun 23:00	30,470	534	53,389	51,307	12,827	40,562	38,659	186,212	253,923
Mon 0:00	30,045	497	49,706	50,593	12,648	37,058	38,111	185,159	252,870
Mon 1:00	29,650	445	44,462	49,927	12,482	31,980	37,576	179,564	247,274
Mon 2:00	29,341	428	42,846	49,407	12,352	30,494	37,068	172,990	240,700
Mon 3:00	29,310	414	41,383	49,354	12,338	29,044	36,609	165,425	233,136
Mon 4:00	30,274	353	35,347	50,978	12,744	22,602	37,948	150,080	217,790
Mon 5:00	30,953	328	32,813	52,121	13,030	19,782	38,480	131,382	199,093
Mon 6:00	32,404	326	32,553	54,564	13,641	18,912	40,338	109,956	177,666
Mon 7:00	33,794	499	49,887	56,904	14,226	35,661	41,157	104,461	172,171
Mon 8:00	37,408	602	60,239	62,991	15,748	44,491	46,392	102,560	170,270
Mon 9:00	39,430	746	74,559	66,396	16,599	57,960	49,275	111,245	178,956
Mon 10:00	40,670	762	76,222	68,484	17,121	59,101	51,183	119,163	186,874
Mon 11:00	41,099	766	76,562	69,205	17,301	59,260	52,015	126,409	194,119
Mon 12:00	40,835	767	76,669	68,761	17,190	59,479	51,353	134,534	202,245
Mon 13:00	41,351	771	77,061	69,630	17,408	59,653	52,080	142,107	209,818
Mon 14:00	41,689	869	86,934	70,199	17,550	69,385	52,854	158,638	226,349
Mon 15:00	41,204	886	88,637	69,382	17,346	71,291	52,544	177,386	245,097
Mon 16:00	40,000	837	83,680	67,355	16,839	66,842	51,795	192,432	260,143
Mon 17:00	36,960	724	72,384	62,237	15,559	56,825	47,297	201,960	269,671
Mon 18:00	35,490	630	63,005	59,761	14,940	48,065	45,081	204,944	272,655
Mon 19:00	34,873	525	52,486	58,722	14,680	37,805	44,178	198,572	266,282
Mon 20:00	34,549	498	49,842	58,177	14,544	35,298	43,808	190,061	257,772
Mon 21:00	34,132	559	55,898	57,474	14,368	41,529	43,524	188,066	255,777
Mon 22:00	33,136	530	53,015	55,797	13,949	39,065	42,301	184,830	252,541
Mon 23:00	32,059	534	53,389	53,983	13,496	39,893	40,908	183,815	251,525
Tue 0:00	31,059	497	49,706	52,300	13,075	36,631	39,437	181,009	248,720

Date and Time	Average Campus Consumption (kW)	Average Production per Turbine (kW)	Average Array Production (kW)	Campus Consumption in 2038 (kW)	25% Penetration Limit (kW)	Production to Storage (kW)	Production from Storage (kW)	Cumulative Storage (kWh)	Shifted Storage (kWh)
Tue 1:00	30,554	445	44,462	51,450	12,862	31,600	38,830	173,778	241,489
Tue 2:00	29,977	428	42,846	50,478	12,620	30,227	37,770	166,235	233,945
Tue 3:00	30,188	414	41,383	50,833	12,708	28,675	37,733	157,177	224,888
Tue 4:00	31,118	353	35,347	52,400	13,100	22,247	38,954	140,470	208,181
Tue 5:00	31,940	328	32,813	53,783	13,446	19,367	39,800	120,037	187,748
Tue 6:00	33,217	326	32,553	55,934	13,984	18,569	41,157	97,449	165,160
Tue 7:00	35,102	499	49,887	59,108	14,777	35,111	42,689	89,871	157,582
Tue 8:00	39,002	602	60,239	65,675	16,419	43,820	48,577	85,115	152,825
Tue 9:00	40,617	746	74,559	68,394	17,099	57,460	51,009	91,566	159,276
Tue 10:00	41,297	762	76,222	69,539	17,385	58,837	52,189	98,214	165,924
Tue 11:00	41,214	766	76,562	69,400	17,350	59,212	52,231	105,194	172,905
Tue 12:00	40,784	767	76,669	68,676	17,169	59,500	51,504	113,190	180,901
Tue 13:00	40,791	771	77,061	68,687	17,172	59,889	51,402	121,677	189,388
Tue 14:00	41,059	869	86,934	69,138	17,285	69,650	51,933	139,394	207,105
Tue 15:00	40,871	886	88,637	68,822	17,205	71,431	52,134	158,691	226,402
Tue 16:00	39,641	837	83,680	66,750	16,688	66,993	51,316	174,368	242,079
Tue 17:00	36,663	724	72,384	61,737	15,434	56,950	46,840	184,478	252,189
Tue 18:00	35,388	630	63,005	59,589	14,897	48,108	44,922	187,664	255,374
Tue 19:00	34,841	525	52,486	58,668	14,667	37,819	44,085	181,398	249,108
Tue 20:00	34,641	498	49,842	58,332	14,583	35,259	43,986	172,671	240,382
Tue 21:00	34,078	559	55,898	57,383	14,346	41,552	43,503	170,720	238,430
Tue 22:00	32,970	530	53,015	55,517	13,879	39,136	42,026	167,829	235,540
Tue 23:00	32,047	534	53,389	53,963	13,491	39,898	40,889	166,838	234,548
Wed 0:00	31,057	497	49,706	52,296	13,074	36,632	39,426	164,044	231,754
Wed 1:00	30,570	445	44,462	51,477	12,869	31,593	38,741	156,895	224,606
Wed 2:00	30,253	428	42,846	50,943	12,736	30,110	38,126	148,880	216,591
Wed 3:00	30,446	414	41,383	51,267	12,817	28,566	37,981	139,465	207,175
Wed 4:00	31,560	353	35,347	53,144	13,286	22,061	39,574	121,951	189,662
Wed 5:00	32,234	328	32,813	54,279	13,570	19,243	40,242	100,952	168,663
Wed 6:00	33,344	326	32,553	56,148	14,037	18,516	41,357	78,111	145,822
Wed 7:00	35,135	499	49,887	59,163	14,791	35,097	42,926	70,282	137,992
Wed 8:00	38,570	602	60,239	64,947	16,237	44,002	47,899	66,385	134,096
Wed 9:00	40,497	746	74,559	68,193	17,048	57,511	50,575	73,321	141,032
Wed 10:00	41,852	762	76,222	70,473	17,618	58,604	52,765	79,160	146,870
Wed 11:00	42,064	766	76,562	70,831	17,708	58,854	53,278	84,735	152,446
Wed 12:00	41,695	767	76,669	70,210	17,553	59,116	52,415	91,436	159,147
Wed 13:00	42,271	771	77,061	71,179	17,795	59,266	53,408	97,295	165,005
Wed 14:00	42,215	869	86,934	71,085	17,771	69,163	53,305	113,153	180,864
Wed 15:00	42,237	886	88,637	71,123	17,781	70,856	53,780	130,229	197,940
Wed 16:00	41,197	837	83,680	69,371	17,343	66,338	53,437	143,130	210,841
Wed 17:00	37,851	724	72,384	63,737	15,934	56,450	48,474	151,106	218,817
Wed 18:00	36,257	630	63,005	61,053	15,263	47,742	46,142	152,706	220,416
Wed 19:00	35,421	525	52,486	59,645	14,911	37,574	44,804	145,477	213,187
Wed 20:00	35,255	498	49,842	59,366	14,842	35,001	44,663	135,815	203,525
Wed 21:00	34,927	559	55,898	58,814	14,703	41,194	44,594	132,414	200,125
Wed 22:00	33,777	530	53,015	56,877	14,219	38,795	43,091	128,118	195,829
Wed 23:00	32,747	534	53,389	55,143	13,786	39,603	41,806	125,916	193,626
Thu 0:00	31,682	497	49,706	53,348	13,337	36,369	40,314	121,971	189,682
Thu 1:00	30,962	445	44,462	52,136	13,034	31,428	39,244	114,156	181,866

Date and Time	Average Campus Consumption (kW)	Average Production per Turbine (kW)	Average Array Production (kW)	Campus Consumption in 2038 (kW)	25% Penetration Limit (kW)	Production to Storage (kW)	Production from Storage (kW)	Cumulative Storage (kWh)	Shifted Storage (kWh)
Thu 2:00	30,625	428	42,846	51,568	12,892	29,954	38,689	105,421	173,132
Thu 3:00	30,594	414	41,383	51,517	12,879	28,504	38,241	95,683	163,394
Thu 4:00	31,537	353	35,347	53,105	13,276	22,071	39,530	78,225	145,935
Thu 5:00	32,248	328	32,813	54,302	13,576	19,237	40,195	57,266	124,977
Thu 6:00	33,510	326	32,553	56,427	14,107	18,446	41,564	34,148	101,859
Thu 7:00	35,306	499	49,887	59,452	14,863	35,024	43,253	25,920	93,630
Thu 8:00	38,480	602	60,239	64,796	16,199	44,040	47,903	22,057	89,767
Thu 9:00	40,127	746	74,559	67,569	16,892	57,666	50,144	29,579	97,289
Thu 10:00	41,393	762	76,222	69,700	17,425	58,797	52,278	36,098	103,809
Thu 11:00	41,386	766	76,562	69,689	17,422	59,139	52,457	42,781	110,492
Thu 12:00	40,936	767	76,669	68,931	17,233	59,436	51,430	50,787	118,498
Thu 13:00	41,573	771	77,061	70,005	17,501	59,560	52,432	57,915	125,626
Thu 14:00	41,744	869	86,934	70,291	17,573	69,362	52,940	74,337	142,048
Thu 15:00	41,218	886	88,637	69,406	17,351	71,285	52,668	92,954	160,665
Thu 16:00	39,760	837	83,680	66,952	16,738	66,942	51,424	108,473	176,184
Thu 17:00	36,886	724	72,384	62,111	15,528	56,856	47,093	118,236	185,946
Thu 18:00	35,675	630	63,005	60,072	15,018	47,987	45,209	121,013	188,724
Thu 19:00	35,306	525	52,486	59,451	14,863	37,623	44,767	113,869	181,580
Thu 20:00	34,880	498	49,842	58,734	14,684	35,159	44,240	104,788	172,499
Thu 21:00	34,431	559	55,898	57,978	14,494	41,403	43,980	102,211	169,921
Thu 22:00	33,251	530	53,015	55,990	13,998	39,017	42,395	98,833	166,543
Thu 23:00	32,295	534	53,389	54,381	13,595	39,793	41,091	97,535	165,246
Fri 0:00	31,569	497	49,706	53,159	13,290	36,417	40,070	93,882	161,593
Fri 1:00	31,092	445	44,462	52,356	13,089	31,373	39,390	85,865	153,576
Fri 2:00	30,799	428	42,846	51,861	12,965	29,881	38,906	76,840	144,550
Fri 3:00	30,776	414	41,383	51,822	12,956	28,427	38,486	66,781	134,492
Fri 4:00	31,679	353	35,347	53,344	13,336	22,011	39,657	49,134	116,845
Fri 5:00	32,512	328	32,813	54,746	13,687	19,126	40,597	27,663	95,374
Fri 6:00	33,610	326	32,553	56,595	14,149	18,404	41,770	4,297	72,008
Fri 7:00	35,216	499	49,887	59,300	14,825	35,063	43,173	-3,814	63,897
Fri 8:00	38,308	602	60,239	64,506	16,126	44,112	47,678	-7,379	60,331
Fri 9:00	39,974	746	74,559	67,311	16,828	57,731	50,050	302	68,012
Fri 10:00	41,003	762	76,222	69,044	17,261	58,961	51,678	7,585	75,296
Fri 11:00	41,252	766	76,562	69,464	17,366	59,196	52,286	14,495	82,205
Fri 12:00	40,805	767	76,669	68,711	17,178	59,491	51,504	22,483	90,193
Fri 13:00	40,876	771	77,061	68,830	17,207	59,853	51,628	30,707	98,418
Fri 14:00	40,862	869	86,934	68,806	17,202	69,733	51,783	48,657	116,368
Fri 15:00	40,437	886	88,637	68,091	17,023	71,614	51,665	68,606	136,316
Fri 16:00	39,019	837	83,680	65,703	16,426	67,254	50,575	85,286	152,996
Fri 17:00	35,938	724	72,384	60,515	15,129	57,255	46,015	96,526	164,237
Fri 18:00	34,445	630	63,005	58,001	14,500	48,505	43,706	101,325	169,036
Fri 19:00	33,958	525	52,486	57,182	14,295	38,190	43,021	96,495	164,205
Fri 20:00	33,639	498	49,842	56,643	14,161	35,681	42,749	89,427	157,138
Fri 21:00	33,006	559	55,898	55,578	13,894	42,003	42,072	89,358	157,069
Fri 22:00	32,082	530	53,015	54,022	13,505	39,509	40,750	88,118	155,828
Fri 23:00	31,527	534	53,389	53,088	13,272	40,117	40,344	87,890	155,601
Sat 0:00	30,273	497	49,706	50,976	12,744	36,962	38,398	86,454	154,165
Sat 1:00	29,879	445	44,462	50,313	12,578	31,884	37,890	80,448	148,159
Sat 2:00	29,511	428	42,846	49,693	12,423	30,423	37,351	73,521	141,231

Date and Time	Average Campus Consumption (kW)	Average Production per Turbine (kW)	Average Array Production (kW)	Campus Consumption in 2038 (kW)	25% Penetration Limit (kW)	Production to Storage (kW)	Production from Storage (kW)	Cumulative Storage (kWh)	Shifted Storage (kWh)
Sat 3:00	29,318	414	41,383	49,367	12,342	29,041	36,894	65,668	133,378
Sat 4:00	29,631	353	35,347	49,894	12,474	22,873	37,341	51,200	118,911
Sat 5:00	29,820	328	32,813	50,213	12,553	20,259	37,423	34,036	101,747
Sat 6:00	30,382	326	32,553	51,160	12,790	19,763	38,474	15,325	83,036
Sat 7:00	30,135	499	49,887	50,744	12,686	37,201	37,869	14,658	82,368
Sat 8:00	30,584	602	60,239	51,501	12,875	47,364	38,300	23,721	91,432
Sat 9:00	31,357	746	74,559	52,801	13,200	61,359	39,381	45,698	113,409
Sat 10:00	31,878	762	76,222	53,678	13,420	62,803	40,052	68,449	136,160
Sat 11:00	32,369	766	76,562	54,506	13,626	62,935	40,767	90,617	158,328
Sat 12:00	32,636	767	76,669	54,955	13,739	62,930	41,061	112,486	180,197
Sat 13:00	33,005	771	77,061	55,576	13,894	63,167	41,763	133,890	201,601
Sat 14:00	32,812	869	86,934	55,252	13,813	73,122	41,354	165,657	233,368
Sat 15:00	33,012	886	88,637	55,589	13,897	74,740	41,855	198,542	266,253
Sat 16:00	32,625	837	83,680	54,937	13,734	69,946	41,347	227,142	294,852
Sat 17:00	32,283	724	72,384	54,360	13,590	58,794	40,856	245,080	312,790
Sat 18:00	32,080	630	63,005	54,019	13,505	49,500	40,430	254,150	321,860
Sat 19:00	32,279	525	52,486	54,354	13,589	38,897	40,862	252,184	319,895
Sat 20:00	32,049	498	49,842	53,967	13,492	36,350	40,709	247,826	315,537
Sat 21:00	31,495	559	55,898	53,033	13,258	42,639	40,062	250,404	318,114
Sat 22:00	30,814	530	53,015	51,886	12,972	40,043	39,318	251,129	318,839
Sat 23:00	29,855	534	53,389	50,273	12,568	40,820	50,273	241,676	309,387

Lead acid costs

Year	Cost	Discounted Cost	Cycles	Battery #	New Battery
1	$40,950,000	$40,950,000	365	1	1
2	$0	$0	730	1	0
3	$40,950,000	$36,445,354	1095	2	1
4	$0	$0	1460	2	0
5	$0	$0	1825	2	0
6	$40,950,000	$30,600,222	2190	3	1
7	$0	$0	2555	3	0
8	$0	$0	2920	3	0
9	$40,950,000	$25,692,537	3285	4	1
10	$0	$0	3650	4	0
11	$40,950,000	$22,866,266	4015	5	1
12	$0	$0	4380	5	0
13	$0	$0	4745	5	0
14	$40,950,000	$19,198,958	5110	6	1
15	$0	$0	5475	6	0
16	$0	$0	5840	6	0
17	$40,950,000	$16,119,815	6205	7	1
18	$0	$0	6570	7	0
19	$0	$0	6935	7	0
20	$40,950,000	$13,534,508	7300	8	1
21	$0	$0	7665	8	0
22	$40,950,000	$12,045,664	8030	9	1
23	$0	$0	8395	9	0
24	$0	$0	8760	9	0
25	$40,950,000	$10,113,772	9125	10	1
26	$0	$0	9490	10	0
27	$0	$0	9855	10	0
28	$40,950,000	$8,491,718	10220	11	1
29	$0	$0	10585	11	0
30	$0	$0	10950	11	0
Total		**$236,058,813**			

Nickel Cadmium Costs

Year	Cost	Discounted Cost	Cycles	Battery #	New Battery
1	$81,900,000	$81,900,000	365	1	1
2	$81,900,000	$77,264,151	730	2	1
3	$81,900,000	$72,890,708	1095	3	1
4	$0	$0	1460	3	0
5	$81,900,000	$64,872,471	1825	4	1
6	$81,900,000	$61,200,444	2190	5	1
7	$81,900,000	$57,736,268	2555	6	1
8	$0	$0	2920	6	0
9	$81,900,000	$51,385,073	3285	7	1
10	$81,900,000	$48,476,484	3650	8	1
11	$81,900,000	$45,732,532	4015	9	1
12	$0	$0	4380	9	0
13	$81,900,000	$40,701,791	4745	10	1
14	$81,900,000	$38,397,916	5110	11	1
15	$0	$0	5475	11	0
16	$81,900,000	$34,174,008	5840	12	1
17	$81,900,000	$32,239,631	6205	13	1
18	$81,900,000	$30,414,746	6570	14	1
19	$0	$0	6935	14	0
20	$81,900,000	$27,069,016	7300	15	1
21	$81,900,000	$25,536,807	7665	16	1
22	$81,900,000	$24,091,327	8030	17	1
23	$0	$0	8395	17	0
24	$81,900,000	$21,441,196	8760	18	1
25	$81,900,000	$20,227,543	9125	19	1
26	$0	$0	9490	19	0
27	$81,900,000	$18,002,441	9855	20	1
28	$81,900,000	$16,983,435	10220	21	1
29	$81,900,000	$16,022,109	10585	22	1
30	$0	$0	10950	22	0
Total		**$906,760,099**			

Lithium ion costs

Year	Cost	Discounted Cost	Cycles	Battery #	New Battery
1	$327,600,000	$327,600,000	365	1	1
2	$0	$0	730	1	0
3	$0	$0	1095	1	0
4	$327,600,000	$275,059,277	1460	2	1
5	$0	$0	1825	2	0
6	$0	$0	2190	2	0
7	$327,600,000	$230,945,073	2555	3	1
8	$0	$0	2920	3	0
9	$0	$0	3285	3	0
10	$327,600,000	$193,905,937	3650	4	1
11	$0	$0	4015	4	0
12	$0	$0	4380	4	0
13	$0	$0	4745	4	0
14	$327,600,000	$153,591,664	5110	5	1
15	$0	$0	5475	5	0
16	$0	$0	5840	5	0
17	$327,600,000	$128,958,523	6205	6	1
18	$0	$0	6570	6	0
19	$0	$0	6935	6	0
20	$327,600,000	$108,276,062	7300	7	1
21	$0	$0	7665	7	0
22	$0	$0	8030	7	0
23	$0	$0	8395	7	0
24	$327,600,000	$85,764,783	8760	8	1
25	$0	$0	9125	8	0
26	$0	$0	9490	8	0
27	$327,600,000	$72,009,765	9855	9	1
28	$0	$0	10220	9	0
29	$0	$0	10585	9	0
30	$327,600,000	$60,460,788	10950	10	1
Total		**$1,636,571,871**			

Electrolysis Costs

Year	Cost	Discounted Cost
1	$41,372,265	$39,030,439
2	$41,372,265	$36,821,168
3	$41,372,265	$34,736,951
4	$41,372,265	$32,770,709
5	$41,372,265	$30,915,763
6	$41,372,265	$29,165,814
7	$41,372,265	$27,514,919
8	$41,372,265	$25,957,471
9	$41,372,265	$24,488,180
10	$41,372,265	$23,102,057
11	$41,372,265	$21,794,393
12	$41,372,265	$20,560,748
13	$41,372,265	$19,396,932
14	$41,372,265	$18,298,993
15	$41,372,265	$17,263,201
16	$41,372,265	$16,286,038
17	$41,372,265	$15,364,187
18	$41,372,265	$14,494,516
19	$41,372,265	$13,674,072
20	$41,372,265	$12,900,068
21	$41,372,265	$12,169,875
22	$41,372,265	$11,481,014
23	$41,372,265	$10,831,146
24	$41,372,265	$10,218,062
25	$41,372,265	$9,639,681
26	$41,372,265	$9,094,039
27	$41,372,265	$8,579,282
28	$41,372,265	$8,093,662
29	$41,372,265	$7,635,530
30	$41,372,265	$7,203,330
Total		**$569,482,240**

Discount Rate (%)	6		Year	Cost (million $)	Discounted Cost (million $)
Average Design Rate (kW)	43,600		0	23.3	23.3
Design Rate (MMBtu/hr)	148		1	18.68	17.63
Conversion	211		2	18.68	16.63
Design Rate (kg/d H2)	31,279		3	18.68	15.69
Electric power for compression (kw/kg/h)	2.3		4	18.68	14.80
Electric power for compression (kW)	2,998		5	18.68	13.96
Flow rate hydrogen (kg/hr)	1,303		6	18.68	13.17
Storage time (hrs)	0.615384615		7	18.68	12.43
Amount stored (kg)	802		8	18.68	11.72
Conversion 2	8.5		9	18.68	11.06
Gal physical vol H2 (gal)	6,817		10	18.68	10.43
Tanker fill ups/d	39		11	18.68	9.84
			12	18.68	9.28
Capital Cost		Total Cost (million $)	13	18.68	8.76
Compressor Cost ($/kW)	$3,349	10.04	14	18.68	8.26
Storage cost ($/gal phy vol)	$116	0.79	15	18.68	7.80
Total Process Units		**10.83**	16	18.68	7.35
General Facilities %	20	2.17	17	18.68	6.94
Engineering Permitting and Startup %	15	1.62	18	18.68	6.55
Contingencies %	10	1.08	19	18.68	6.17
Working Capital Land and Misc %	5	0.54	20	18.68	5.83
Total Onsite Capital Costs		16.24	21	18.68	5.50
Tank and Undercarriage		2.82	22	18.68	5.18
Truck Cabe		4.23	23	18.68	4.89
Total Capital Cost		**23.3**	24	18.68	4.61
			25	18.68	4.35
Variable Operating Cost		Annual Cost (million $)	26	18.68	4.11
Labor		9.46	27	18.68	3.87
Fuel		5.26	28	18.68	3.65
Variable non-fuel O&M (%/yr of capital)	1	0.23	29	18.68	3.45
Total Variable Operating Cost		14.96	30	18.68	3.25
Fixed Operating Cost (%/yr of capital)	**2**	**0.47**	**Total NPV (million)**		**$280.5**
Capital Charges (%/yr of capital)	**14**	**3.26**			
Total Operating Cost		**18.68**			
Cryogenic tank (module cost)	$0				
Undercarriage (trailer cost)	$60,000				
Cabe (cab cost)	$90,000				
Truck capacity (kg/truck)	819				
Fuel economy (mpg)	6				
Average speed (km/hr)	50				
Load/unload time (hr/trip)	2				
Truck availability (hr/day)	24				
Hour/driver (hr/driver)	12				
Driver wage and benefits (hourly wage)	$28.75				
Fuel price ($/gal)	$3.28				
Average delivery distance (mi)	500				
Average delivery distance (km)	805				
Truck utilization (%)	80				
Trips per year	9624				
Total Distance (km)	15,494,640				
Total Distance (mi)	9,622,171				
Time for each trip (hours)	32.2				
Trip length	34.2				
Delivered product (kg/yr)	11,416,704				
Total delivery time (hr/yr)	329,141				
Total driving time (hr/yr)	309,893				
Total load/unload time (hr/yr)	19,248				
Truck availability (hrs)	7008				
Truck requirement	47				
Driver time (hr)	3504				
Drivers required	94				
Fuel usage (gal/yr)	1,603,695				

Discount Rate (%)	6		Year	Cost (million $)	Discounted Cost (million $)
Average Design Rate (kW)	43,600		0	39.7	39.7
Design Rate (MMBtu/hr)	148		1	11.75	11.09
Conversion	211		2	11.75	10.46
Design Rate (kg/d H2)	31,279		3	11.75	9.87
Electric power for liquification (kw/kg/h)	11		4	11.75	9.31
Electric power for liquification (kW)	14,336		5	11.75	8.78
Flow rate liquid hydrogen (kg/hr)	1,303		6	11.75	8.29
Storage time (hrs)	3		7	11.75	7.82
Amount stored (kg)	3,910		8	11.75	7.37
Conversion 2	3.72		9	11.75	6.96
Gal physical vol H2	14,545		10	11.75	6.56
Tanker fill ups/d	8		11	11.75	6.19
			12	11.75	5.84
Capital Cost		Total Cost (million $)	13	11.75	5.51
Liquification cost (kg/d H2)	$707	22.1	14	11.75	5.20
Storage cost ($/gal phy vol)	$5	0.1	15	11.75	4.90
Total Process Units		**22.2**	16	11.75	4.63
General Facilities %	20	4.4	17	11.75	4.37
Engineering Permitting and Startup %	15	3.3	18	11.75	4.12
Contingencies %	10	2.2	19	11.75	3.89
Working Capital Land and Misc %	7	1.6	20	11.75	3.67
Total Onsite Capital Costs		33.7	21	11.75	3.46
Tank and Undercarriage		5.1	22	11.75	3.26
Truck Cabe		0.9	23	11.75	3.08
Total Capital Cost		**39.7**	24	11.75	2.90
			25	11.75	2.74
Variable Operating Cost		Annual Cost (million $)	26	11.75	2.58
Labor		1.94	27	11.75	2.44
Fuel		1.08	28	11.75	2.30
Variable non-fuel O&M (%/yr of capital)	1	0.40	29	11.75	2.17
Total Variable Operating Cost		3.41	30	11.75	2.05
Fixed Operating Cost (%/yr of capital)	**5**	**1.99**			
Capital Charges (%/yr of capital)	**16**	**6.36**	**Total NPV (million)**		**$201.5**
Total Operating Cost		**11.75**			
Cryogenic tank (module cost)	$450,000				
Undercarriage (trailer cost)	$60,000				
Cabe (cab cost)	$90,000				
Truck boil off (%/day)	0.3				
Truck capacity (kg/truck)	4000				
Fuel economy (mpg)	6				
Average speed (km/hr)	50				
Load/unload time (hr/trip)	2				
Truck availability (hr/day)	24				
Hour/driver (hr/driver	12				
Driver wage and benefits (hourly wage)	$28.75				
Fuel price ($/gal)	$3.28				
Average delivery distance (mi)	500				
Average delivery distance (km)	805				
Truck utilization (%)	80				
Trips per year (correct this)	1971				
Total Distance (km)	3,173,310				
Total Distance (mi)	1,970,626				
Time for each trip (hours)	32.2				
Trip length	34.2				
Delivered product	11,246,477				
Total delivery time	67,408				
Total driving time	63,466				
Total load/unload time	3,942				
Truck availability	7008				
Truck requirement	10				
Driver time	3504				
Drivers required	20				
Fuel usage	328,438				

Discount Rate (%)	6	
Average Design Rate (kW)	43,600	
Design Rate (MMBtu/hr)	148	
Conversion	211	
Design Rate (kg/d H2)	31,279	
Delivery Distance (mi)	500	
Delivery distance (km)	805	
Delivery Pressure (psia)	440	
Capital Cost		Total Cost (Million $)
Pipeline cost (million $/mi)	0.3	
Pipeline cost ($/km)	600,000	483
General Facilities and Permitting (%)	15	72.45
Startup (%)	10	48.3
Contingencies (%)	7	33.81
Working Capital, Land & Misc. (%)	5	24.15
Unit Capital Costs		**661.71**
Operating Cost		Annual Cost (Million $)
Variable Operating Cost (%)	1	6.6171
Fixed Operating Cost (%)	3	19.8513
Capital Charges (%)	16	105.8736
Total Operating Costs		**132.342**

Year	Cost (million $)	Discounted Cost (million $)
0	661.71	661.71
1	132.34	124.85
2	132.34	117.78
3	132.34	111.12
4	132.34	104.83
5	132.34	98.89
6	132.34	93.30
7	132.34	88.01
8	132.34	83.03
9	132.34	78.33
10	132.34	73.90
11	132.34	69.72
12	132.34	65.77
13	132.34	62.05
14	132.34	58.53
15	132.34	55.22
16	132.34	52.10
17	132.34	49.15
18	132.34	46.37
19	132.34	43.74
20	132.34	41.26
21	132.34	38.93
22	132.34	36.73
23	132.34	34.65
24	132.34	32.69
25	132.34	30.84
26	132.34	29.09
27	132.34	27.44
28	132.34	25.89
29	132.34	24.42
30	132.34	23.04
Total NPV (million)		**$2,483**

Fuel Cell Cost

Discount Rate %	6	
Desired Output (MW)	54	
Desired Electricity Production (kW-hrs)	382061227	
Desired Electricity Production (kW-yrs)	43614.29536	
Operating current (kA)	90000	
Cell Voltage (mV)	600	
Current Density (mA/cm2)	400	
Cell Area (m2/cell)	1	
Cells per stack	280	
Area (m2)	22,500	
# of cells	22500	
# of stacks	80	
Capital Cost		Total cost (Thousand $)
Capital Cost ($/kW)	1000	54000
Variable Cost		Annual cost (Thousand $)
Operating and Maintenance Cost ($/kW-yr)	20	872.2859071

Year	Cost (million $)	Discounted Cost (million $)
0	54	54
1	0.87	0.82
2	0.87	0.78
3	0.87	0.73
4	0.87	0.69
5	0.87	0.65
6	0.87	0.61
7	0.87	0.58
8	0.87	0.55
9	0.87	0.52
10	0.87	0.49
11	0.87	0.46
12	0.87	0.43
13	0.87	0.41
14	0.87	0.39
15	0.87	0.36
16	0.87	0.34
17	0.87	0.32
18	0.87	0.31
19	0.87	0.29
20	0.87	0.27
21	0.87	0.26
22	0.87	0.24
23	0.87	0.23
24	0.87	0.22
25	0.87	0.20
26	0.87	0.19
27	0.87	0.18
28	0.87	0.17
29	0.87	0.16
30	0.87	0.15
Total (million $)		**66.01**