Modeling of a Renewable Energy System
Experiential Innovation and Technology Centre

by

Charles Hua

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Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Charles Hua

Abstract

Energy consumption has been increasing rapidly over the last few decades. In 2003, Ontario's energy needs were in the order of 155.1 TWh and are expected to increase to 168.9 TWh by 2014. This will create an increased demand for power generation, electricity distribution, resources, as well as the generation of pollution. Thus, there is a requirement for infrastructure renewal and expansion within a sustainable energy management framework.

With respect to stationary power requirements, there are many solutions available such as consumption reduction and overall energy efficient. Demand side management and energy conservation will mitigate the problem, is it likely that more power generation will be required. A distributed generation system is most desirable as there is relief for the electricity distribution grid. Key to this study is the examination of the potential for the distributed energy system to produce electricity for the facility while also producing hydrogen to support a small fleet of vehicles for use at the facility, demonstrating an integrated energy system. The results for the fleet of vehicles are preliminary only, while most of the focus was put into the energy system of the facility.

The application of this distributed system will be in the commercial/industrial sector where a technology center will be the primary load while supplying power to the grid when excess power is generated. There are many sources of distributed energy available to be used in distributed generation systems ranging from diesel generators to wind turbines, the various green generation technologies have been evaluated during this study. The evaluation takes into account cost, efficiency, size, and availability. This study has shown that such a facility can produce emissions free distributed electricity in a Net Zero manner with an electrical grid connection, as well as economically support refuelling a fleet of hydrogen fuel cell vehicles.

The selected systems have been modeled and sized to demonstrate operating conditions and assess the energy/power flow. Different scenarios were simulated to show how the system will react to intermittent environmental conditions, such as wind speed.

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1.0 Introduction

1.1 Background Information

Energy consumption has been increasing rapidly over the last few decades. In 2003, Ontario's energy needs were in the order of 155.1 TWh and are expected to increase to 168.9 TWh by 2014 (Rogers, 2004). That kind of increase will create a lot of problems in the years between now (2006) and 2014, including key environmental issue of climate change and urban air quality. With respect to stationary power requirements, there are many solutions available such as consumption reduction and overall energy efficiency. Demand side management and energy conservation will on mitigate the problem, is it likely that more power generation will be required. Distributed generation system is most desirable as then there is relief for the electricity distribution grid. Key to this study is the examination of the potential for the distributed energy system to produce electricity for the facility while also producing hydrogen to support a small fleet of vehicles for use at the facility demonstrating an integrated energy system.

There have been countless debates over whether to build large centralized power plants or to use distributed generation systems. Although there are benefits to both systems, this work will focus on technologies for distributed generation, and how such a system can support the electricity needs of a facility as well as a limited hydrogen vehicle fleet.

Building another centralized power plant will definitely have a larger capacity, however, the electrical grid will be challenged to accommodate this increased capacity. To transport more electricity to high load areas where it is needed the most, more transmission lines will need to be installed since the current transmission network in high load areas are operating close to maximum capacity already (Carpinelli, Celli, Pilo, & Russo, 2001). Distributed generation systems do not need lengthy transmission lines since the system can be installed close to the load, or ideally, on site of the load.

Some argue that distributed generation systems are expensive and have low capacities and in most cases, this statement is only partially true. From an economical perspective, the cost per unit of electricity installed for a distributed generation system is generally higher (especially with renewable sources) than the cost per unit of electricity installed for a centralized power plant. This statement, however, does not take into account the auxiliary costs of installing more transmission lines, substations across the service area, and the complexity of both systems.

The complexity of centralized systems lies in the increase of transmission network capacity where the complexity of distributed generation systems lies in the connection to the grid, the management of the voltage of this connection as well as the electricity supply and demand. There are two ways of connecting distributed generation systems: the first being a connection directly to the load on the customer's side of the utility meter, and the second being a connection to the grid on the utilities side of the utility meter. The distributed generation grid connections, electrical management of such a connection, and policy issues of electrical supply is beyond the scope of this work, and therefore it will not be addressed.

Installation of distributed generation systems are relatively easy when compared to centralized power plants. This is largely because of the modularity of distributed generation systems. The power capacity as a result of this can be incrementally increased when needed and decreased to accommodate the specific facility needs. This reduces the amount of waste energy that is produced and when sized properly the system can be designed to run closer to its peak efficiency. New large centralized power plants have very high capital with excess unused capacity, making the plant run outside of its optimal efficiency long after its startup.

Benefits of distributed generation systems are usually more apparent from a customer's perspective rather than from a utilities perspective. Distributed generation systems have the potential for increased reliability, higher efficiency with combined heat and power, and puts them in a position to generate some profit by selling power back to the grid when necessary.

Table 1: Distributed Generation Systems vs. Centralized Power Plants, (Ackermann, Andersson, & Soder, 2001)

Criteria	**Distributed Generation Systems**	**Centralized Power Plants**
Cost	More expensive per kWh installed capacity	Less expensive per kWh installed capacity
Maintenance	If one company owns multiple generation systems, regular maintenance becomes more complex and expensive	Maintenance is relatively simple since procedures for similar plants are already in place
Installed Capacity	Installed capacity can be done to meet demand incrementally since this system is usually modular	New plant provides more capacity than is required, therefore wasting of power plant's capabilities (and lowering efficiency)
Transmission Network	Little to no additional transmission network is required since the system is installed close to the load or ideally on site of the load	More transmission lines and substations are required for a new power plant
Grid Congestion	Help to relieve the congestion when designed and installed properly	Increases grid congestion; new transmission lines or upgrades are required to meet the higher demand/supply

Air Quality	Technologies for this system can be green or can be traditional technologies	Nuclear and hydro power plants generally have no emissions, however, natural gas, coal, and oil power plants have high emissions of harmful pollutants
Combined Heat and Power	If the installation is sufficiently close to the load, the system can also provide heating to the load, thereby increasing efficiency	Heat and power are separate systems since the power source is too far away for combined heating and power to be realizable

Figures 1 and 2 show how different a centralized system and a distributed system is visually.

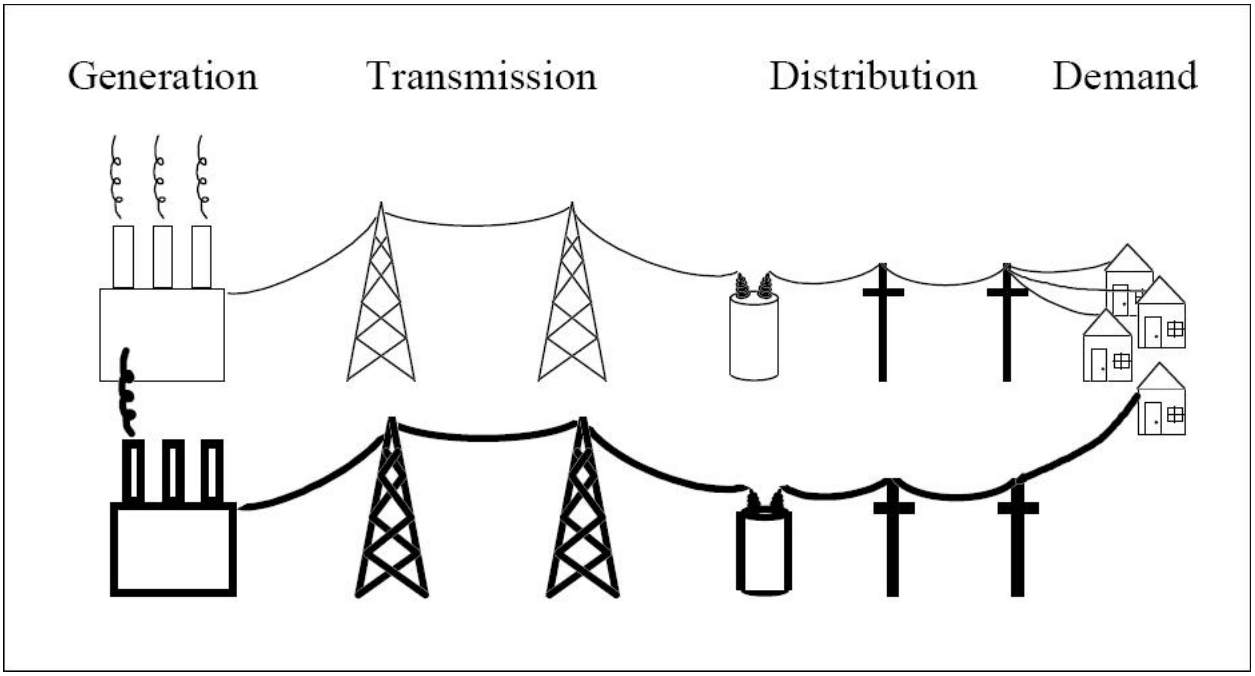


Figure 1: New Centralized Power Generation System, (Hoff, Wenger, & Farmer, 1996)

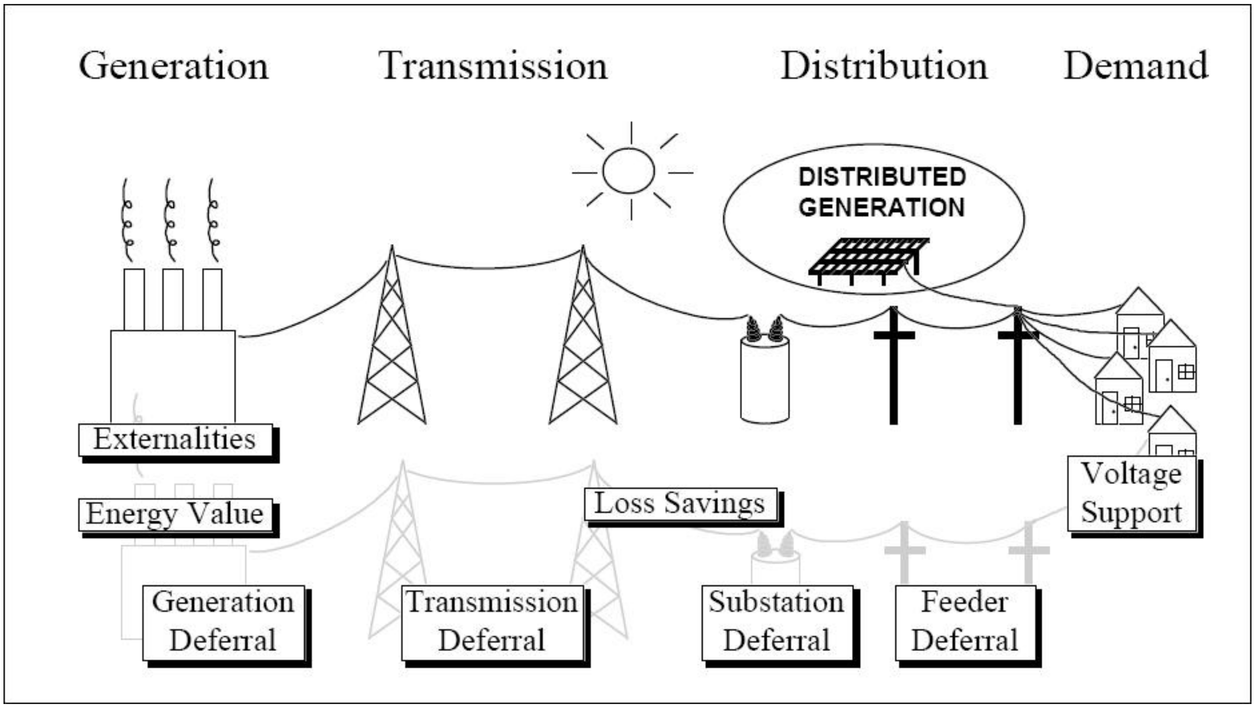


Figure 2: New Distributed Power Generation System, (Hoff et al., 1996)

1.2 Motivation and Objective

Hybrid Strategies and Moriyama and Teshima Architects have proposed a design for a research facility for state of the art technology research and development located at the North Campus of The University of Waterloo. This research facility is called the Experiential Innovation and Technology Centre (EITC).

The motivation behind a renewable energy system for the EITC stems from the need for alternative energy systems in society. Additional motivation would be to address electrical grid congestion through distributed generation of electricity at the site of the electrical demand. Traditional as well as current energy production technologies have relied primarily on fossil fuels worldwide, but this must change since fossil fuels are in limited quantities. Not only are fossil fuel resources depleting, the traditional energy delivery system is also brought into question; that is the centralized fashion for energy delivery. The use of renewable technologies such as wind turbines and/or solar PV allows for the opportunity to develop distributed generation to decentralize the mode for energy transportation. Since the EITC will be a research facility for state of the art technology, a renewable energy system will compliment the facility well, showcasing the latest in energy production technology.

The objective of the renewable energy system for the EITC will be to provide sufficient electrical energy to the facility while maintaining a net zero energy flow with the grid annually. The system will consist of a primary renewable source such as wind or solar and will be complimented by a sophisticated energy storage system including batteries and a hydrogen system.

1.3 Thesis Organization

This thesis is separated into a total of ten chapters.

Table 2: Thesis Organization

Chapter Number	Description
Chapter 1	Provides background for the current need for alternative energy generation. Also oulines the motivation and objectives of this thesis.
Chapter 2	This chapter describes and defines distributed generation concept to be used in an electrical energy production application.
Chapter 3	Chapter 3 outlines various design challenges with distributed generation in today's society.
Chapter 4	Chapter 4 describes and compares various technologies available for use in the EITC energy production system.
Chapter 5	This chapter provides background information about the EITC facility.
Chapter 6	This chapter compares various different software packages available for modeling the EITC's energy system.

Chapter 7	Chapter 7 describes the conceptual energy system as well as the equipment and parameter specifics.
Chapter 8	This chapter outlines the results from the modeling efforts for the EITC’s energy system.
Chapter 9	This chapter outlines the conclusions and decisions made for the EITC’s system.
Chapter 10	Chapter 10 lists the reference material for this thesis.

2.0 Definition of Distributed Generation

In literature, there are many definitions that suggest how large distributed energy generation systems should be, but the basic feature is that the energy generation and load are co-located. Table 3 compares various sources and their definitions.

Table 3: Various Definitions of Distributed Generation, (Ackermann et al., 2001)

Source	Definition
Electric Power Research Institute	A few kW to 50 MW
Gas Research Institute	25 W to 25 MW
Preston and Rastler	A few kW to over 100 MW
International Conference on Large High Voltage Electric Systems	Smaller than 100 MW
English and Welsh Market	Smaller than 100 MW
Sweden	Less than 1.5 MW, but large wind farms are still DG

Generally speaking, it is up to interpretation about what defines one system over another, either central or distributed. From the examples in table 3, it can be noted that all sources other than potentially Sweden will consider distributed systems to be under 100 MW, however, no general definition of power rating can be given to a distributed system as the rating will depend heavily on the design and application of a specific system. This therefore makes the rating a poor specification to define a system by. In the journal article entitled '*Distributed generation: a definition*', Ackermann et. al suggest categories for clearly defining various distributed generation capacities:

- *Micro* distributed generation – 1 W to <5 kW
- *Small* distributed generation – 5 kW to < 5 MW
- *Medium* distributed generation – 5 MW to <50 MW
- *Large* distributed generation – 50 MW to <300 MW

The purpose of distributed generation is the same for any generation system; to provide a source of active electric power for a load. It can also be designed to act as a source of thermal energy if the system is installed sufficiently close to the load for it to be efficient (Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005).

3.0 Design Challenge with Distributed systems

Installing distributed systems in different locations around the city brings up many issues that must be addressed before full scale distributed generation can really be taken seriously. Such issues include what technologies to use, where to install generation facilities, and how to safely install these systems with the current transmission network (Caisheng Wang & Nehrir, 2004), (Carpinelli et al., 2001). There are also issues of community acceptance that are beyond the scope of this project.

As mentioned earlier, internal combustion technologies are the cheapest and easiest to install for small scale distributed generation such as residential installations. The issue with this system is with the amount of pollution that is generated so close to urban areas. Clearly fossil fuel distributed generation systems will impact global climate change and resource depletions, but more importantly if they are located with the urban airshed they will have a dramatic impact on urban air quality and smog generation (Puttgen, MacGregor, & Lambert, 2003). Renewable technologies such as wind and solar are much better suited for small scale residential and commercial power generation because of their relatively transparent operating conditions (Daly & Morrison, 2001).

Synchronizing power with the grid is also a problem with having distributed systems able to feed into the grid network (Dugan & McDermott, 2001). Especially when dealing with sources that create DC electric power, additional equipment such as inverters to convert DC power to AC power (Barker & De Mello, 2000), (Slootweg & Kling, 2002).

Safety is another issue that must be addressed. In the event of a power outage, the distributed system must be able to safely isolate itself from the area of damage. If there are linesmen working on damaged lines, the distributed system must not be forcing power into the lines that are being repaired. New procedures must be put in place for maintenance personnel to ensure that new distributed systems can be properly maintained in a safe manner (Doyle, 2002).

Building a distributed generation facility requires significantly less time to complete when compared to a centralized facility (Dugan, McDermott, & Ball, 2001). This is because the technologies used for distributed generation facilities are usually off the shelf components such as solar PV arrays, inverters, or batteries (Marei, El-Saadany, & Salama, 2002). A central nuclear facility, for example, does not use off the shelf components and require twenty or more years from the beginning of construction to completion. Not only do distributed systems come online quicker, they can also be incrementally upgraded to meet increasing demands a little bit at a time rather than in chunks (Dugan et al., 2001).

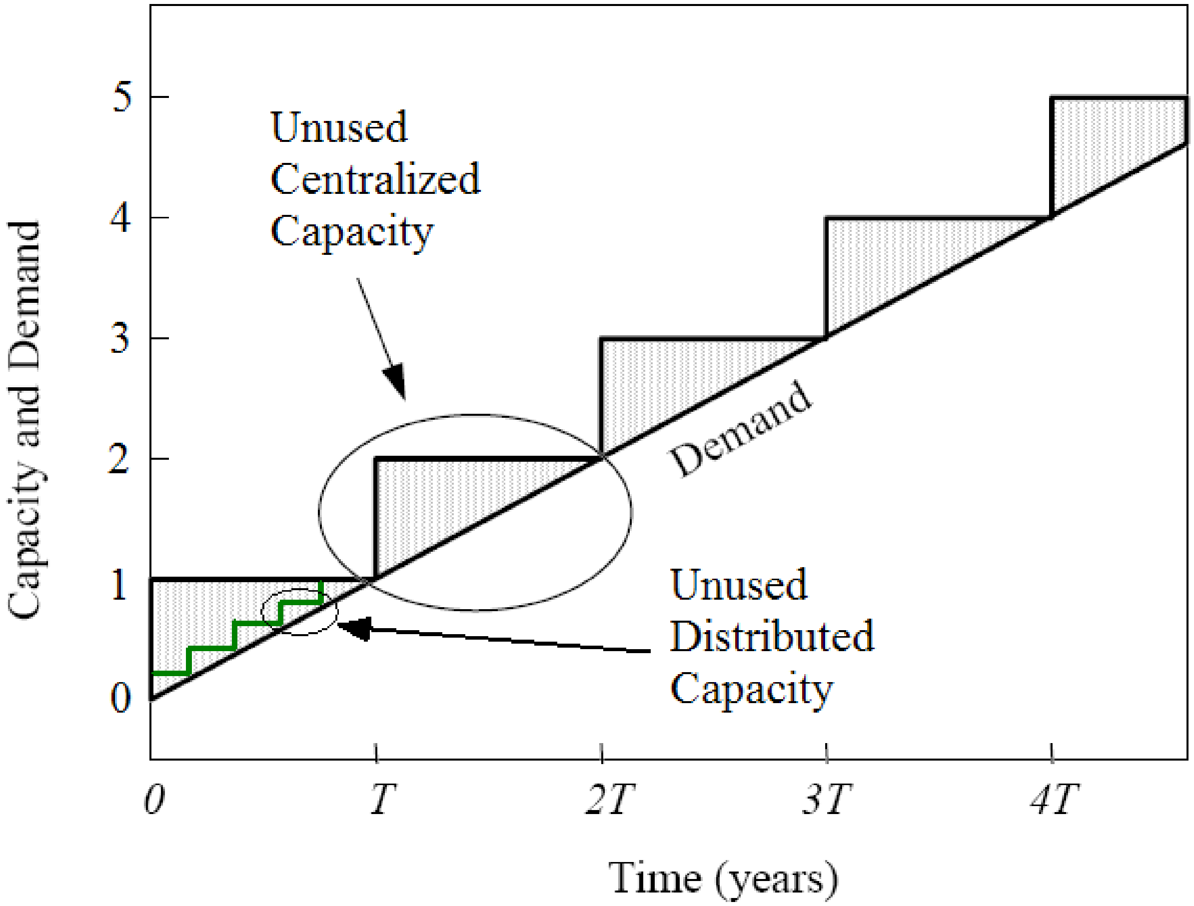


Figure 3: Comparison of Unused Capacities, (Hoff et al., 1996)

Figure 3 shows a comparison of wasted capacities between distributed generation facilities and centralized facilities. Although distributed facilities typically cost more per kWh installed capacity, its initial capital cost is much less than that of a centralized facility. The stepping of increases in distributed capacity in Figure 3 is a crude way of showing how it can meet demands when in reality it would be a much smoother transition.

Centralized generation provides a large amount of power that we rely on today, but distributed generation clearly offers many advantages, especially when considering renewable power sources. Economically, in the big picture, centralized generation is typically cheaper than distributed generation, so when a large amount of power is needed in the near future such as a boom in an economy, or rapid development of countries (such as China), centralized generation is the most economical way of producing power. If a large amount of power is needed, but not immediately, distributed generation can help to defer the original plan by a number of years depending on its capacity (Strachan & Dowlatabadi, 2002).

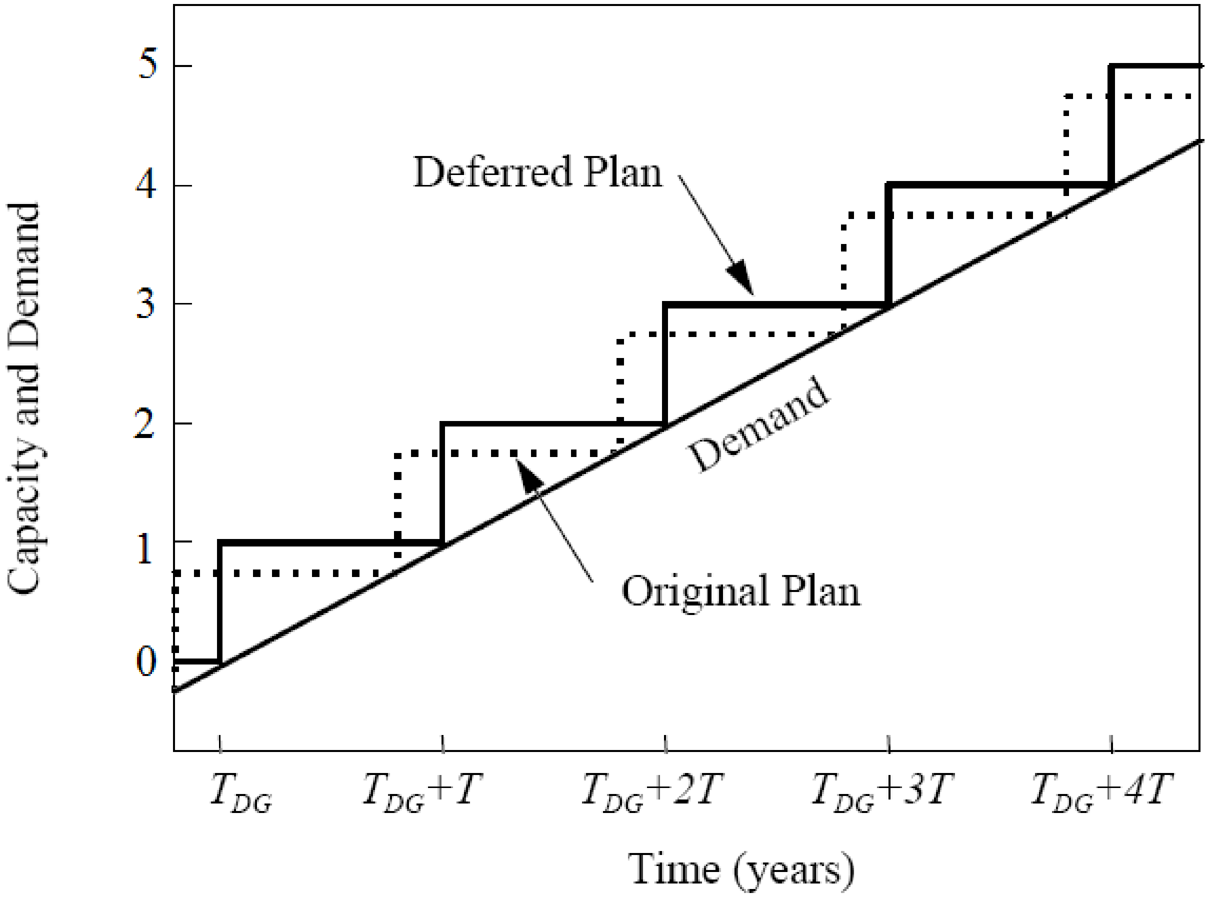


Figure 4: Distributed Generation can defer the original plan, (Hoff et al., 1996)

Figure 4 shows how the installation of distributed generation can help to defer the original plan of installing new centralized generation plants. This is valuable when a large investment into a centralized plan is not desirable.

4.0 Technologies

Various technologies can be used for both centralized systems and distributed systems. Technologies that are sizable and relatively simple to maintain (such as wind turbines and combustion engines) are better suited for distributed systems while technologies that are harder to manage (such as nuclear reactors) are more suited for centralized systems. Some technologies can be effective in both systems such as wind turbines (distributed wind power and wind farms) and burning of fossil fuels (coal plants and combustion engines). Currently, small distributed systems are being used as a secondary power source for commercial and industrial facilities. These systems are typically either diesel engines or gasoline combustion engines due to their simplicity and technological maturity.

Even though combustion engines are the most popular forms of distributed generation, many systems opt to use renewable sources such as wind power or solar energy. Table 4 shows a comparison of different power sources per square meter of the earth's surface.

Table 4: Specific Power Comparision of Various Sources, (Fraser, R.A., 2008)

Source	Specific Power	Percent of Solar
Solar	220 W/m^2	-
Tidal	0.005 W/m^2	0.0021%
Geothermal	0.063 W/m^2	0.0290%
Fossil Fuels / Nuclear	0.016 W/m^2	0.0073%

As can be seen from table 4, solar energy is much more abundant than other sources that are available to be used today. This is due to the fact that solar energy reaches all sun-facing surfaces of the earth at all times.

The technologies used for distributed generation systems usually vary with the application, intention, and cost. In applications where pollution control is a major issue such as highly populated urban areas, clean sources may be used to alleviate this issue. If a system is built with intentions of being green and renewable, then renewable sources may be used (Joos, Ooi, McGillis, Galiana, & Marceau, 2000). Currently most systems are installed with cost and reliability in mind, which is why internal combustion engines are primarily used. The cost of these generators are generally lower than clean, renewable technologies.

Clean and renewable energy generation technologies have been available for many decades now. Until only recently, they haven't been very popular since traditional fossil-fuel technologies were better developed and more cost efficient. It has become more obvious now that traditional fossil-fuel technologies are approaching the end as resources around the world are being depleted (Ramakumar, Abouzahr, Krishnan, & Ashenayi, 1995).

Wind, photovoltaic, solar thermal, geothermal, biomass, and fuel cell technologies will be discussed.

4.1 Wind Power

Wind power has been around for a fairly long time. Wind mills have been used on farms as a source of power for grinders or pumps; they simply convert kinetic energy into mechanical energy. Even as far back as nautical exploration, sails were used to harness the power of the wind to give motion to boats and ships.

Wind is created by the different temperature gradients in the atmosphere caused by the sun and because of this, wind is considered a form of solar energy which puts it into the renewable category. Similar to solar energy, wind power is very clean since it produces no harmful emissions. Fortunately, when the sun is blocked by clouds in the sky, wind is still generated by the temperature gradient between the ground and the sky.

The concept of converting wind energy into electrical energy is very simple and in a way, similar to any form of traditional generation methods; using a source to power a generator but without the harmful emissions (Sherif, Barbir, & Veziroglu, 2005). Wind turbines can be thought of as the exact opposite as what fans does; instead of using electricity to generate wind, they use wind to generate electricity. The blades on the wind turbine convert the kinetic energy from the wind into mechanical energy that is then used to turn a shaft in a generator to generate electricity. This is similar to traditional generation techniques but instead of using coal or oil to generate steam to power a generator, wind is used directly.

Typically, when someone thinks about a turbine, they picture a turbine that is similar in appearance to a typical household fan. There are actually two types of wind turbines; horizontal-axis and vertical-axis turbines. The horizontal-axis turbine is the most common turbine that is currently used around the world today. These turbines have yaw motors installed so they can turn and face the wind to maximize the power output. They come in a variety of sizes ranging from 50 W to 5 MW depending on their application. Vertical-axis turbines are not as popular as horizontal-axis, but they have proven to be a good solution for generating power in low wind speed applications (Sherif et al., 2005). Operational data have also shown that vertical-axis turbines are generally less efficient than equivalent horizontal-axis turbines. Vertical-axis turbines do not need to have a separate system to control which direction it is facing because these turbines are. Since they are vertical facing, the generator and the gearbox may be placed at ground level to help maintenance become an easier task. Whenever the main bearing in the rotor must be removed, the rotor must be completely removed in both horizontal-axis and vertical-axis turbines. In vertical-axis turbines, however, the entire turbine must be taken apart to get to the bearing. Vertical-axis turbines may also need guy wires to hold it up, which is impractical in most cases. Also, since the turbine is lower to the ground, the lower part of the rotor is only exposed to low speed wind which decreases the overall effectiveness of the turbine.

In general, a larger turbine will have a higher power rating, especially for horizontal-axis turbines since larger turbines will need to be higher off the ground due to length of the blades and because of this they are exposed to faster, more laminar winds.

There are seven classes of wind power densities at both altitudes of 10 meters and 50 meters outlined by the United States Department of Energy (DOE). Table 5 is an overview of what each class represents. Usually, low wind speeds are considered unusable since it is not economical to build a turbine that produces a less than reasonable amount of power. The opposite is also true when the wind speeds are too fast; the turbines must be shut down to avoid damage of the turbine itself.

Table 5: Classes of Wind Power Density at Heights of 10m and 50m, (Union of Concerned Scientists, 2008)

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

Even though wind is a fairly abundant resource, an assessment of location-specific wind resource potential must be done. The DOE’s National Renewable Energy Laboratory is currently producing and validating a high-resolution wind resource potential assessment to replace the existing, less accurate assessment from 1991. Preliminary assessments have found that even at class 3 wind power densities, wind turbines are able to power up to four times more than the current electricity needs of the United States.

Wind speed and density both play a role in how much power is generated by the turbine. The wind’s speed is important for determining the speed of the turbine while the density is important for maintaining the speed of the turbine. For example, low density air at high speeds will be able to turn the turbine slowly since there isn’t enough force behind the air to overcome the friction in the turbine. High density air at low speeds will be able to yield the same results since the friction is easily overcome by the density of the air, however, its low speed is unable to turn the turbine any faster. Fortunately, in practice, the air density varies within a very small range therefore density does not play a significant role in wind power when compared to wind speed alone.

As with some of the modern renewable technologies, intermittency is a concern for wind power and because of this, it is very improbable that a wind turbine will be able to generate the power that it is rated for. A few techniques have been used to measure a more realistic output rating of a wind turbine. The c*apacity factor* is calculated over a certain amount of time by taking the amount of power that is actually generated divided by the amount of power that would have been generated at its full capacity. This capacity factor is location specific since the same turbine can operate at a different capacity factor at a different location. *Specific yield* is used most often as a comparison between turbines. The specific yield is measured as the amount of power that the turbine is generating per year divided by the area that is swept by the blades during rotation. It can also be a useful tool for sensitivity analysis for determining how much gain or loss can be had by increasing or decreasing the length of the blades. Intermittency of the wind in most applications is not a large issue since the system will be grid-tied. In more remote areas, intermittency is a larger issue since these areas seldom have grid connections.

The cost of the turbine can be assessed to determine the value of the actual turbine. Installation costs, however, is much trickier to assess. Since the location of the installation is usually different for each application, a survey of the area must be done prior to the actual installation. Factors such as the distance from the turbines to the load and the angle of the surface contribute to the installation costs. As for the cost of the electricity produced, this will vary depending on when the electricity is needed the most as well as when the wind is blowing the hardest. If the wind blows the hardest during peak demand periods, the power from the turbines will be valued more highly than if the wind blows during off-peak periods.

While the United States used to be the leader in wind power, it currently ranks third worldwide behind Germany and Spain. Figure 5 shows the increase and breakdown of wind power capacity around the world. As can be seen in Figure 5, wind power is increasing in popularity each year over the last. In 2005, worldwide installations reached more than 11,500 MW since 2004, approximately a 40.5% increase. At the end of 2005, the United States' wind turbine capacity reached 9100 MW, capable of powering up to 2.3 million homes (Martins, Krajacic, Duic, Alves, & Carvalho). Denmark has one of the best wind resources around the world and so they are able to supply approximately twenty percent of their power by using wind turbines alone. The reason for Denmark being only fourth or fifth is that although twenty percent of their power is wind, they are still a fairly small country compared to the top three powerhouses.

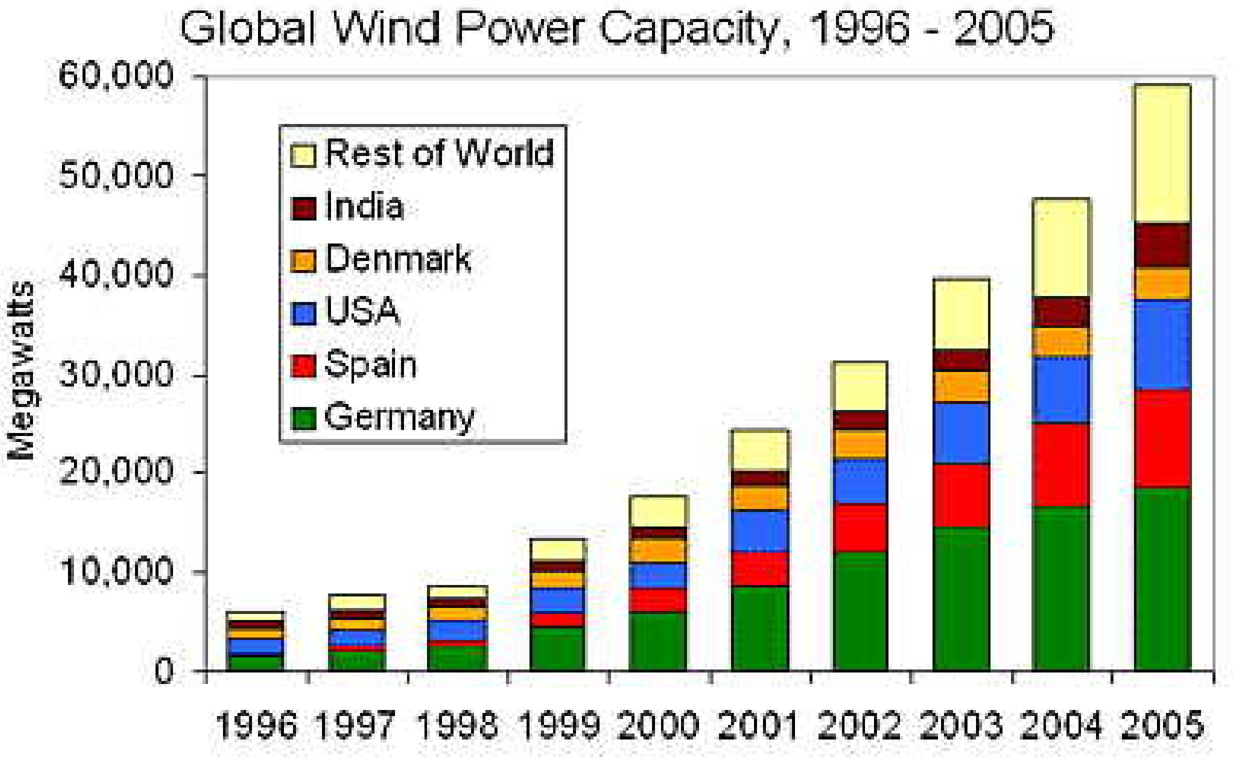


Figure 5: Global Wind Power Capacity, (Union of Concerned Scientists, 2008)

The cost of electricity generated by wind turbines have decreased from 25 cents per kWh to approximately 4-6 cents per kWh since 1981. This is due to the considerable increase in wind power popularity across the globe in the past decade. The cost of wind turbines, as projected by the DOE, will continue to decrease in the next 10 to 15 years but the rate of decrease will not be as dramatic as the past 20 years have shown. With almost all rapidly growing industries, there are challenges that slow their growth and in the case of wind turbines, the amount of steel and the cost of steel is the major factor. General public acceptance is also a large factor in the success of wind power. Many will agree that wind power is a good technology but when it comes time to install turbines, many people will disagree to having a turbine close to their property. This is known as the “not-in-my-backyard” mentality.

Wind power shows the most amount of promise to steer the future of power generation towards a cleaner, renewable industry (Menzi). Public awareness and available material resources will contribute largely to the success of this technology.

4.2 Solar Power

The term solar power usually means converting sunlight into useable electricity. The actual term "solar power" has very little meaning since it is not specific enough. Solar power can be separated into two main categories: solar PV (photovoltaic) and solar thermal. We can say that the most common perception of solar power is solar PV.

4.2.1 Photovoltaics

PV cells are very common in everyday electronic devices. The most abundant examples are calculators and watches. Most calculators, if not all are hybrids of PV cells and batteries. The PV cells are used when there is sufficient light where the batteries are used during lower illuminated situations.

The biggest application of PV cells used to be strictly for space programs such as satellite projects or space shuttles. The use of PV cells in space applications is ideal since objects in space can be located in such a way to ensure that there is constant sunlight exposure to the cells. Solar PV cells are also used in remote areas where conventional sources of electricity are not readily available (Kolhe, Agbossou, Hamelin, & Bose, 2003).

The material used for solar PV cells vary depending on the manufacturer and the cost. Silicon is the most commonly used semiconductor for solar PV applications. There are different kinds of silicon that are used with single crystalline silicon being the most efficient. Polycrystalline silicon and amorphous silicon are used primarily to reduce the cost of PV cells. Other materials are used in combination with silicon to enhance the overall efficiency of the final PV panel, and this will be discussed further into the paper. Multiple solar PV cells are connected together to form a solar PV panel. This is the most common form of solar PV generation.

Contrary to logical thinking, pure silicon is actually a very poor material to use for capturing sunlight energy or photons. The stable crystalline structure of pure silicon is what makes it a poor material for producing electricity. Silicon has four valence electrons that are bonded to four other silicon atoms in its crystalline structure and in order to destabilize this structure, impurities are desirable for efficient operation. Phosphorous is a common element that is used to destabilize the crystalline silicon structure. Generally, any element that has a number other than four valence electrons is considered and impurity to this crystalline structure. The process of introducing impurities to a pure substance is called *doping*.

There are two paths to dope silicon; adding elements with more than four valence electrons and adding elements with less than four electrons. These two ways are called N-type and P-type doping, respectively. Both N-type and P-type cells are required for a solar PV cell to be able to operate. In N-type cells, phosphorous is commonly used, which has five valence electrons. The fifth electron creates an imbalance of electrons, where these electrons are highly unstable and are relatively easy to dislodge. In P-type cells, boron is commonly used, which has three valence electrons. The absence of the fourth electron creates a “positive” hole for electrons to migrate to. P-type cells and N-type cells are put together to create an electric field that allow electrons to travel across. One P-type cell and one N-type cell come together to form one solar PV cell, since a P-type or N-type cell on their own will do nothing.

The potential difference is created by the gap between the P-type cell and the N-type cell. Electrons travel across the gap from the N-type cell to the P-type, however, this does not continue until the electrons in the N-type cell are exhausted. There is equilibrium of electrons between the two cells and this is called the electric field. This electric field acts as a diode, preventing electrons from moving in the reverse direction from the P-type cell to the N-type cell. This diode-like behaviour is what actually drives this system to generate useable electricity. When the photons reach the P-type side of the PV cell, electrons are dislodged from the electron-positive hole pair. Since the electrons are not able to travel across the gap to the N-type side, metal wires are connected to the P-type side to allow the electrons to travel to a load, and then back to the N-type side to complete the circuit. Simultaneously, since electrons have been dislodged from the P-type side, electrons move across the gap from the N-type side to the P-type side to fill the holes that have been left while the "used" electrons return to the N-type side from the wires. Figure 6 shows the schematic for this process.

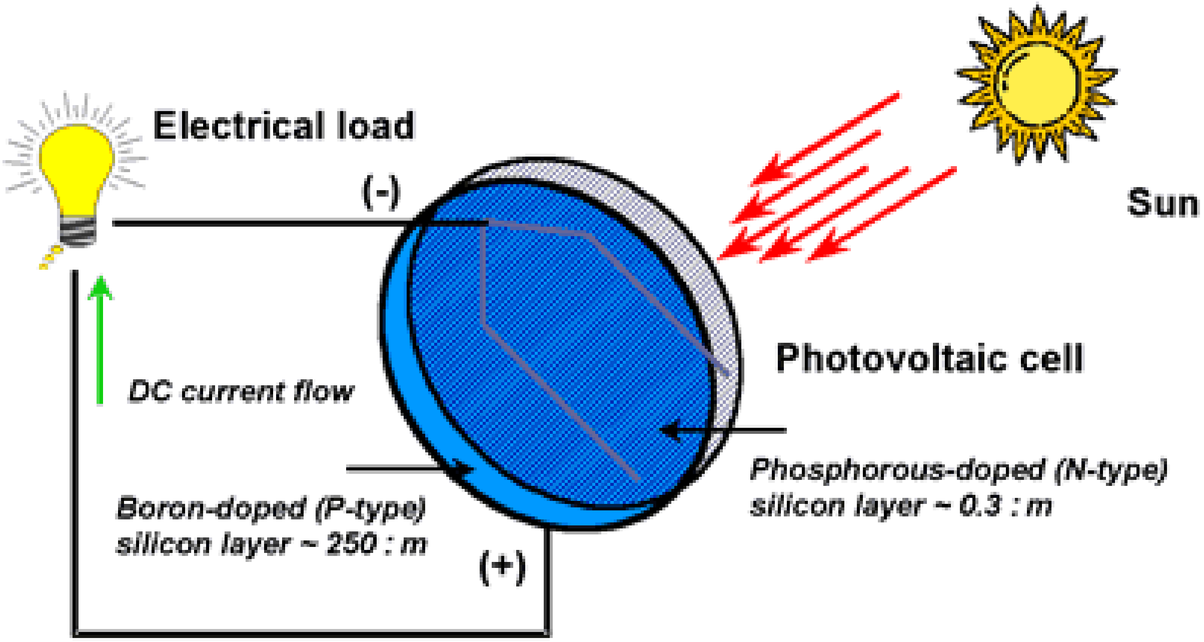


Figure 6: Photovoltaic Cell, (Florida Solar Energy Center, 2007)

The solar PV cells, depending on their material, are able to absorb only a certain range of sunlight. This is called the *band gap energy*. Other wavelengths that are incompatible simply pass through the panel unused. This is the largest contributor to a low operating efficiency of approximately 10% to 15%. To put this into perspective, approximately 1000 W/m^2 of power actually reaches the surface of the earth on a clear day, however, these panels are only able to convert 100 W/m^2 to 150 W/m^2 of sunlight to useable power.

Since the energy required to dislodge an electron is fairly specific, it is possible to have twice the amount of energy to dislodge two electrons simultaneously, but this effect is very insignificant so it does not increase the efficiency by any measurable amount. Material with lower band gap energy will be able to absorb more of the sunlight that the cell is exposed to, thus generating a higher current, however, a lower band gap energy material inherently operates at a lower voltage. In crystalline silicon, the energy required to dislodge an electron is approximately 1.1 eV.

Depending on the impurities used, this energy can vary. Optimality has been found using materials that require 1.4 eV.

Turning this electric field into usable electricity by connecting conductors is not an easy task either. Since each cell itself within a panel must be treated as a power producing unit, connections must be made at each site that contains a cell. Attaching conductors at the side of the cells is far from ideal since electrons that are dislodged in the center of the cell will have a long path to travel before it gets to the conductor. Since silicon is only a semi-conductor, it has a very high resistance when compared to metal conductors, resulting in high loses. To overcome this problem, conductors are connected to many points within the cell to create a low resistance travel path for the electrons. This is called the metallic contact grid. This solution is fairly efficient for the bottom side of the cell but the top side of the cell is not as simple. The top side of the cell is the actual surface that comes into contact with the sunlight, therefore the same conductor setup cannot be used for this surface. Small thin conductors are used for the top surface of the cells but this introduces two problems. First, thin conductors have higher resistances than thicker conductors and secondly, the conductors themselves block some of the sunlight from reaching the cells. If no conductors are used, no power is generated and likewise, if too many conductors are used, no power is generated. Therefore, there exists an optimal point where enough conductors are used to get the most power. More expensive cells use transparent conductors that minimize the amount of sunlight that is blocked.

Another inherently inefficient property to consider is silicon’s natural reflectivity. If the solar PV cells are left naturally exposed, most of the sunlight will simply reflect off of the surface with little photons remaining to be absorbed. An anti-reflective coating is used to combat this issue to reduce reflection losses to less than 5%.

As mentioned earlier, different materials can be used to capture different spectrums of light while incompatible light energies simply pass through or reflect off of the panel. Some solar PV panels use a combination of solar cells with different materials in a layered setup. This is called a multi-junction panel. Figure 7 gives a simple layout schematic of a multi-junction panel. This increases the overall efficiency of the panel since more sunlight is actually absorbed as energy.

This setup, however, re-introduces the problem with mounting conductors since the only metallic contact grid is on the very bottom of the panel where transparent conductors must be used even between the layers.

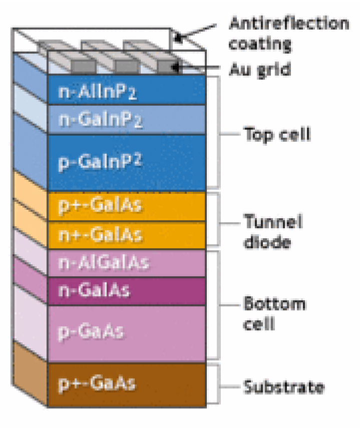


Figure 7: Multijunction Solar Cell, (U.S. Department of Energy, 2008)

Solar PV panels, as mentioned earlier, are most typically used in portable applications. To properly apply solar PV panels in a larger scale such as residential areas, many factors must be taken into account before PV can be considered. From a cost perspective, the actual panels themselves are fairly expensive with payback periods that are not reasonable. Next, the orientation of the solar PV panels is of the largest concern. Usually, the angle of the roof on a house and the direction the house is facing is already set (on a built house) and impossible to change without tearing the house down. In the Northern hemisphere, solar PV panels should be oriented so that they face the south. The angle that the solar PV panels should be tilted at is dependent on the time of the year. Estimations of angles are easily estimated by subtracting the suns altitude (North = 0°) from 90°. Typically, for residential use, tracking systems to track the location of the sun are too expensive for the amount of panels installed. Commercial solar PV panels, however, may easily have tracking systems to optimize their sunlight collection since commercial arrays are much larger. Where tracking systems are not economically viable, a compromised angle can be used depending on the purpose of the array. If summer collection is desirable, then a shallow angle is used to optimize summer collection. Having a shallow angle, however, will render the panel useless in the winter when the snow piles up onto the surface. Even if part of the panel is covered, the efficiency of the panel will decrease to less than half of its optimal operating efficiency. Winter collection requires a steeper angle since the sun is lower in the sky during that season. A compromise between winter and summer can be had by doing simulations using solar data to get good winter and good summer collection rather than excellent one or the other.

Solar PV is normally sized to assist with peak demands in electricity (where demand is higher than solar PV output) while providing enough electricity to run the house during times with high levels of sunlight (where solar PV output is higher than demand) with excess electricity being sold back to the grid. While this setup looks attractive at first glance, there are many issues that must be addressed, both from a technical and safety perspective. In order to be connected to sell power back to the grid, a few criteria must be met. First, the power that the grid provides is in AC while solar PV panels are DC so inverters must be used. Household appliances and devices also require AC power rather than DC so inverters are required to convert DC power to AC regardless of being connected to the grid or not. This results in an efficiency loss regardless of how high the operating efficiency of the inverter is. Not only is an inverter required to convert the power from DC to AC, it also has to make sure that the sinusoidal wave of the electricity from the output of the inverter matches that of the grid. Second, if the solar PV system is providing electricity into the grid, the system must be able to tell when there is a power outage in the community and cease providing electricity to the grid. This is very important since outages are usually caused by physical faults which can be further damaged if electricity is forced through the fault. This concept is called *islanding*. Islanding is also very important to the safety of the linesmen working on the fault.

Solar PV panels are fairly maintenance free where they can run for up to 20 years with little to no maintenance. In residential areas where there is snowfall and has a high density of trees may increase the maintenance on the solar PV panels.

While sunlight energy is free, solar PV panels are not. In fact, they are fairly expensive as a generation technology. At $9 per watt installed, it is the most expensive renewable generation technology on the market at this time. In North Carolina, a solar demonstration house has installed a 3.6 kW solar PV system. At $9 per wall, this system cost $32,400 and this system only covers approximately fifty percent of the electricity needs of this home.

4.2.2 Solar Thermal

Solar thermal heating has been around in natural habitats for a very long time. Essentially, solar thermal uses the sun to heat either water or air. The earth, during summer months can be thought of as being heated using the principle behind solar thermal heating. We have all experienced solar thermal heating whether by a hot car interior in the summer or warm water from a hose that has been sitting in the sun.

Typically, solar thermal technologies are applied to water heating since hot water is a valuable resource. There are two types of solar thermal systems; passive and active systems. The passive systems rely solely on thermodynamics to move the water while active systems achieve this by means of a pump.

Within passive and active systems, there are two further distinctions; direct and indirect systems. In direct systems, the hot water that is used in the facility is directly passed through the solar collectors and is heated directly by the sun's radiation. Direct systems are also known as "open loop" systems. Even though water is heated directly at the solar collectors, the water is still stored in a conventional hot water tank where it is kept warm by electricity or natural gas. Since this water is directly circulated through the collectors that are typically installed outdoors, during the cold winter season, freezing of water inside of the collector or any pipes that are exposed to the outdoors may create additional design issues. Indirect systems, otherwise known as "closed loop" systems, heat the water that is used in the facility indirectly. This is done by having an antifreeze solution in a closed loop with the solar collector. This heat from the antifreeze solution is transferred to a tank of water through a heat exchanger. Although this system solves the issue of freezing during the winter months, it does not heat the water as well as a direct system. Similar to direct systems, the warm water is kept warm by electricity or natural gas in a hot water tank.

As it may seem obvious by now, solar thermal water heating systems whether direct or indirect cannot be stand-alone systems due to the fact that sunlight may be intermittent during the day and non-existent during the night. Solar thermal systems must be combined with another form of water heating for when the sun is not shining; specifically electrical or natural gas heating. Natural gas heating is the most common method of heating water since it is currently cheaper than electricity, however, it is not renewable and will not be discussed in this paper. Electrical heating, depending on the source of the electricity, can be considered the cleaner form of energy between the two. Using solar PV to provide this electricity will suffer from the same problems related to solar thermal water heating. The difference, however, lies in the fact that batteries can be used to store the electricity to be later used to keep the water warm.

Solar thermal systems, similar to solar PV systems, must be able to absorb the sun’s energy. Solar thermal, however, does not absorb the energy and convert it to electricity, rather it absorbs the sunlight as heat; very much like wearing a black shirt on a bright and sunny day. Flat plate collectors are among the most commonly used collectors on the market. These collectors work by having copper pipes snake back and forth through the collector. The pipes are in direct contact with the collector material and are painted black to increase heat absorption. The collector material can be any material that is resistant to thermal degradation with high heat transfer properties. The pipes are also covered in glass and glazing which helps to reduce the amount of heat escaping. The anatomy of the collector can be seen in Figure 8.

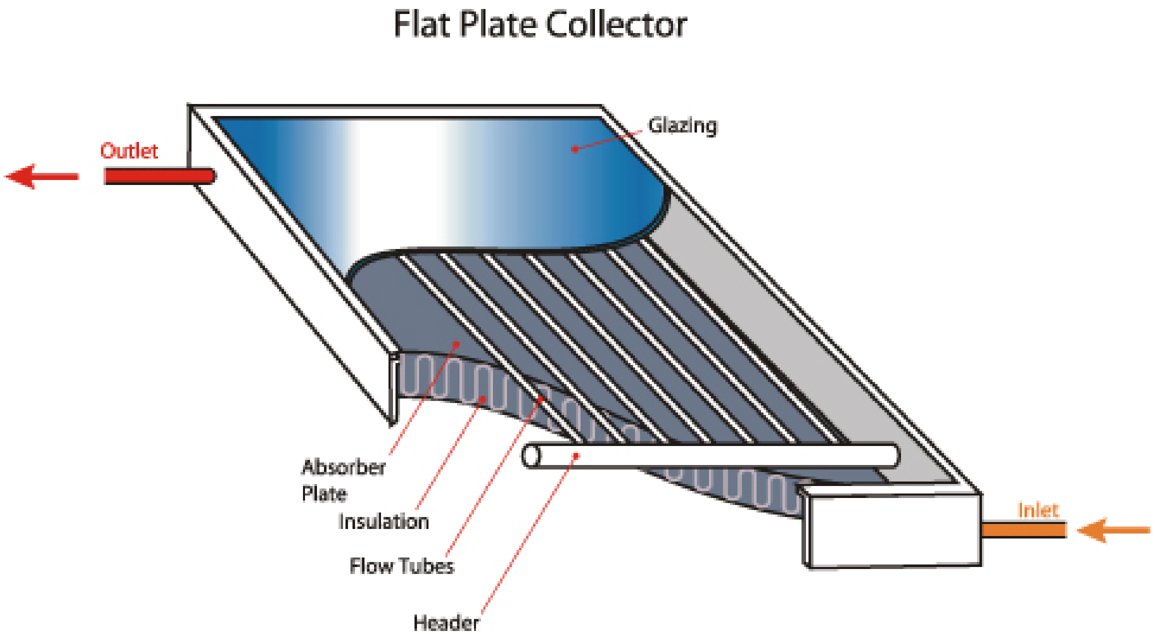


Figure 8: Solar Thermal Collector, (Southface Energy Institute, 2008)

If water at higher temperatures is required, more efficient systems such as evacuated tube collectors or parabolic trough collectors can be used.

Parabolic trough collectors use what are essentially reflectors to reflect sunlight to a central collector to effectively increase the light gain per area. This concept allows for cheaper systems and higher efficiencies since reflectors (mirrors) are cheaper than actual solar thermal or PV panels. Solar thermal collectors benefit from parabolic trough setups with little to no drawbacks, however, solar PV loses efficiency as the temperature increases, therefore parabolic troughs are normally a solar thermal technology.

4.3 Geothermal

Geothermal energy is the most accepted and widely used renewable source in the world. This is because it is fairly abundant, and has been available (mostly in direct usage) for a very long time. France has been using geothermal water to heat up to 200,000 homes since the 1960's.

A geothermal resource is found in the ground as reservoirs of water that is superheated by the earth's temperature under pressure. These reservoirs are located using geological, electrical, magnetic, geochemical, and seismic surveys.

There are two methods of utilizing this resource: electrical generation and direct uses. Direct uses are the first methods that geothermal resources were used for. These include using the water's heat directly for cooking, bathing, heating, agriculture, aqua-culture, recreational, and medicinal purposes. These applications are primitive, but they are highly effective and can be treated as valuable methods for reducing our dependence on fossil-fuels.

Electrical generation is a little more complicated than direct uses, however, the concept is still fairly simple. Within electrical generation, there are three subgroups: dry, flash, and binary plants. The use of these plants depends on the conditions of the reservoir that they are built upon.

Dry steam power plants use reservoirs that contain mostly steam and very little water. This type of reservoir is relatively rare when compared to other reservoirs. In this type of plant, the reservoir is tapped by drilling a well to allow the steam to escape into the plant. The steam powers a turbine that in turn generates electricity through the movement of the turbine. The steam that was extracted from the reservoir is condensed and injected back into the reservoir via another well. The first dry steam plant was built at Larderello in Tuscany, Italy in 1904. This power plant has been rebuilt since its destruction during World War II. This plant is still operational today. The most successful plant is located at The Geysers, just north of San Francisco. This project was started in 1960 and is still in operation today.

Flash power plants are built on top of reservoirs that contain hot water under pressure. The temperature of the water in the reservoirs can vary between 150°C to 370°C. The same method of retrieving this water is used where a well is drilled into the reservoir to allow the water to travel to the power plant. In this type of reservoir, the water that reaches the surface at atmospheric pressures flash instantaneously to steam which powers a turbine that generates electricity. The steam is re-condensed and is returned to the reservoir for reheating via another well. These reservoirs are the most common reservoirs found around the world and for this reason most geothermal power plants are flash type.

The last type of power plant, the *binary* power plant, is built on top of the same type of reservoir as the flash power plants. The differences, however, are found in the temperature of the water itself. The water in these reservoirs is found to be between 120°C to 180°C. At these temperatures, the water does not flash to steam at a quick enough rate to allow for the turbine to run effectively. The name binary comes from the fact that this type of power plant uses two liquids; water and a liquid with a low boiling point. The hot water is fed into a heat exchanger where the heat is transferred from the reservoir water to the other liquid and the vapour from this liquid is used to power the turbine. In this plant, both the reservoir water and the other liquid are in a closed loop system, therefore very little, if nothing at all, is lost. This allows for power plants with extremely low emissions (usually only steam) to be built. This results in very high efficiencies since all of the generated vapours power the turbine with very little heat loss.

Figure 9 gives an example of wells feeding hot water to the geothermal power plant while returning the warm water back into the earth. The first section on the left is an example of a flash power plant, the middle section a dry power plant, and the last section on the right is a binary power plant.

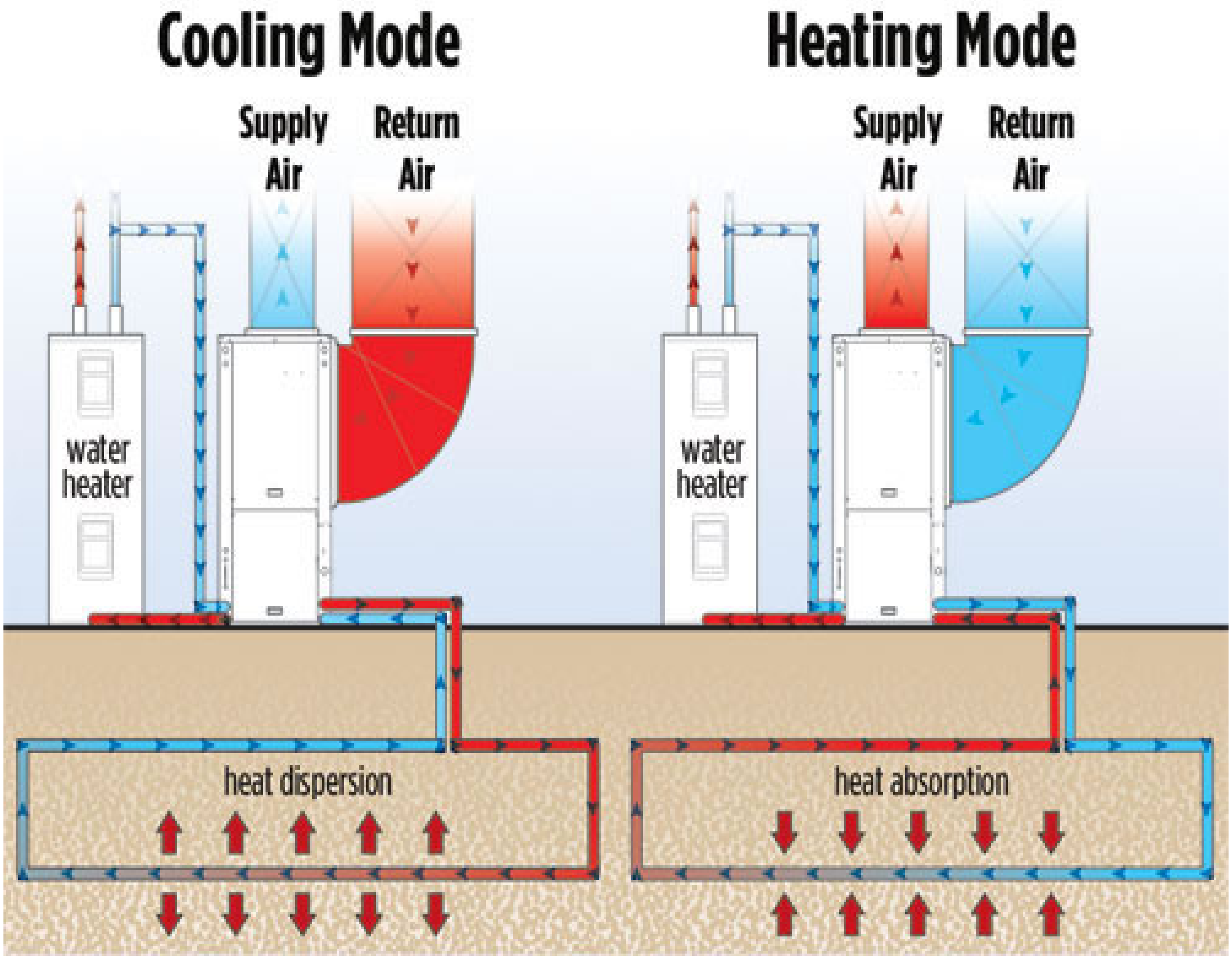


Figure 9: Geothermal Loop, (Alabama Geothermal Services, 2008)

Geothermal energy is very effective since it essentially uses the earth as one big heatsink. Since the heat in the earth is regenerated by the decay of radioactive elements in the earth's core, geothermal sources are considered renewable.

Under direct uses for geothermal energy, there is another subtype known as heat pumps (also known as geo-exchange systems). In this system, reservoirs are not required, which makes this system more attractive for residential use and other applications where reservoirs are not present. Geo-exchange systems work by essentially burying pipes below the surface and pumping a liquid through the pipe to transfer heat to the earth in the summer and retrieve heat from the earth in the winter. When the system is designed and sized properly, it becomes an effective method for supplementing cooling and heating requirements throughout the year. The pump that is required, however, requires electricity to create work so a cost analysis must be done prior to installation to determine if the pump will consume more or less electricity than is originally required for traditional heating and cooling methods. Generally, systems are installed below the earth where the temperatures are relatively constant between 7°C to 15°C. This is to ensure that cooling and heating are both possible during the summer and winter seasons respectively. The United States currently has about 300,000 heat pumps installed for geothermal heating.

As a rule of thumb, the temperature increases between 17°C to 30°C for every kilometer of depth into the earth.

Geothermal plants are fairly reliable since it is only dealing with water or steam with the exception of the binary plant which deals with another liquid. They are designed to run continuously from the time they are started up to the time they are shutdown. Not only are they reliable but they require relatively lower real estate for the same amount of power generated as compared to fossil-fuel plants.

Since most geothermal sources are located in natural habitats (usually a visually stimulating area) the plants are designed with aesthetics in mind to minimize the visual intrusion on the area. Some plants that use air cooling can have a height of as low as only twenty-four feet. Plants are prohibited from being built in certain locations to preserve its natural beauty. Such a place, for example, is the Yellowstone National Park in the United States.

Some geothermal reservoirs naturally contain hydrogen sulphide (H_2S), silica, or even both. H_2S is most commonly detected by our noses as an odour resembling rotten eggs. Industrial scrubbers are used to remove up to 99% of this gas from the water/steam inlet stream. Currently, H_2S can be converted to sulphur and sold to the market and the silica is used to manufacture concrete.

In 1999, approximately 8,200 MW of electrical power was generated world wide with thermal power weighing in at approximately 9,700 MW. Of the 8,200 MW, the United States generated approximately 2,850 MW alone. China had the highest thermal power using geothermal sources at 1913 MW. See appendix C and tables 12 and 13 for the breakdown of the electrical and thermal generation.

4.4 Biomass

When clean and renewable technologies are concerned, wind power and solar power are normally the most talked about. In fact, biomass is the second oldest renewable source of energy known to man kind, first being solar power of course.

Since solar power has been available since essentially the beginning of our solar system, biomass comes in second place with the discovery of fire by burning wood. Similar to the cause of wind, biomass' source of energy and renewability also comes from sunlight energy. The plants, grasses, and trees use a process known as photosynthesis to convert sunlight, carbon dioxide, water, and other nutrients into useful carbohydrates and other complex compounds. They are then burned or converted into liquid fuels to be used as a source for power, whether for heating or for electricity. These plants, grasses, and trees can be thought of as natural batteries for sunlight energy.

During the burning process to create heat, carbon dioxide is released into the atmosphere. Contrary to popular belief, this carbon dioxide is considered clean while the carbon dioxide from fossil-fuel plants is not. This is because there are two different carbon cycles in action today; the natural carbon cycle, and the human-made carbon cycle. In the natural cycle, there is a balance between carbon dioxide consumption and carbon dioxide emission. The amount of carbon dioxide released by the plants is fairly close to the carbon dioxide consumed by the plants during its lifetime. The human-made carbon cycle is at an imbalance with nature since the carbon dioxide being released is from centuries, even millenniums ago, resulting in a positive gain in carbon dioxide. See Figure 10 for a diagram of the natural carbon cycle.

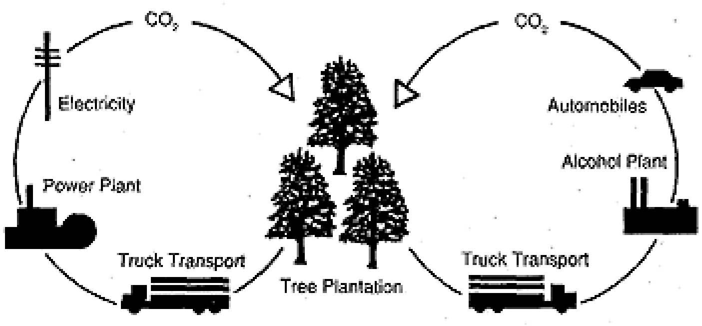


Figure 10: Natural Carbon Cycle, (Union of Concerned Scientists, 2008)

If history has taught the world a lesson, it would be that we cannot keep receiving without giving something back. This is very true for power production using biomass. There are vast amounts of natural plants, grasses, and trees available to be used, however, it can still be depleted if we're not careful. Biomass is only sustainable if the amount that we use is equal to the amount that we grow. This is where energy crops come in.

Various kinds of plantations can be grown and used as energy crops; trees, plants, grasses, and aquatic plants. Trees are a popular choice for energy crops since they grow back fairly quickly and some species of trees even exhibit an ability known as *coppicing*. Coppicing is where trees will grow back even though they have been cut down, as long as the roots and the trunk are left in tact. This ability allows this crop of trees to be harvested every three to eight years up to a maximum of twenty to thirty years before the crop must be replanted. Not only are they able to grow back without replanting, most tress with this ability also grow very fast; up to forty feet between harvesting. Grasses are similar to trees in that they can be harvested many times before replanting is necessary; up to ten years.

Different species of trees and grasses exist in different parts of the world because of the conditions that the trees are subjected to. The same also applies for plants.

Food crops can also be used as a source of biomass energy. The problems, however, are that food crops require much more maintenance than energy crops since they must be replanted after each harvest. Even though food crops require higher maintenance, corn is among the most used source for biomass today. Oils from plants can also be converted to fuels, but also require a high level of maintenance when compared to energy crops.

The most promising plant currently resides underwater; microalgae plants. The reason why these plants are the most promising currently is because of its incredible growth rate in a harsh environment; hot and shallow saline water. Not only are they able to grow in harsh conditions, carbon dioxide can be used to accelerate the growth of this microalgae. Green Fuel Technologies uses a technology called *Emissions-to-Biofuels* that captures carbon dioxide from power plants to accelerate the growth of algae.

Not only are trees, plants, and grasses used for biomass power generation, various kinds of waste can also be used. Similar to trees, branches and tree tops that are left over from lumber harvesting can be used as a source of biomass fuel. Natural habitats for birds and other animals also use these branches and tree tops so a balance must be found as to not disrupt their natural environment. Manure from agriculture are normally used as fertilizers for the food crop or even energy crops but in many cases too much manure results from over fertilization that causes runoff. This runoff in turn causes problems for surrounding bio-systems such as degradation of water quality and soil quality. The extra manure left over from properly fertilized crops can be used to produce fuels. Urban waste such as used wooden shipping pallets, biodegradable garbage, and gases from landfills can also be used in biomass power generation.

Traditionally, biomass is converted to usable heat and power by simply burning them. When fire was discovered, wood was used as the main source of fuel for the fire. This fire was most likely used for keeping warm, cooking food, and lighting purposes. Surprisingly, much of this initial discovery is still used today. This heat can be used directly or indirectly by feeding it into a boiler to make steam that drives a turbine to create electricity. Burning biomass directly is inherently inefficient, as with burning any source. Even though burning biomass is fairly inefficient, it is still fairly clean since it is part of the natural carbon cycle and because of this, biomass is burned in substitution for coal or oil in a traditional power plant. This concept is called *co-firing* where biomass is able to substitute up to as much as twenty percent of the coal used in a boiler. The concept of co-firing is a very economical way to help jump start the biomass industry. The Chariton Valley Biomass Project was a joint effort from Alliant Energy, the DOE, and local biomass groups and was very successful co-firing project in 2000. It was so successful that Alliant Energy was given permission to build a permanent biomass facility.

Aside from the traditional methods of using biomass as an energy source, there are three methods to convert biomass to various fuels; thermochemical, biochemical, and chemical. In thermochemical processes, gases and liquids are produced by the breakdown of biomass from heat. This heating process is done in such a way as to not burn the biomass. These gases and liquids are rich in hydrogen where it can be used in fuel cells. Biochemical processes have been used in different applications such as wine making (known as fermentation) and can also be used for producing methane. Methane can be captured and used to generate heat or power. Chemical processes directly convert natural oils from plants into fuels. The most common process is converting cooking oil into biodiesel. Biodiesel is already being used in some trucks as a substitute for regular diesel. Algae are also a very good source for producing biodiesel.

A common issue with biomass is the ongoing debate as to whether it has a net negative energy loss or a net positive energy gain. A better debate would be whether to include the energy from the sun in the calculations or not. If the sun is considered an infinite source, then the calculations will show that the energy that we as humans input to the energy crop is lower than the amount of energy that we receive by using the crop as an energy source. If a rigorous calculation is done, taking into account every possible vector of energy input, then it can be shown that the total amount of energy going into the energy crop is more than the amount of usable energy we can extract from the crop. Since sunlight is usually the source for renewability, biomass is still considered renewable and sustainable if properly used.

Even though biomass power generation is not the technology people think about when renewability is concerned, it currently provides fifteen times more heat and power than both wind and solar technologies combined. The United States already generates approximately one percent of their current electricity needs and approximately two percent of their total ethanol production by using biomass. The DOE estimates that by year 2030, biomass will be contributing as much as twenty percent of our transportation fuels as well as fourteen percent of our electricity needs.

4.5 Fuel Cells

The majority of the follow section was sourced from the U.S. Department of Energy – Energy Efficiency and Renewable Energy.

Fuel cells come in many different types using different technologies. These fuel cells all have their own advantages and disadvantages, however, some have advantages that make them more appealing overall. The different fuel cells are: polymer electrolyte membrane (PEM), direct methanol, alkaline, phosphoric acid, molten carbonate, and solid oxide.

4.5.1 Polymer Electrolyte Membrane (PEM) Fuel Cells

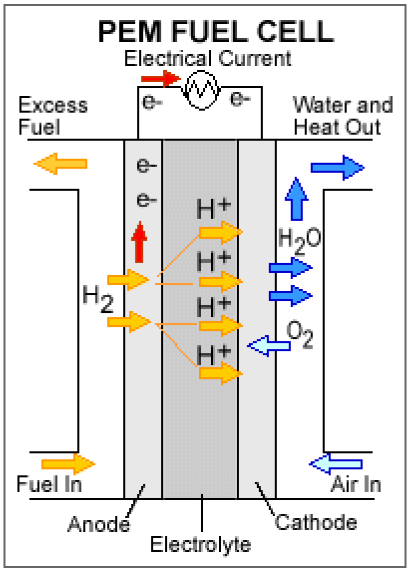


Figure 11: PEM Fuel Cell, (U.S. Department of Energy, 2008)

The PEM fuel cell has the advantages of delivering high power density while occupying a low volume. When compared to other fuel cells, this fuel cell is fairly light in weight also. The PEM fuel cell is also known as the *proton exchange membrane* fuel cell. The electrolyte used is solid, usually varying in material depending on the design of the fuel cell. This fuel cell only requires the input of hydrogen, oxygen from the air, and water, thus eliminating the need for corrosive liquids as found in other types of fuel cells.

PEM fuel cells are particularly attractive for mobile applications such as vehicles because of their high power density, low weight and volume properties. More importantly are its operation conditions: fast start-up time (usually within a few seconds) and its relatively safe operating temperature of 80°C (176°F). Because there are no fluids within this cell, the orientation of this fuel cell is not an issue, making this fuel cell even more attractive.

Even though the PEM fuel cell is a very attractive package, the cost of this fuel cell is fairly high. The reason for the high cost is the noble-metal catalyst that is required for the operation of the fuel cell; usually platinum. Not only is the platinum expensive, but it is very susceptible to carbon monoxide (CO) poisoning. This leads to frequent replacements or hydrogen purification before entering the fuel cell. Both of these solutions add cost, but it’s reassuring to know that the latter is a much cheaper solution than replacing the platinum. Developers are currently looking into different metals that are more resistant to CO poisoning.

Typically, PEM fuel cells have low voltages. These cells can be arranged in series to increase the cells to the required voltage; this is called a fuel cell stack.

With most fuel cells, an onboard hydrogen production system is usually not feasible so hydrogen must be carried onboard in the absence of this system. The most economical and technically feasible solution to carrying hydrogen is in the form of compressed gas. This solution is a good solution because it allows for an easy method to re-fuel the tanks in most applications. Carrying compressed gas onboard a vehicle can create many problems both from an operational perspective as well as from a safety perspective. Continuing with the vehicle example, compressed hydrogen does not have a high energy density which translates directly into a shorter travel distance on a given amount of hydrogen when compared to an equivalent volume of other fuels such as gasoline.

If compressed gas must be used, then increasing the pressure in the tanks will allow more hydrogen to be stored in the same volume. Increasing the storage pressure will increase the weight of the tank since it must be able to safely hold this pressure. Storage and transportation of compressed gases are heavily regulated by the government and will be a major drawback of using PEM fuel cells in vehicles.

4.5.2 Direct Methanol Fuel Cells

Direct Methanol fuel cells are fairly new when compared to other fuel cell types. This fuel cell is also very different from that of traditional fuel cells in that hydrogen isn't fed directly to the cell's anode; it uses methanol.

When compared to other fuel cells, this fuel cell does not suffer as much from the issue of energy density since liquid methanol has a higher energy density than compressed hydrogen but still lower than gasoline or diesel. Using liquid methanol is also favourable to our current infrastructure since our transportation and storage of gasoline and diesel fuels are already in liquid form. Direct Methanol fuel cells are about three to four years behind in research and development when compared to the other types of fuel cells.

Using methanol as a fuel may alleviate some of the infrastructure issues, however, producing methanol is very expensive and energy intensive so it may not gain as much acceptance in the fuel cell market as one would think. On the other hand, for portable electronics (such as notebook computers, cellular phones, and audio players), carrying around a small pack of methanol will be more convenient than carrying small canisters of compressed hydrogen gas.

4.5.3 Alkaline Fuel Cells

Alkaline fuel cells were popular since it was the first fuel cell to be developed. They weren't popular to the general public, but more in specialized fields such as the space program. It was used onboard spacecrafts to produce electricity and water (byproduct of the fuel cell). Since it uses alkaline potassium hydroxide in water as the electrolyte and non-precious metals as the catalyst, overall cost of the fuel cell is lower than PEM, however, alkaline potassium hydroxide is still fairly expensive. It also operates at temperatures that are safe for portable applications and residential use; roughly 23°C to 70°C. High-temperature Alkaline fuel cells operate at 100°C to 250°C which is still fairly low when compared to other fuel cells such as molten carbonate and solid oxide fuel cells. This fuel cell is considered high performance because of the rate of chemical reactions within the cell with applications where efficiencies are as high as sixty percent.

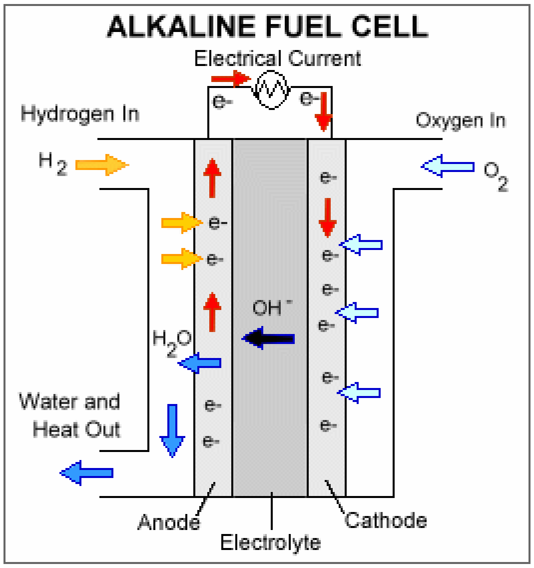


Figure 12: Alkaline Fuel Cell, (U.S. Department of Energy, 2008)

Although this fuel cell has many advantages, it is very easily poisoned by carbon dioxide (CO_2). This offsets any advantages that give it portable or residential applications since purification of hydrogen and oxygen is very costly for that type of use. Even if the purification steps were economically feasible, the lifetime of this fuel cell is only approximately eight thousand operating hours. To make this system economically feasible in a commercial application, it would require a minimum operation lifetime of forty thousand hours before this fuel cell would even be considered.

4.5.4 Phosphoric Acid Fuel Cells

Of all the fuel cells, the phosphoric acid fuel cell is the most developed fuel cell today, even more so than the alkaline fuel cell; it is the first fuel cell to be used commercially. There are over two hundred of these fuel cells currently in use, mostly in stationary applications. Phosphoric Acid fuel cells are mainly used in stationary applications since size is not a large issue. This is because of the fuel cell's relatively low power density, resulting in large sizes for respectable power outputs. When compared to other fuel cells such as the PEM fuel cell, the same weight and volume will yield a lower power output with the phosphoric acid fuel cell.

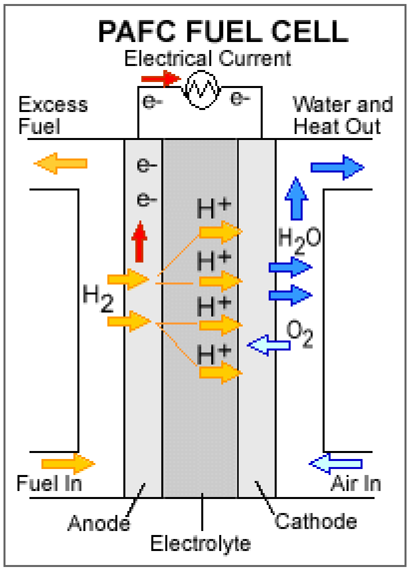


Figure 13: Phosphoric Acid Fuel Cell, (U.S. Department of Energy, 2008)

As with PEM fuel cells, the phosphoric acid fuel cell does not save in costs due to the fact that the catalyst used must be a noble-metal and in this case as well, platinum is used. Unlike the PEM fuel cell though, the phosphoric acid fuel cell is more resistant to catalyst poisoning from the impurities of the fuels, even though it also uses platinum as the catalyst. The life cycle of this fuel cell is fairly low since the hot phosphoric acid within the fuel cell must be circulated continually to maintain good operating efficiencies. The phosphoric acid fuel cell costs approximately $4000 to $4500 per kW of rated power.

Phosphoric acid fuel cells are fairly efficient, running at approximately eighty-five percent efficiency when it is operating in a combined heating and power configuration. It is no more efficient than traditional fossil-fuel combustion plants when the fuel cell is only providing electricity; approximately thirty-seven to forty-two percent.

4.5.5 Molten Carbonate Fuel Cells

The molten carbonate fuel cell is the most radical of the fuel cells mentioned so far. As the electrolyte, it uses a molten carbonate salt mixture suspended in an inert porous lithium aluminum oxide matrix ($LiAlO_2$). Non-precious metals are used as the catalyst and since it operates at 650°C, it is not as prone to poisoning from carbon dioxide or carbon monoxide as phosphoric acid, PEM, or alkaline fuel cells are. The use of non-precious metals greatly reduces the cost of the fuel cell.

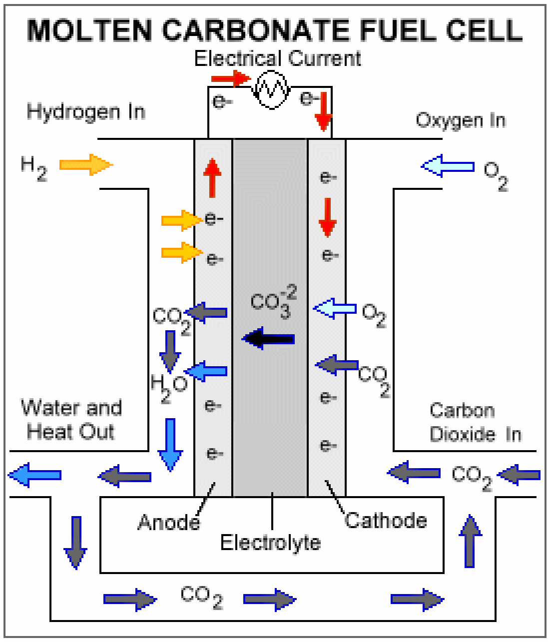


Figure 14: Molten Carbonate Fuel Cell, (U.S. Department of Energy, 2008)

The high temperatures allow for the fuel cell to internally reform hydrogen from natural gas or other sources (Ahmed & Krumpelt, 2001). This further reduces cost since an external reformer is not required to produce the hydrogen for the cell. This process, however, is not considered clean since it is essentially the same process that coal-fired plants use to generate electricity. The fuel cell can also use pure hydrogen that was produced from a cleaner source.

In stationary electricity only applications, this fuel cell is among the top performers in terms of efficiencies. With efficiencies up to sixty percent, it is considerably better than phosphoric acid fuel cells (thirty-seven to forty-two percent) for applications in stationary generation. If heating is also in the equation, then the efficiencies between the two fuel cells are approximately the same at eighty-five percent efficient.

The Molten Carbonate fuel cell is plagued with the problem of durability. The molten carbonate salt mixture as the electrolyte combined with the high operating temperature combine for a very high corrosion rate within the cell. More corrosion resistant materials are currently being developed to increase the life of the cell without degrading the performance of the cell.

4.5.6 Solid Oxide Fuel Cells

The Solid Oxide fuel cell is designed primarily for stationary applications. This is because the operating temperature of 1000°C is not suitable for any type of portable application. Even in stationary applications, the surrounding area must be shielded from the heat to protect personnel and other equipment as well as retain the heat within the fuel cell for optimal operation. Aside from adding bulk by shielding (not a large concern for stationary applications) the high operating temperatures require a very long start up time for the fuel cell to reach its optimum operating conditions. Not only does this limit its application to stationary applications only, now it is being further limited to constant operation rather than intermittent operation.

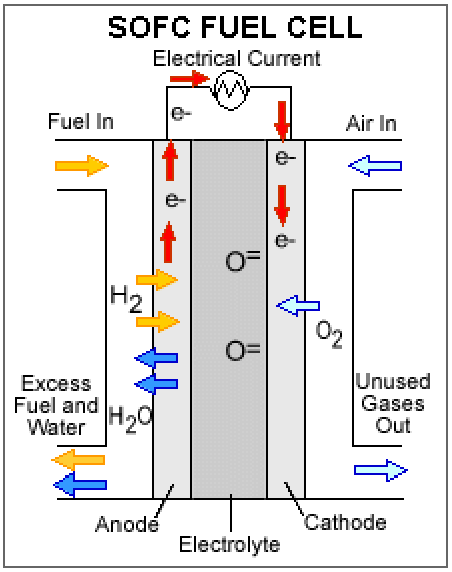


Figure 15: Solid Oxide Fuel Cell, (U.S. Department of Energy, 2008)

Solid oxide fuel cell's high operating temperature affects its durability. Oxidation of materials occurs rapidly within the fuel cell. Scientists are currently researching the development of lower-temperature Solid Oxide fuel cells using low-cost materials with high durability. Lower temperatures, however, lower the output capacity of the fuel cell.

Advantages for this system become apparent when the source of hydrogen is unknown. Due to the high operating temperature of this fuel cell, it is able to internally reform fuels, similar to the molten carbonate fuel cell. Using fossil-fuels, however, eliminate the clean nature of fuel cells. It is not poisoned by carbon monoxide and is orders of magnitude more resistant to sulphur when compared to other fuel cell types.

A comparison chart can be found in appendix C, table 11.

5.0 Experiential Innovation and Technology Centre

5.1 Clean Energy Hub

An energy hub is an interface between energy loads, such as electricity, heat, and hydrogen. An energy hub is also an interface between primary energy sources and carriers, such as electricity, heat, and hydrogen (Hajimiragha, A., Cañizares, C.A., Fowler, M.W., Geidl, G., Andersson, G., 2007).

Due to economic and environmental considerations, as well as flexibility in power production, the use of distributed generation is spreading throughout the world. In systems with distributed generation, there exists different energy flow problems associated with different energy sources and carriers, such as natural gas, electricity, heat, and hydrogen. All of these sources and carriers are tightly coupled due to the interactions among these various sources and carriers. For example, a microturbine using natural gas can produce electricity and heat simultaneously, while an electrolyzer using electricity can satisfy both hydrogen demand and part of the heat demand. A brief overview of energy hubs will be given, as the system proposed can be considered an energy hub (Hajimiragha, A., Cañizares, C.A., Fowler, M.W., Geidl, G., Andersson, G., 2007)

In the last few years, the concept of a “hydrogen economy” has gained much attention both in industry and academia. Hydrogen as an energy carrier can act as an interface for multiple energy resources such as fossil fuels, nuclear, and renewables. This has led to the development of the hydrogen economy concept, which concentrates on the economic aspects associated with the production, distribution and utilization of hydrogen in energy systems. At the present state of technologies related to hydrogen, there are a variety of concerns regarding the production, distribution, storage of the energy carrier, many of these concerns will be addressed in time as the popularity of using hydrogen as an energy carrier in integrated energy systems increase. The economics of production, storage and utilization of hydrogen have become more interesting because of the competitive electricity markets; the significant price differences between peak and low price hours. It is especially appealing when considering that classical generation plants are most efficient when operating at rated load levels.

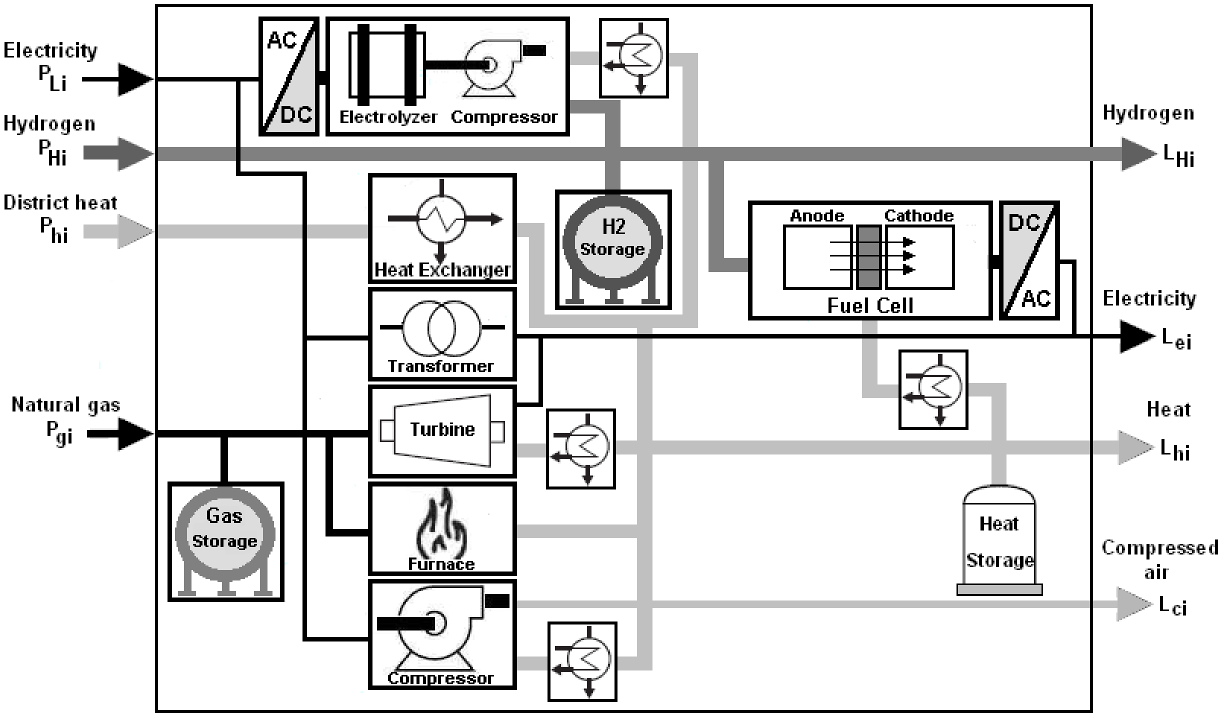


Figure 16: Complex Energy Hub Configuration, (Hajimiragha, A., Cañizares, C.A., Fowler, M.W., Geidl, G., Andersson, G., 2007)

From the power grid's point of view, the use of hydrogen as an energy carrier to increase the efficiency and reliability of the grid becomes a very attractive option. Figure 16 is a diagram to show what a complex energy hub can look like (Hajimiragha, A., Cañizares, C.A., Fowler, M.W., Geidl, G., Andersson, G., 2007).

The implementation of distributed generation systems has already begun with various projects around the United States. In Kerman, California, a 500 kW solar PV plant was installed as a distributed generation system to assist in supplying electricity during peak loads. Solar thermal water heating is one of the most economical ways to reduce the amount of electricity and natural gas required to heat water in residential homes. Using clean and renewable sources for distributed generation systems will not only provide electricity to relieve the grid of congestion but it will also pave the way for a cleaner future. (Agbossou et al., 2001)

5.2 Net Zero Energy

5.2.1 The Net Zero Concept

The Net Zero concept was coined by the Net Zero Energy Home (NZEH) Coalition (Net-Zero energy home coalition, 2008). The NZEH Coalition is an incorporated, multi-stakeholder organization comprised of Canadian champions in advanced energy efficient residential construction and building products, the utility sector, research and development and, manufacturing and deployment of onsite renewable energy technologies. The objective of the Coalition is to advance the benefits of the more efficient use of zero or very low impact resources including cleaner air and healthier homes, climate protection and, economic development opportunities resulting from the expanded manufacturing and deployment of energy efficient technologies and appliances and on-site renewable energy generation in Canada's residential marketplace.

The Net Zero concept is normally meant for residential housing rather than a commercial facility. A Net Zero energy home is capable of producing an annual output of renewable energy that is equal to the total amount of its annual purchased energy. The concept, however, is the same for a commercial facility and will be used in the same fashion for the Experiential Innovation and Technology Centre facility.

5.2.2 Coalition Background

In 2004, a group of forward looking home builders and developers of new decentralized energy systems began meeting to discuss how residential energy could be supplied in a sustainable manner which minimized the production of greenhouse gases and created healthier and greener communities. The group agreed that there were already existing renewable energy technologies and energy efficiency/conservation technologies that allow homes to consume no energy on an annual net-basis and significantly reduce greenhouse gas emissions.

Since this time, the Coalition has made positive strides in promoting and establishing with decision makers a national Net Zero Energy Home demonstration initiative with the support of Canada Mortgage and Housing (CMHC), Natural Resources Canada, Industry Canada and Environment Canada. The Coalition subsequently helped to develop a deployment plan for this demonstration. CMHC agreed to lead the initial phase of the demonstration initiative under its healthy housing program, entitled the Net Zero Energy Healthy Housing Initiative.

The Coalition continues to work with industry and other levels of government building support for NZEH deployment and providing expertise, knowledge and insight.

5.3 Experiential Innovation and Technology Centre

The following description of the Experiential Innovation and Technology Centre is a description as described by Hybrid Strategies.

5.3.1 Concept

The EITC is a cross between a research park, a think tank, a public showcase, and an operation dedicated to the commercialization of intellectual property in base sciences and their converged technologies. The mission of the EITC is to attract quality research projects from the global science and technology community, and to facilitate technology transfer and dissemination worldwide in a commercially viable manner. The premise of EITC is that there is a need, domestically and globally, for specialized research facilities and supporting amenities on a short term or project term basis. This need comes from government, NGO research bodies and commercial companies. The business objective of the EITC is to satisfy a portion of that market need. In the pursuit of this mission, the EITC also seeks to:

- Distinguish itself from prior generations of other research centres and to set a new standard

- Operate in an integrated manner with its associated companies, with the adjacent university community, with the domestic community and with the regional and global science and technology community
- Act as a bridge/facilitator between science/ technology theory and commercialization of intellectual property

The concept of the EITC begins by distinguishing between the EITC as physical facility, and the EITC project. The EITC as a facility is an element within the EITC Project. The concept of the EITC Project is to create, organize and provide a matrix of elements in a unique blend in a commercially viable manner. This matrix is a substrate of amenities which researcher-clients draw upon to optimize their ability to produce intellectual property in an environment that is also optimally conducive to those ends. This EITC concept and vision is what and how the EITC distinguishes itself from older generation research centers and sets a new standard.

Critical to the concept are the elements of the matrix. The EITC as a physical facility is an element of the matrix as well as the nest in which all of the elements are brought together and housed. There are also the EITC operational components, including the usual operations and maintenance aspects of the EITC facility, the strategic linkages to support, and the other elements of the matrix outlined below.

> Location and external infrastructure are important elements of this matrix. The Research and Technology Park at Waterloo provides the external infrastructure of transportation and high-speed data communication cabling.
>
> There must be at the location, and in the proximity, a body of intellectual resources for the researcher-clients to draw upon. The location at Waterloo provides this with the local and regional universities and technology, government and NGO institutions, as well as a local community that is focused on supporting this kind of business development.

Through contract relations or strategic alliances which the EITC has or plans to create, the EITC operations are organized to connect the researcher-clients to the pipeline of state-of-the art information about parallel research taking place in other national and global facilities.

The EITC assists its researcher-clients on an integrated basis with its associated companies, Hybrid and ITOptima. These associated companies are focused on core skills and information technologty and intellectual property for mathematics, chemistry, physics and environmental sciences. These components of EITC bring to the clients sophisticated intellectual assets and management support, as well as unique intellectual property tools to enhance the productivity of the researcher-clients. These associated companies can also assist entrepreneurial clients under commercial joint-venture arrangements.

The EITC structure itself brings together physical attributes and philosophical elements that reinforce the mission in a manner which is innovative, and which inspires collaborative work. The Center offers a full complement of resources for clients needing short and medium term solutions:

- wet and dry laboratories
- secure work environments
- offices
- temporary residences
- conference and training center
- media center
- technology infrastructure (i.e. high performance computing, virtual reality labs etc.)

A design feature that is especially commercially attractive is that EITC can adapt lab configurations on short notice to the specific needs of the users.

The term "Experiential" in the name is a key element in the concept, and it is this philosophy especially, which together with the matrix, distinguishes the EITC from the other research centers. The experiential character is demonstrated in various ways and permeates every aspect of the EITC facility.

> "Brains attract other brains". The EITC facility offers a radical design, creating an environmentally responsible and attractive ambiance that researcher clients can enjoy with an array of hard, state-of-the art support systems to induce researcher-clients to want to do their work at EITC.
>
> The innovation and creative process of science comes not only from hard work in labs, but also from the opportunities of researchers/scientists to share and cross-pollinate ideas in formal and in unstructured settings. They do this best through experiencing opportunities for social and intellectual contact with peers.
>
> The EITC optimizes this interactive milieu to induce collaborations with its conference centers and meeting rooms for large scale interaction, and with its abundant gardens, boutique cafes and plazas, for meetings at a more intimate scale.
>
> The design embodies the vision for what is the ideal research center. The buildings and grounds are a showcase of ecologically sensitive design and technology, with a view to take the project "off-line" where possible for:
>
> - power
> - heat/ cooling
> - waste and water treatment and recycling
>
> all in self-sustaining processes. Some of these technologies will be exhibited as demonstrations of client technology.
> While research is performed in restricted secure areas, the public areas showcase the technologies being developed at the EITC. In this approach, the EITC mirrors the most current thinking on research center philosophy to be showcase/theme oriented as it is also evidenced by the NASA Ames facility in Silicon Valley.

The EITC intends to provide to the domestic and global research community this matrix of amenities which are unique, which set a new standard, and which create the EITC as a showcase for the world. We expect that through careful design we can create a place that encourages the interactions and connections between people and the emerging ideas and technology.

5.3.2 Site Selection Criteria

- Availability of knowledge workers and facilities
    - Universities, Research Centres, technology rich area
- High Speed Network Infrastructure
    - 2 x 48 OC from two providers, connection to scientific networks
- Site selection
    - minimum available size to support the Project
    - expansion capability
    - favourable zoning
    - setting and configuration of site
    - suitability of site for implementation of ecological showcase design concepts
- Excellent transportation links & access locally and to international ingress and egress
- Good standard of living that appeals to knowledge workers
- Local, regional support for project
- Inducements

5.3.3 Facilities

The facility itself is constructed with materials and processes that reduce the impact on the environment and community. At the same time, it provides public access and physical security to both, the clients and visitors, in a non-intrusive manner. Access to labs and other sensitive areas are restricted. Public areas, seminar and training areas are designed to encourage mingling and sharing of ideas. Quiet areas for contemplative thought are also provided.

The residential and the training areas are vital components of the facility and experience. Key clients and their staff are expected to be global in origin. Some are here for a few days, some for much longer. Scientists and executives want to focus on their work and issues. They do not want worry about where to find suitable accommodation and transportation.

It is expect that both, the work of Hybrid Strategies and of clients own work, will involve frequent seminars and training sessions to deploy those innovations to commercialization. A residence on site, therefore, increases the attractiveness of the location. Scientists, clients' executives and visitors will find the proximity to the labs, seminars and training convenient. Accommodations for various terms are incorporated in the offering package to clients. These training activities and their requirements for space are an additional revenue stream for the EITC facility.

5.3.4 Architectural/structural description of the EITC Campus

The architecture of the EITC Campus should be inspiring and playful, spilling into the green and bringing it inside. The vision of the architecture will have many expressions such as:

- being an art object combining beauty, playfulness and function in the public areas where people stroll, eat, relax and connect
- somewhat whimsical and unexpected where they learn, discover and experience
- inspiring with a touch of spirituality where they create and are motivated
- calming and friendly where they do business

The EITC will contain about 100 companies and about 3,000 people. It therefore creates considerable demand for complementary businesses, such as banking, legal and other consulting, and commercial/retail-restaurant services for the EITC employees and clients.

The buildings shall tie in with the indoor/outdoor gardens and commercial spaces allowing people means to walk to EITC facilities. Determination will be made later which labs are explosion-proof, sterile or waterproof. All lab floors have showers and locker rooms installed in the washrooms. The interior will have restricted and public areas, with security extending to the perimeter of the restricted buildings, where a moat surrounding the buildings and kept above freezing in the winter.

5.3.5 Moriyama & Teshima Architects – Preliminary Model

Two exterior perspectives extracted from the CAD model prepared by Moriyama & Teshima (Moriyama and Teshima Architects, 2008) are shown in Figure 17 and 18. One extract is a high level south to north view. The other is a low level view from north to south.

Both are images that illustrate an overall design built upon the massing blocks of the project elements: labs, offices, residences, common areas, etc. They are devoid of external features such as building skin and roof treatments.

Figure 17 (the high view) discloses the following features:

- The gray rectangle is the Sybase site for orientation reference and scale perspective.
- The buildings along the top of the High View are the labs and office facilities.
- The three buildings arrayed along the bottom are the residences and the conference/meeting rooms associated with event activities.
- The white/blue feature in-between are the commons with cafés, gardens, etc. that will showcase technologies to the public.

- The commons also are designed to convert into a conference facility with the seating capacity of the 1000+. This commons is open to the public and available to the community for community activities.
- The black globe is a combination auditorium, library and 3D visualization laboratory.
- There is no asphalt, as parking is below ground.

The orientation of the buildings is set to optimize the ecological effects of wind, sunrise, sunset, etc. The design intends to make transparent the division between the building and outdoor natural spaces.

The water features surround the labs/office buildings and extend to the lands already intended as public green spaces. The purposes of the water feature are three-fold: it is aesthetic to maximize appeal. The feature also serves as a moat to provide security around the lab/office areas. Finally, water feature incorporates techniques developed by Moriyama & Teshima for Riyadh, Saudi Arabia. This process recycles site generated and site utilized water to a higher standard than a water in Columbia Lake.

Non-visible design features incorporate technologies that showcase those developed by businesses at the EITC. As well there are technologies that will enable the EITC to operate completely off-line in a manner which is optimally environmentally sensitive and commercially viable.

Figure 18 (the low view) shows the dramatic impact of street level and approach perspectives.

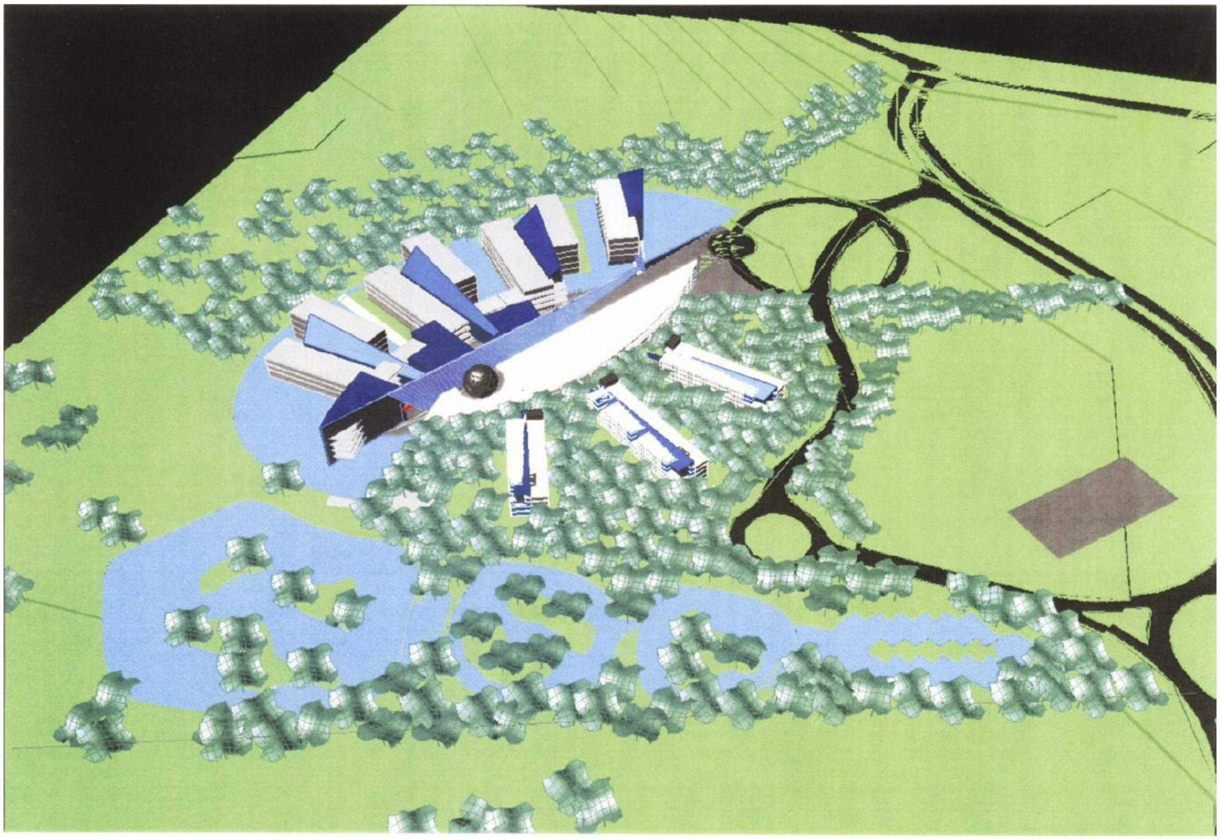


Figure 17: The EITC High View (Hybrid Strategies Corporation, 2008)

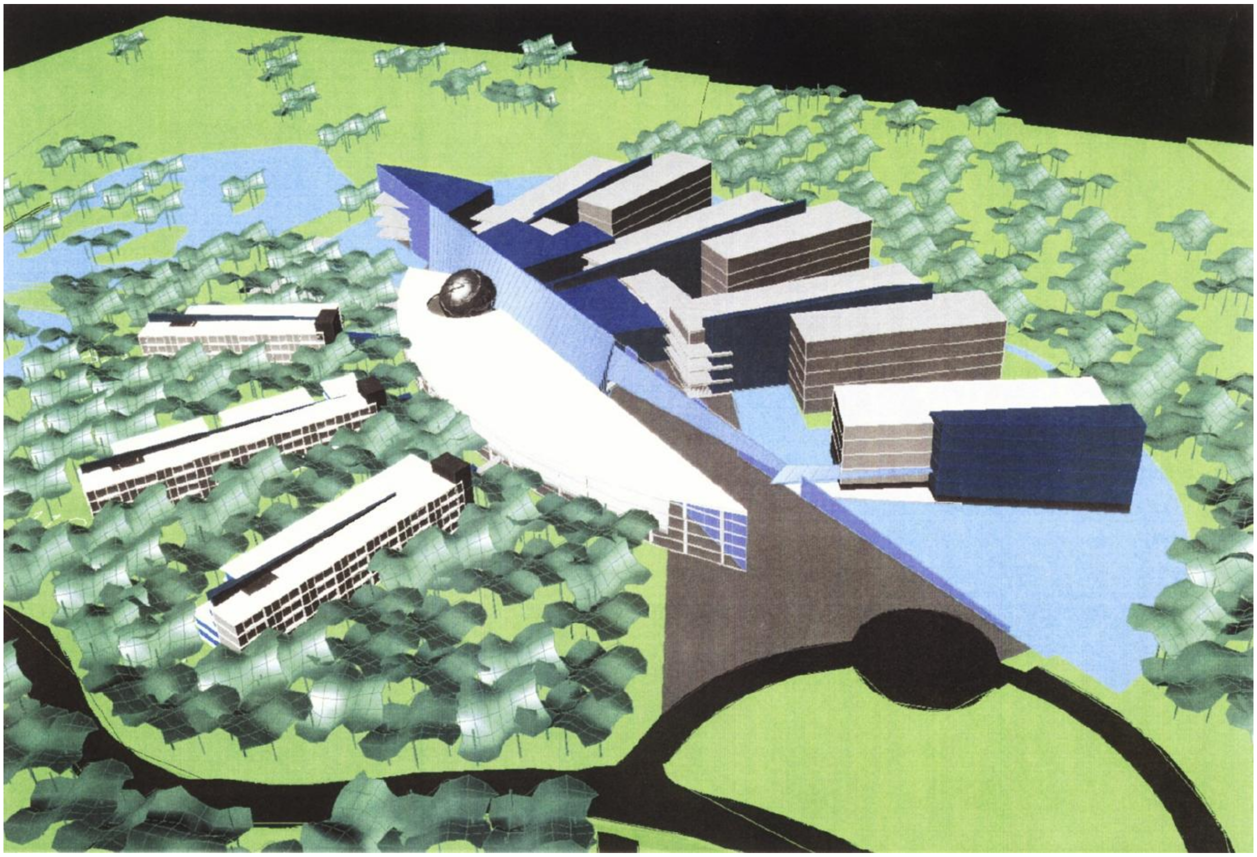


Figure 18**: The EITC Low View (Hybrid Strategies Corporation, 2008)**

6.0 Software

Various software packages were considered to simulate and model the energy system for the Experiential Innovation and Technology Centre. Depending on what the goal is for specific tasks, different software packages are better suited to achieving those goals of those specific tasks. Because of the complexity of the system, more than one package has been chosen for this project.

The following are the software packages that were considered for this system (U.S. Department of Energy, 2008):

- RETScreen
- Homer
- EE4 CBIP
- BILDTRAD
- HOT2XP
- HOT2000
- HOT3000
- HOT2EC
- BASECALC
- FRAMEplus
- TRNSYS
- MATLAB/Simulink

Most of these software packages are available through the United States Department of Energy (U.S. DOE) Energy Efficiency and Renewable Energy (EERE) department. MATLAB/Simulink, RETScreen, Homer, and TRNSYS are available through other sources. Table 6 outlines the advantages and disadvantages of each software package and how the right packages were chosen for this project.

Table 6: Software Package Comparision, (U.S. Department of Energy, 2008)

Software Package	Advantages	Disadvantages	Chosen
RETScreen	• Excel based • Financial feasibility • User Friendly	• Too simplified • Analyzes one piece of equipment only • Mostly business feasibility	NO
Homer	• User friendly • Overall system analysis	• Fairly simplified • Lack of control over specific systems	YES
EE4 CBIP	• Used in Industry • Part of Incentive Program	• Not user friendly • Too complex without training	NO
BILDTRAD	• Actual building analysis • User friendly	• No electrical energy analysis	NO
HOT2000, HOT2XP, HOT3000	• Allows for geometric inputs • User friendly • Location specific weather data	• Residential housing focus • HOT3000 still in beta phase	NO
HOT2E	• Allows for innovative designs • Can compare different designs	• Expensive, no support • Not user friendly	NO
BASECALC	• Assess foundation needs	• Residential focus • No relevance to project	NO
FRAMEplus	• Analyzes heat transfer in building	• Not user friendly • No electrical analysis	NO

TRNSYS	• Licensed to UW • Support from within UW • Comprehensive analysis abilities	• Not user friendly • Don’t have full control of system	NO
MATLAB/Simulink	• Licensed to UW • Comprehensive abilities • Limited only to programming skills	• Already have experience with software • Full control of system	YES

Homer and MATLAB/Simulink were chosen as the final software packages to use because of their unique characteristics and abilities. In Homer, most models are setup and ready to run to provide some quick preliminary results that can be used in feasibility analyses. Most parameters are plug and play for customized equipment, such as a wind turbine. This allows for selection and evaluation of a number of potential technology mixes. In MATLAB/Simulink, all of the models must be set up manually in Simulink, but allowed for more detailed sensitivity analysis of the most promising technology senarios. The following section describes both software packages and how they were used to design and simulate the electrical system.

6.1 Homer

The biggest advantage of Homer is its ability to produce results in a quick and easy manner. The models can be as simple or as complex as the user wants, but the underlying operational characteristic of the system is set by Homer and allows for very limited control by the user.

Homer is a software package that allows the user to easily evaluate the design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation applications. Homer uses computer generated models to illustrate results from systems defined by the user. The results produced from Homer can allow the user to evaluate the economic and technical feasibility of a large number of technology options (Lambert, Gilman, Lilienthal, 2005).

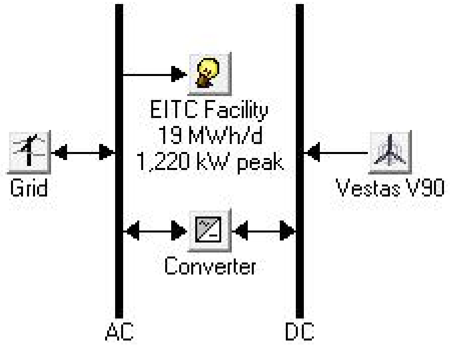
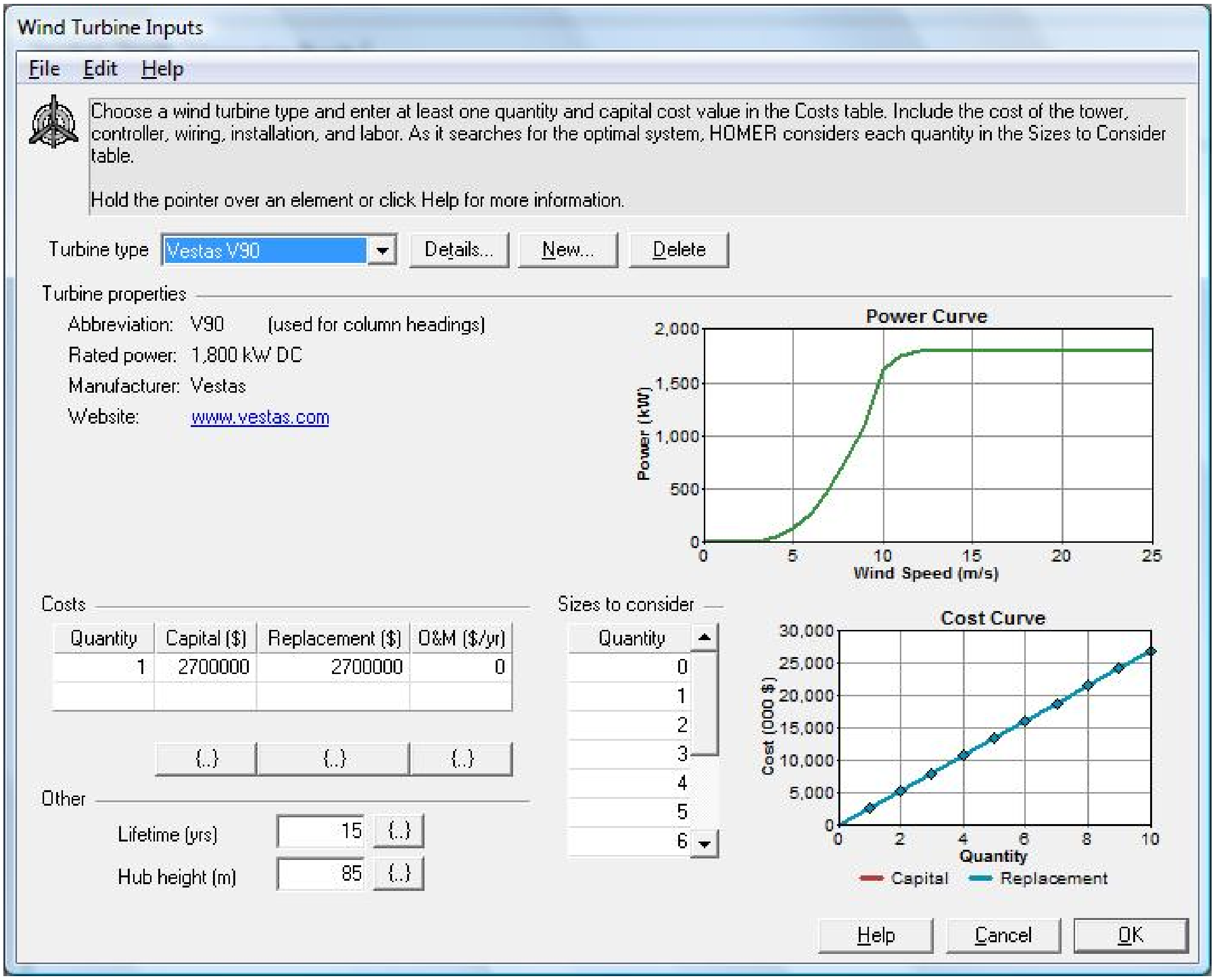


Figure 19: Simple Homer Model for EITC Facility

A simple model setup in Homer can be seen in Figure 19; one wind turbine, DC/AC inverter, grid connection, and an electrical load. Within this system, Homer can find the optimal system within the given parameters that you provide. It finds the optimal result based on simple economical analyses and ranks all of the results from lowest to highest annualized costs.



Choose a wind turbine type and enter at least one quantity and capital cost value in the Costs table. Include the cost of the tower, controller, wiring, installation, and labor. As it searches for the optimal system, HOMER considers each quantity in the Sizes to Consider table.

Hold the pointer over an element or click Help for more information.

Turbine type: Vestas V90

Turbine properties

Abbreviation: V90 (used for column headings)
Rated power: 1,800 kW DC
Manufacturer: Vestas
Website: www.vestas.com

Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	2700000	2700000	0

Sizes to consider

Quantity
0
1
2
3
4
5
6

Other

Lifetime (yrs): 15
Hub height (m): 85

Figure 20: Sample Parameters in Homer

A sample screenshot of Homer's parameter input window can be seen in Figure 20. The cost and power curve define the turbine's characteristics and how it will operate given the wind data (also provided to homer by the user) while the "Sizes to consider" box defines the search space that Homer can operate within to find the lowest cost result.

The system shown in Figure 19 is relatively simple and requires little time to produce results. For example; given three sizes to consider for both the wind turbine and inverter search spaces each, the number of iterations to simulate the system is nine. Figure 21, however, requires significantly more time as the iterations increase dramatically.

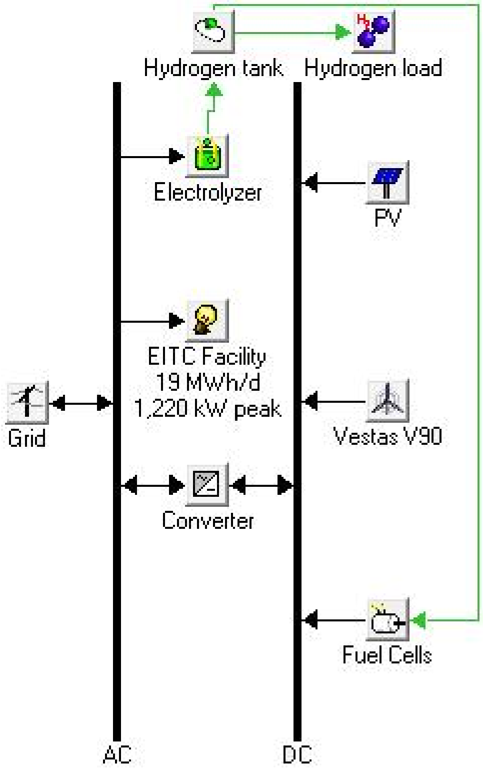


Figure 21: Complex Homer Model for EITC Facility

If the same three sizes to be considered are applied to each of the sizeable components in the complex model, the number of iterations becomes 729. This becomes an exponentially increasing problem, especially when the length of each system is simulated over the course of one year, with a resolution of 15 minutes. Regardless of Homer's simulation time, results were obtained and will be discussed in the next chapter.

Although Homer is simple to use and can generate results very quickly, the allowable control over the system is very limited. Specific data such as efficiency loss and operational strategies such as charging at night using the grid cannot be done easily, if at all. MATLAB/Simulink allows the user to have 100% control over the system; this is because the system must be modeled and programmed by the user.

6.2 MATLAB/Simulink

MATLAB/Simulink was chosen as the main software of choice because of its ability to model any system. This program is much more difficult to use than Homer, but the flexability of the system analysis was necessary for this work.

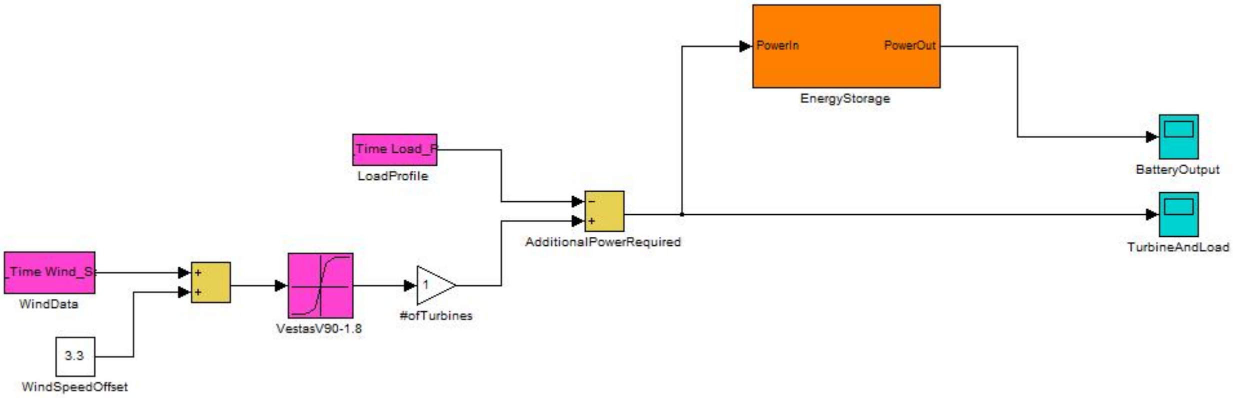


Figure 22: Simple MATLAB/Simulink Model for EITC Facility

The model shown in Figure 22 is a preliminary model showing a wind turbine (VestasV90-1.8), a load (LoadProfile), as well as a battery system (EnergyStorage). In this model, the components are very primitive in its operation; the wind turbine is simply a look-up table while the battery is able to take any charge and load without limits. In later revisions, the models are modified to reflect more real world operation strategies. Figure 23 and 24 show the difference between a simple battery model and a more complex battery model.

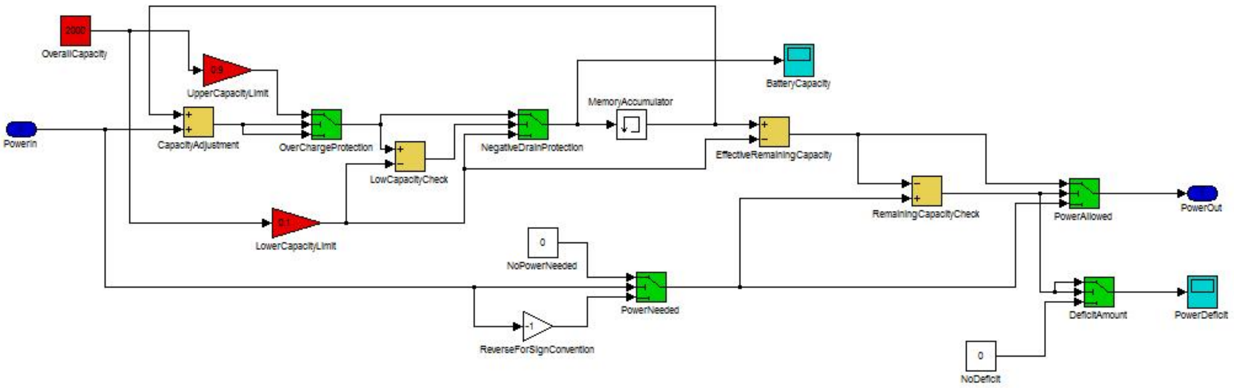


Figure 23: Simple Battery Model for EITC Facility

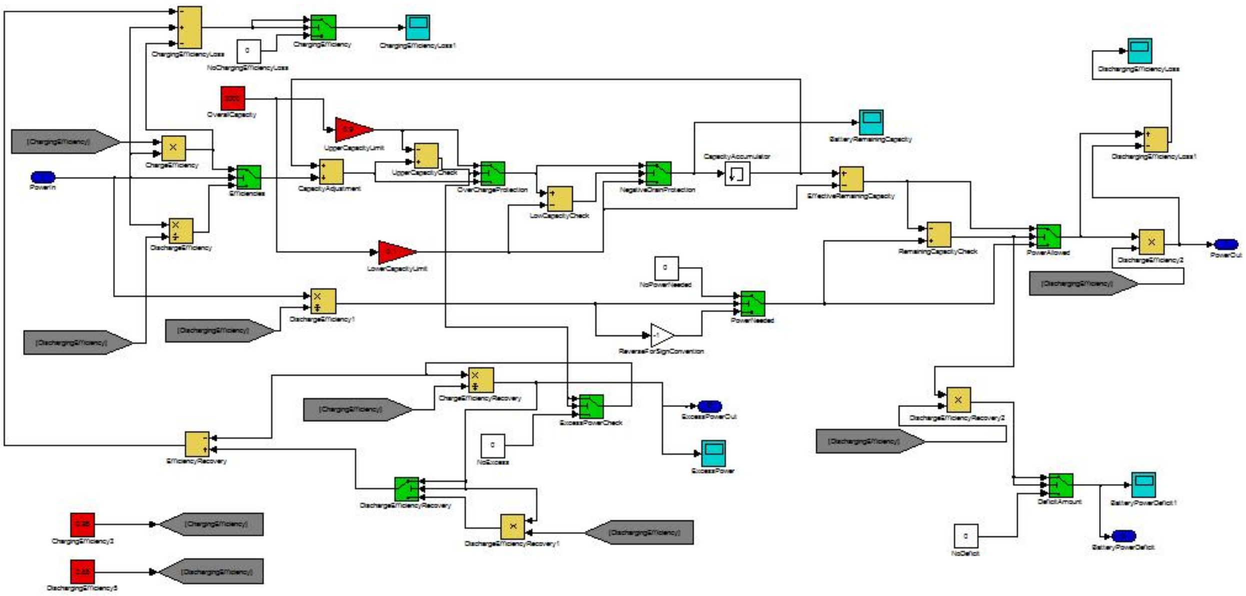


Figure 24: Complex Battery Model for EITC Facility

As can be seen in Figures 23 and 24, there is a significant difference in the two battery models. The complex battery model ensures that limitations are in place so that the battery acts as how a real world battery operates; charging current limits and charge capacity and discharge capacity limits.

This is an example of how the user has full control over every aspect of the system when using Simulink as the simulation software over using a pre-determined model set such as Homer.

Simulink was also used as a validation tool to validate the results from Homer and to also make sure that the models are running as expected in the overall system in Simulink.

7.0 Energy Management System for the Clean Energy Hub

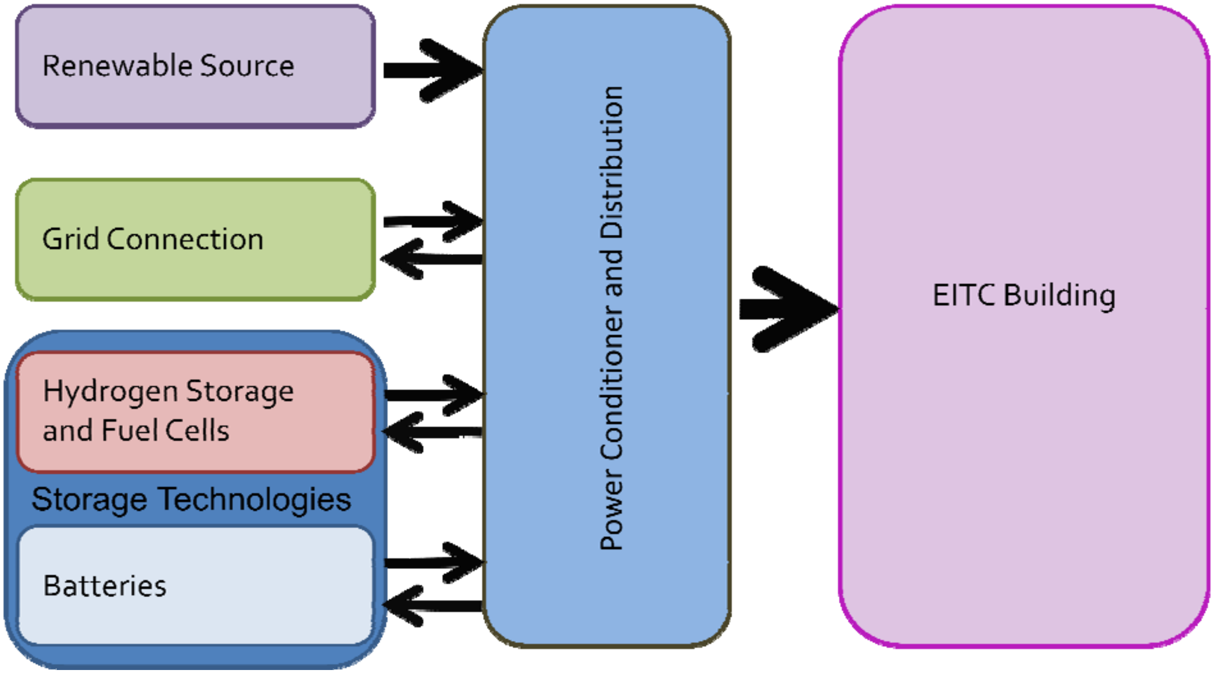


Figure 25: Conceptual Schematic of Overall System for EITC Facility

The overall system can be conceptualized by Figure 25. It includes the flow of electric power from equipment to equipment as well as the relative amounts as estimated by the thickness of the flow arrows. A model was constucted in MATLAB/Simulink that consisted of wind turbines, batteries, electrolyzers, hydrogen storage, fuel cells, a stationary facility load, and a mobile hydrogen load. The results of this model are described below.

Before the system can be fully understood, some specifications of the system components must be shown first.

7.1 Equipment

The main power generating component in the system is a wind turbine. Figure 26 shows how the turbine performs with a given wind speed.

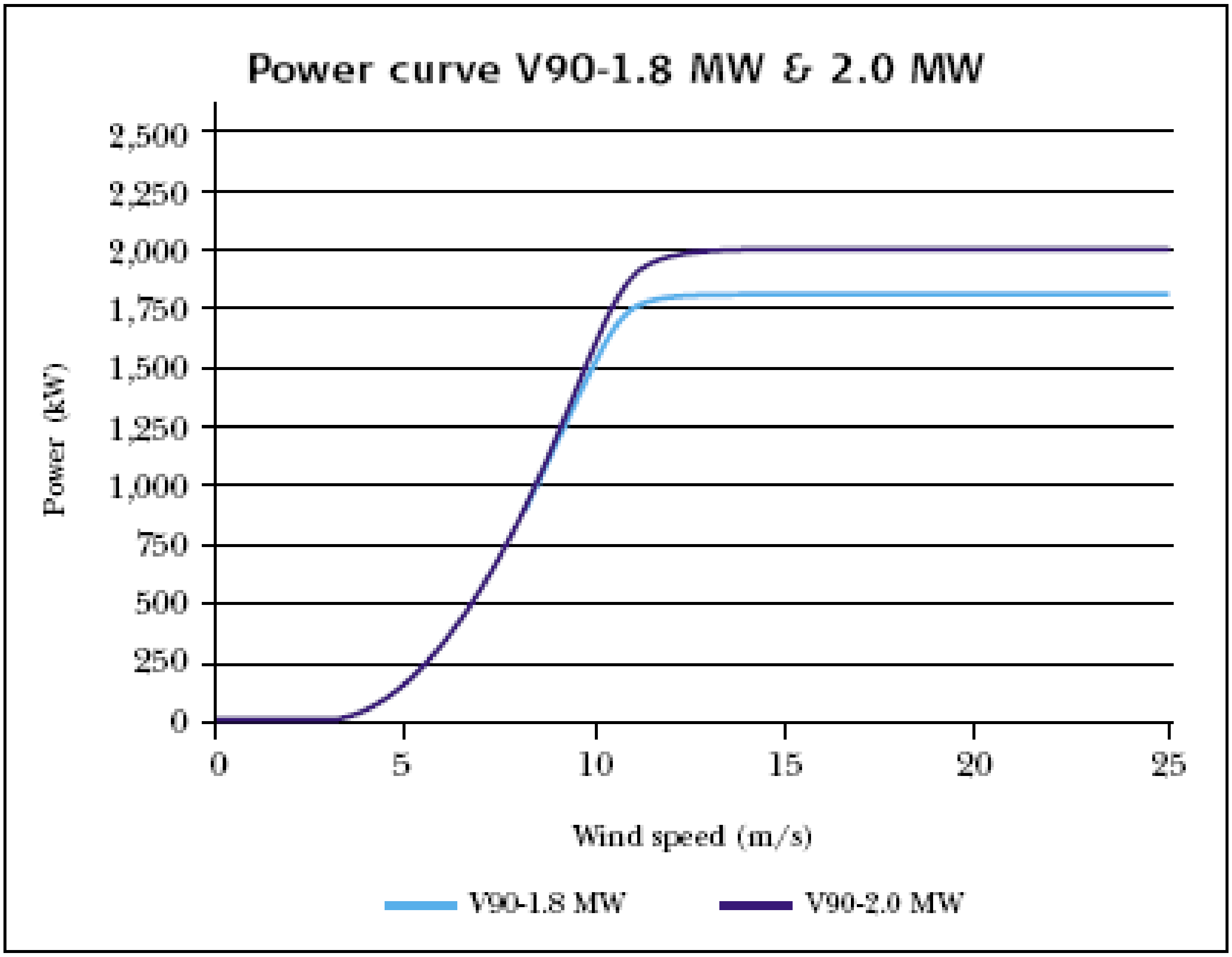


Figure 26: Wind Turbine Performance

The peak power of the turbine used in the system is 1.8 MW and can be achieved at a wind speed of approximately 12.5 m/s. It should be noted that below 3.5 m/s, the wind turbine is not able to generate any power.

The wind speed data is complete for the full year of 2004 at a resolution of every hour for the Kitchener/Waterloo area.

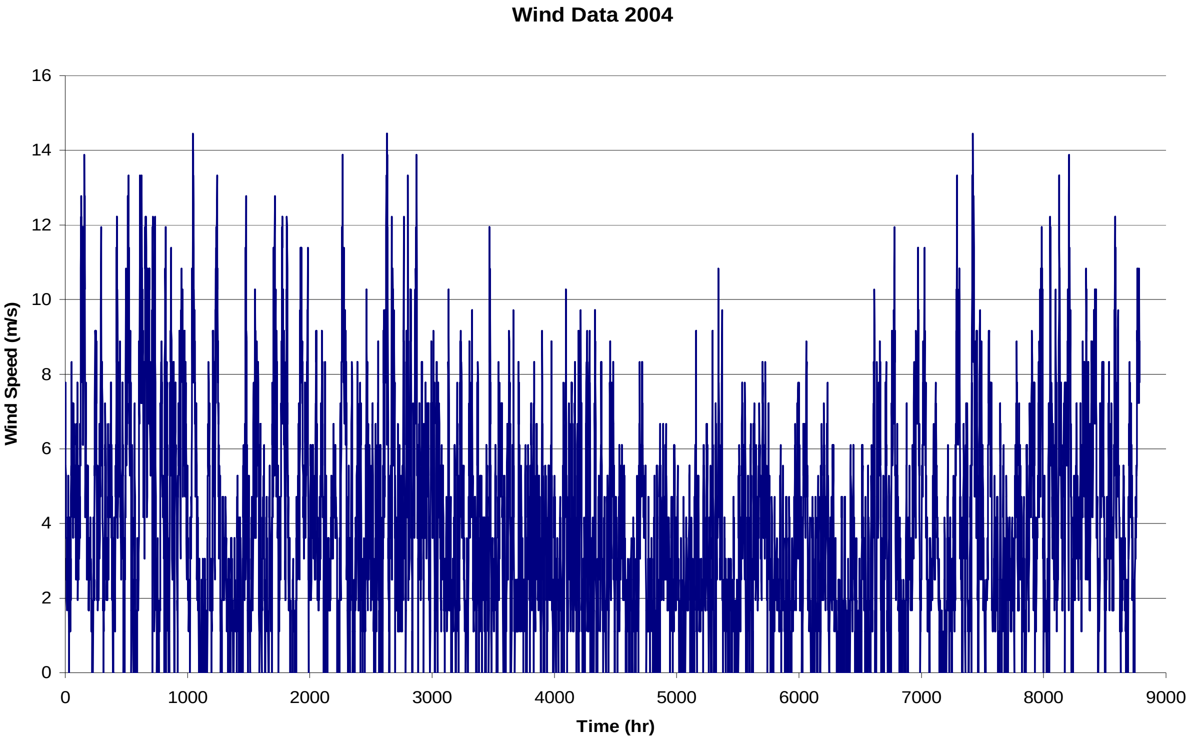


Figure 27: Kitchener/Waterloo Wind Data 2004

The average speed for the year of 2004 was 3.86 m/s. The wind speed measurement was at a height of 10 m, therefore a correction factor can be added to this number to account for the 80 m hub height of the wind turbine.

The load profile of the building was based on a typical office environment of computers, lights, and a typical work load day.

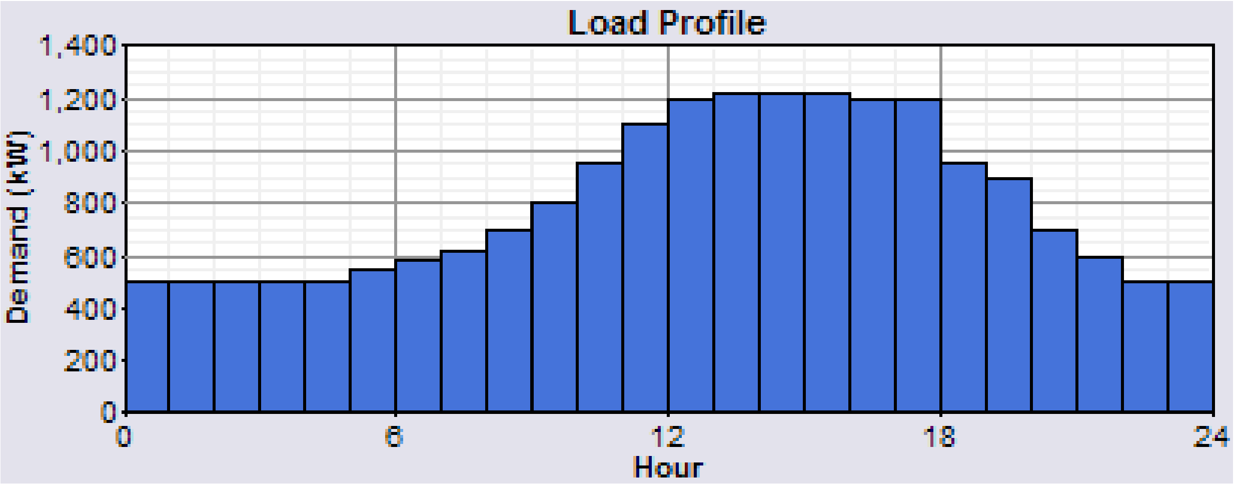


Figure 28: EITC Load Profile

The breakdown of this profile was created to simulate a realistic work day rather than assuming a constant load. During the late night and early morning hours, it is assumed that only a small number of workstations and equipment will be operational or idle, requiring the least amount of energy during the 24 hour period. In the afternoon, when it is the busiest, the electrical profile reflects that by having its highest demand during those hours.

The fuel cells are modeled after the Hydrogenics HyPM 65kW module that is used in the University of Waterloo Alternative Fuels Team Challenge X vehicle. The author of this work is had extensive experience with the operation of this power module during the conduct of this work, and thus a clear understanding of the performance capabilities. It is a 65kW continuous power fuel cell that is designed to be run in a stationary application. The module has a peak efficiency of approximately 58% at 120kW.

As for vehicle hydrogen demand, the Challenge X vehicle was used once again as a benchmark for data. The Challenge X vehicle is able to store approximately 5 kg onboard to operate the vehicle for a range of approximately 240 km. Once again this is a based on actual experience with the operation of the vehicle.

The operation of the vehicle(s) was limited to the hours of 6:00am to 8:00pm, a total of 14 hours of operation. Since vehicles used are typically local to the EITC facility, a worst case average speed assumption is made at 60 km/h. At 60 km/h, the hourly hydrogen demand is approximately 1.25 kg/h per vehicle. Note, this is considered a very high estimate for the energy consumption for the vehicle as it assumes that this is a service vehicle that is 'driving' for the entire period.

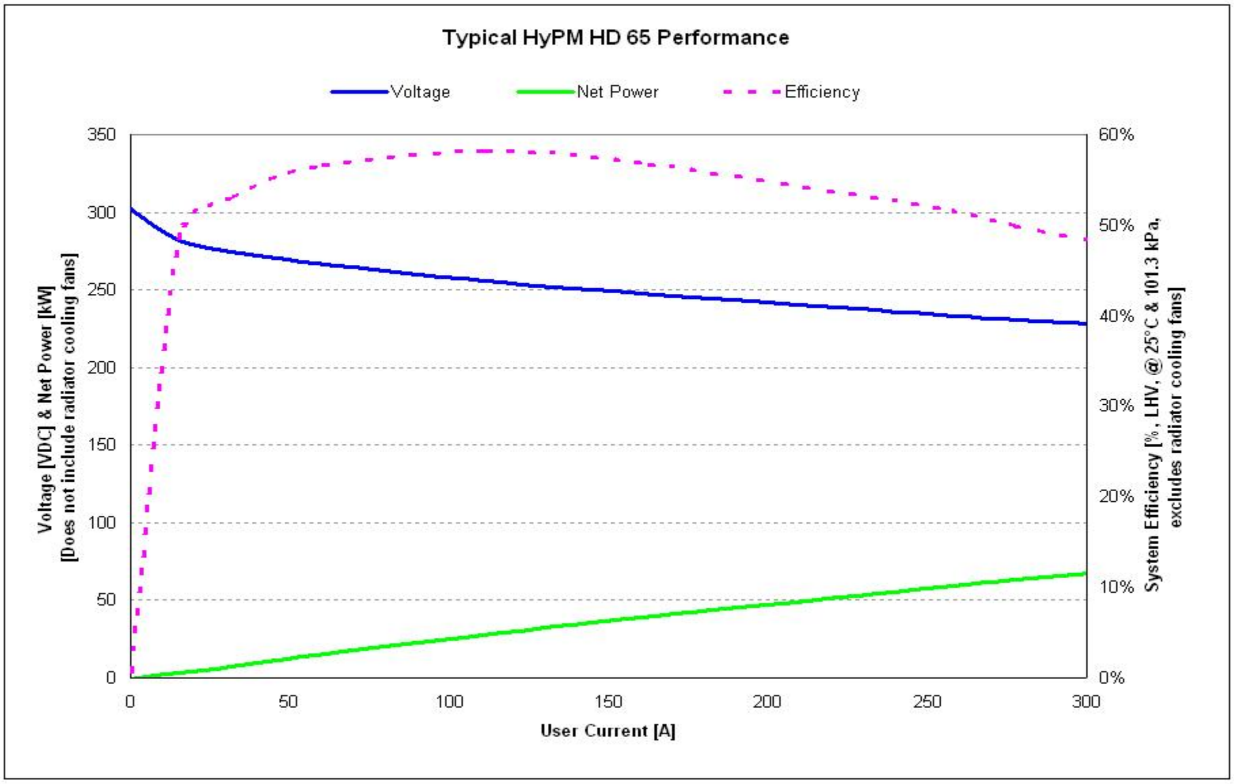


Figure 29; Fuel Cell Power Module Polarization Curve

The polarization curve of the fuel cell (Figure 29) shows the module's performance over its entire range of operation (once again this is actual experiment results obtained during this work).

7.2 System Algorithm Flowchart

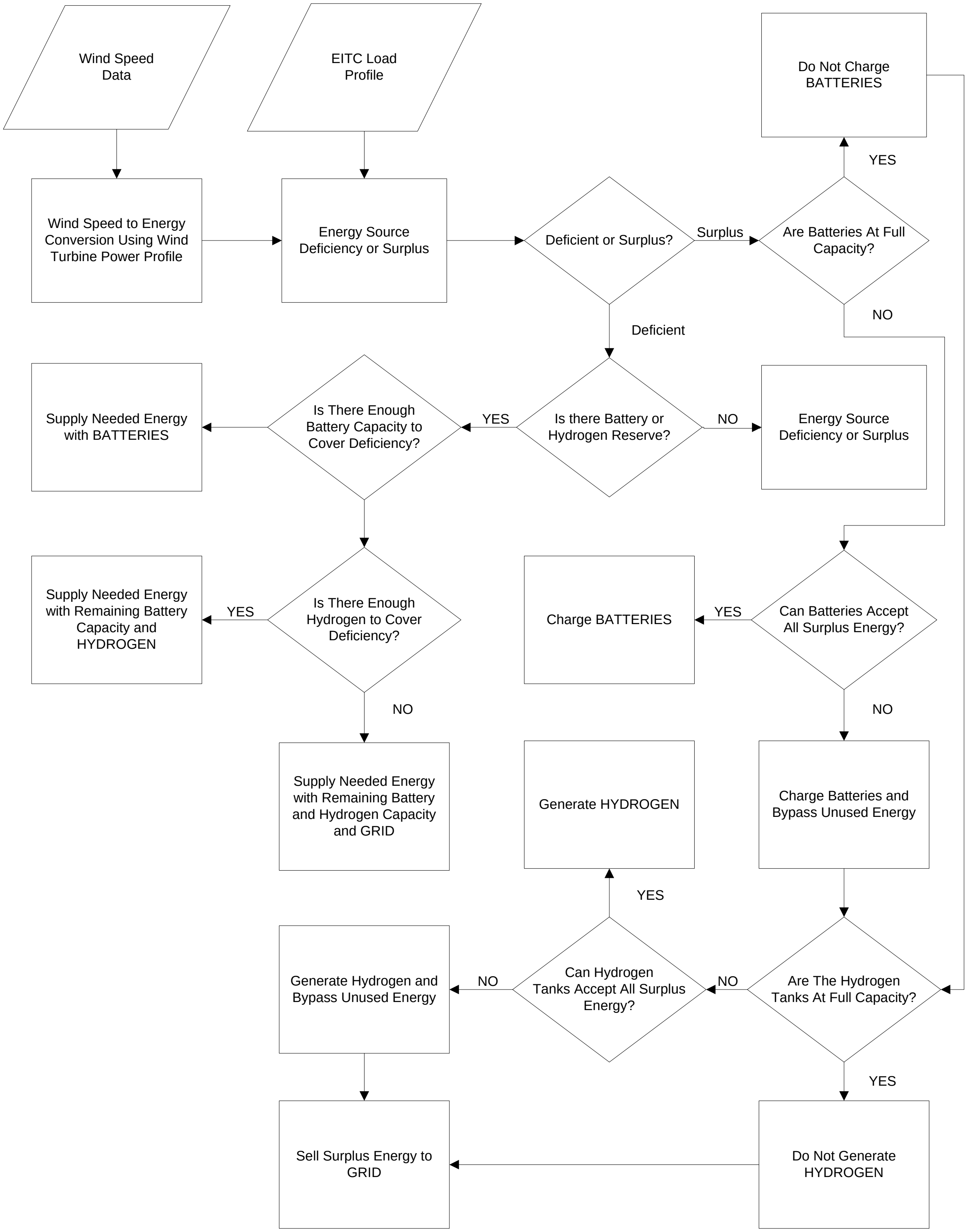


Figure 30: Algorithm Flowchart for Decision Making

8.0 Results

The results discussed here will be a series of systems, starting from a simple system to a complex system. The simple system consists of one wind turbine, one inverter, the load profile, and a grid connection. These systems will be compared between the results of Homer and the results from Simulink.

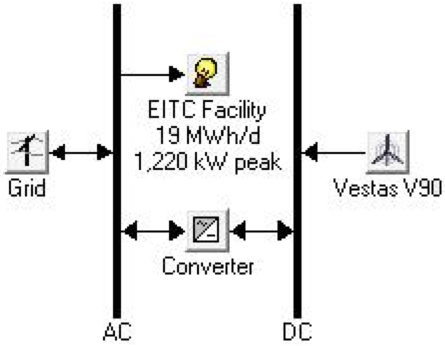


Figure 31: Simple Homer Model for a Wind energy system for the facility.

As can be seen in Figure 31, the simple Homer system consists of only the equipment listed above. The results from this system can be objectively compared to other systems by the input and output of energy through the system as well as the cost of the system.

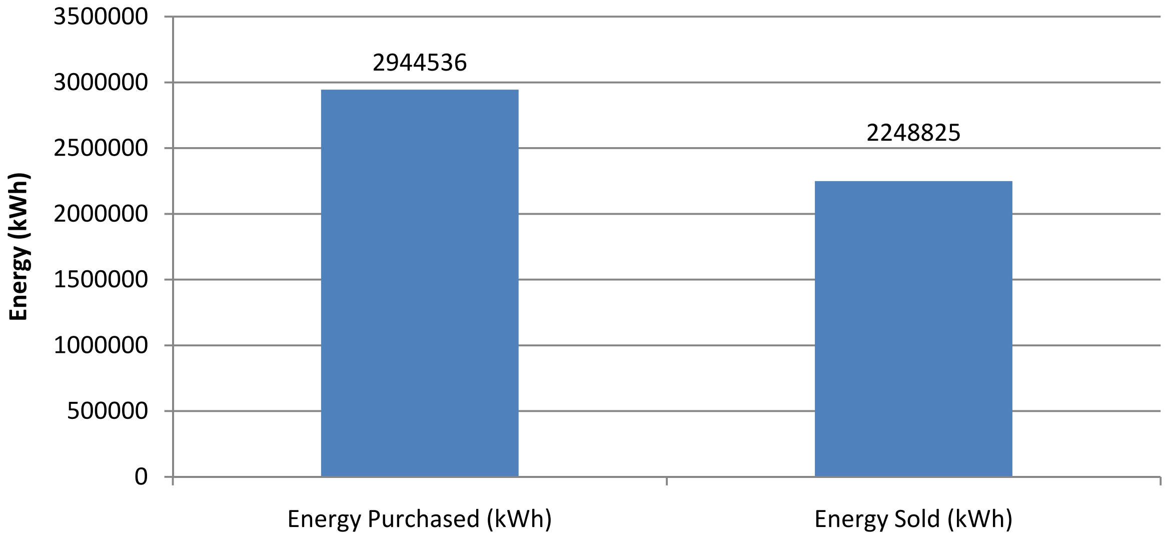


Figure 32: Results from Simple Homer System for a single wind turbine.

The results can be seen from Figure 32 show clearly that the simple Homer system consisting of the bare minimum equipment to operate the system does not meet the Net Zero objective of this project. There is approximately 695,712 kWh purchased from the grid over the entire year. At the time of this project, Ontario has a standard offer program that is offering $0.11 per kWh of energy that is generated back into the grid. At a current cost of energy (assuming $0.055 per kWh), a simple calculation can show that the energy movement shown in Figure 32 yields a positive income.

The results from Simulink show that there is a discrepancy between the two. The amount of energy purchased from the grid according to Simulink is 5,218,552 kWh over the year.

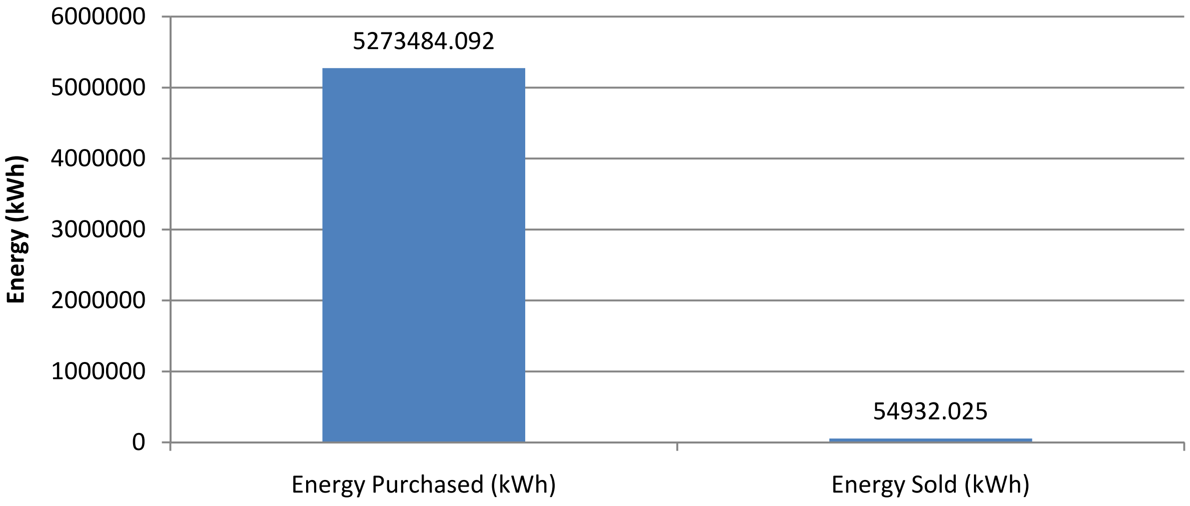


Figure 33: Results from Simple MATLAB/Simulink System

The way Simulink calculates the amount of energy produced is a direct calculation between the wind speed and the wind turbine. It then compares the available power with the defined load profile to determine whether there is excess power or a power deficit.

The discrepancy between the two results brings up an interesting situation. There is no clear explanation for the discrepancy, except that the mechanism behind MATLAB/Simulink is known to be mechanistic. Because the mechanism is known for Simulink, it makes Homer seem more clouded and convoluted, and the Homer simulation does not account well enough for the actual observered wind speed.

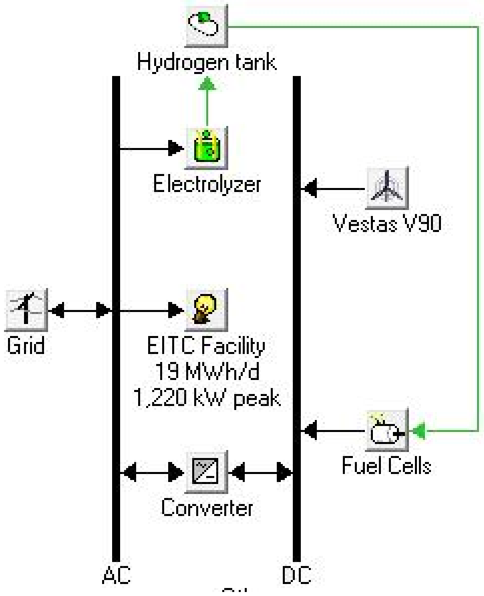


Figure 34: More Complex Homer Model for EITC Facility

In this system, Homer produced some interesting results. The complex Homer system consists of:

- 2 Wind Turbines
- 1000 kW Electrolyzer
- 1000 kg hydrogen storage tank
- Grid Connection
- Operating Cost: Income of $83,234 per year
- Capital Cost $7,070,000

The results that Homer produced from this system start to show that the mechanism behind Homer's system is not fully understood. Although fuel cells are an option in this system, Homer chose not to employ fuel cells because of economical reasons, however, the electrolyzer is still chosen to meet some of the hydrogen transportation demand. The added load of the electrolyzer accounts for the need of two wind turbines.

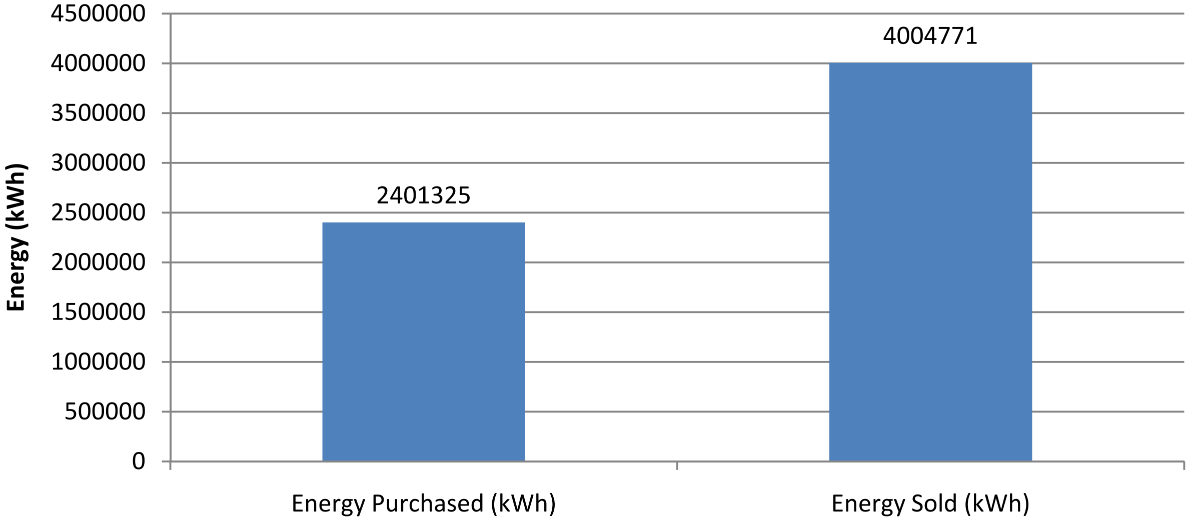


Figure 35: Results from More Complex Homer System for EITC Facility

Since Homer's system requires an electrolyzer and a second wind turbine, the system is generating much more energy than is required by the system itself, therefore putting the system in a position that is beyond Net Zero so there is a net selling of energy to the grid.

Other interesting results that were generated in Homer show that there are other results that have better Net Present Cost characterizations, but only if the initial capital costs can be met. The following result shows this case.

- 3 Wind Turbines
- 200 kW Fuel Cells
- 1000 kW Electrolyzer
- 1000 kg hydrogen storage tank
- Grid Connection
- Operating Cost $-104,103 per year

The use of the fuel cells requires more hydrogen to be generated, therefore requiring three wind turbines rather than two. The system in MATLAB/Simulink show different results, because of better sensitivity to the local wind speed.

A sensitivity analysis was done in Simulink to see how sensitive the system is to various changing parameters. Such parameters include wind speed and number of turbines.

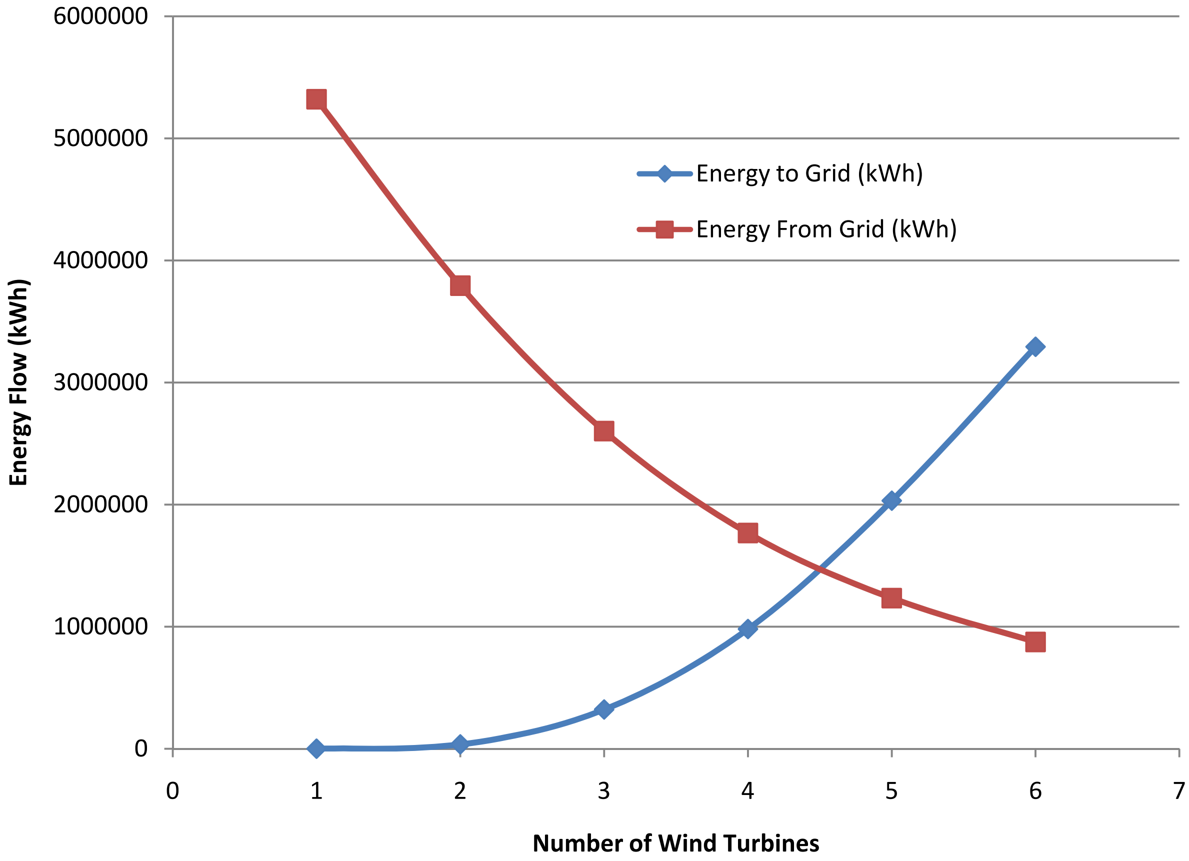


Figure 36: MATLAB/Simulink Results with Normal Wind Speed

In this series of results, it can be seen that Simulink reaches Net Zero between four and five wind turbines. This results conflicts with Homer since Net Zero is reached easily with one turbine in Homer.

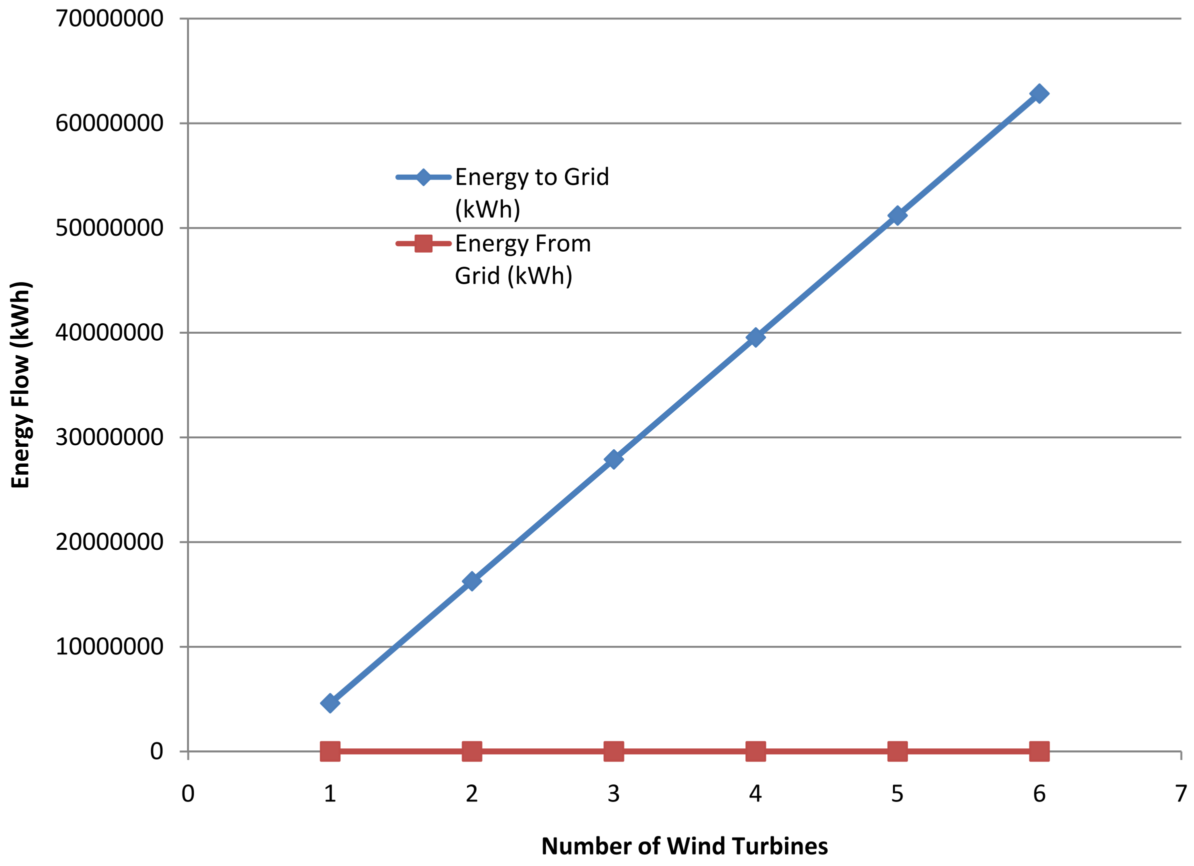


Figure 37: MATLAB/Simulink Results with 6 m/s Average Wind Speed Increase

At the extreme side, an increase of 6 m/s in average wind speed allows for the system to easily operate beyond Net Zero over the operating year. Thus, the location of the actual facility would be important to the overall viability of such a system. As expected, an increase in wind speed allows the wind turbine to operate in a more favourable range that allows the wind turbine to generate significantly more power.

It is unrealistic, however, to expect an average increase of 6 m/s in wind speed in the current proposed location, therefore, the point where Net Zero is exactly met must be found. For now, one turbine will be taken as the point at where Net Zero will be met.

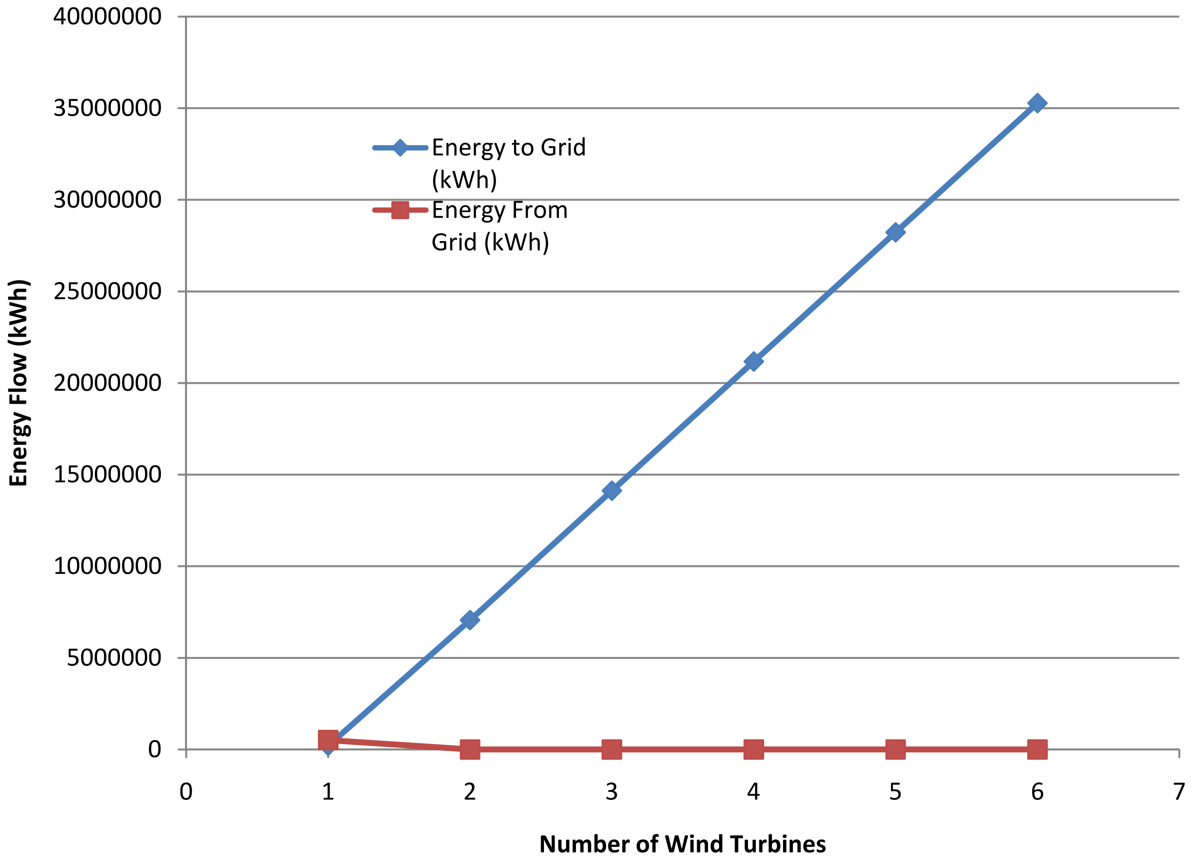


Figure 38: MATLAB/Simulink Result with 3.5 m/s Average Wind Speed Increase

At 3.5 m/s average wind speed increase, the system begins to show that Net Zero is being met with one wind turbine. If more than one turbine is considered, Net Zero is much more easily met since the energy production is effectively multiplied by a factor determined by the number of turbines; at least twice as much.

Although Net Zero can be met eventually with a wind speed increase, it still remains as an uncertainty that cannot be relied on because of its unpredictable nature. In order to see the entire picture, the reverse must be analyzed as well; how the system reacts with respect to wind speed when the number of wind turbines is changed.

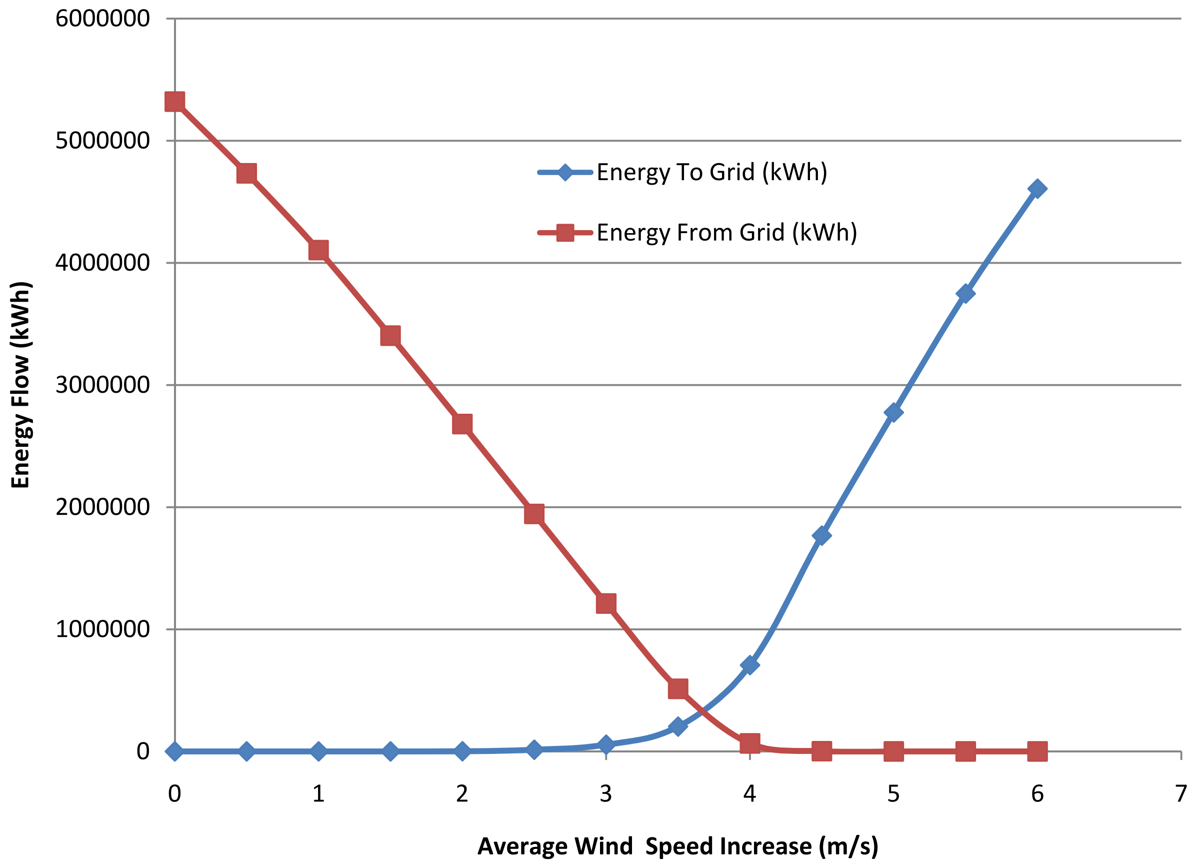


Figure 39: MATLAB/Simulink with One Turbine and Changing Average Wind Speed Increases

When using only one turbine, the average wind speed will need to be approximately 3.75 m/s faster in order to achieve Net Zero. Before this point, however, it can be seen that the system does not produce enough energy to be supplied to the grid to achieve Net Zero. Beyond this point, the system is creating an excessive amount of energy that can be sold to the grid.

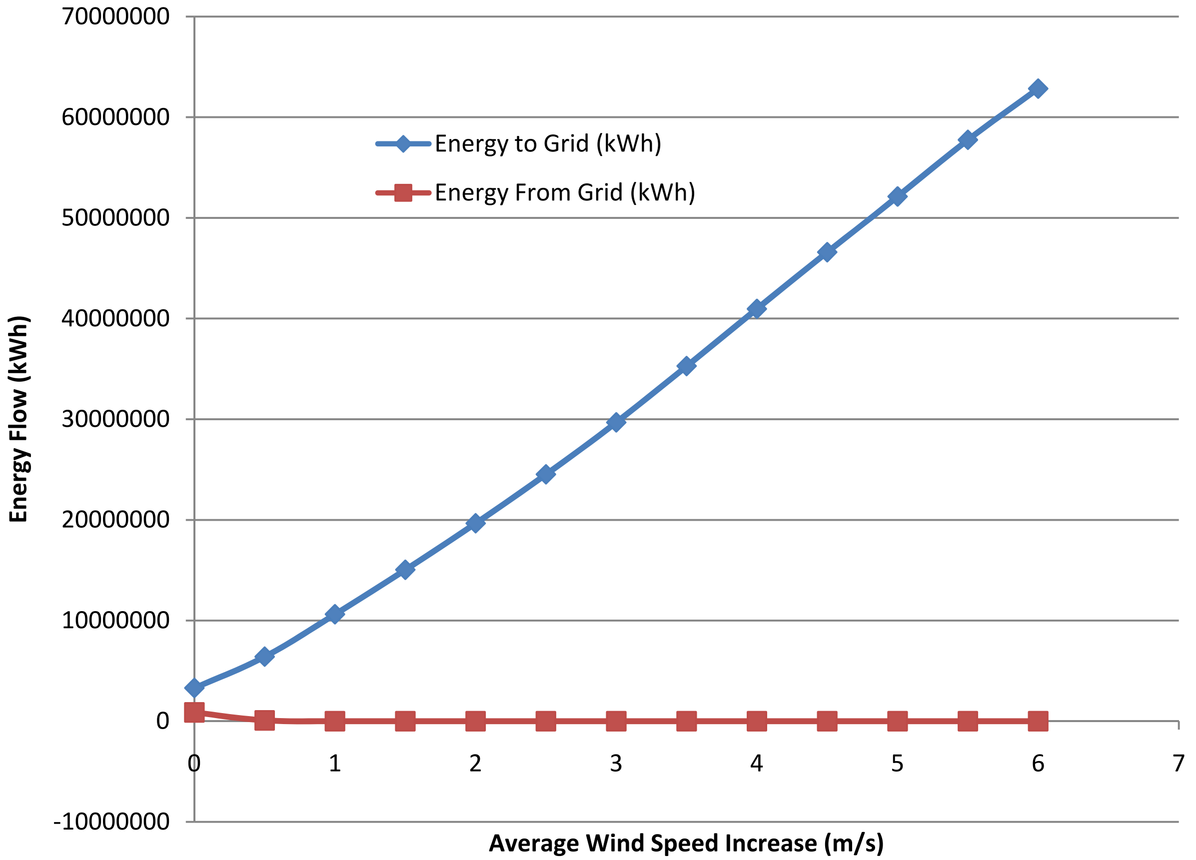


Figure 40: MATLAB/Simulink Results with 6 Wind Turbines, Varying Average Wind Speed Increases

On the other extreme, using six wind turbines allow the system to generate enough energy to be beyond Net Zero. Using six wind turbines, however, is very economically unsound as it is extremely expensive to purchase this system for one facility, and there is not the available property to support this many wind turbines. One interesting thing to note is that at 0 m/s increase in wind speed, the system seems to just barely be above the Net Zero requirement.

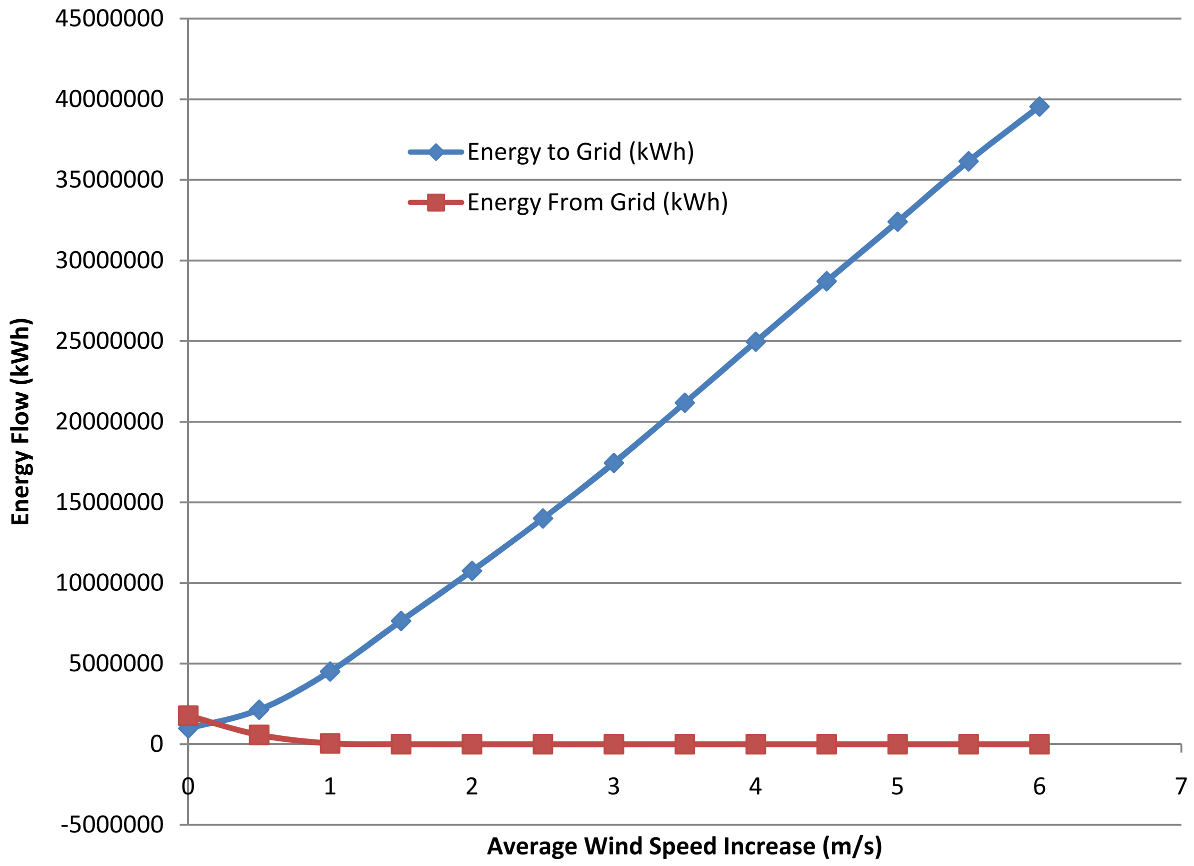


Figure 41: MATLAB/Simulink Results with 4 Wind Turbines, Varying Average Wind Speed Increases

At four wind turbines, the system shows that the system achieves Net Zero at an increase of 0 m/s in average wind speed.

In order to show how the system reacts to various parameters, the system was tested using a matrix of the two parameters; average wind speed increase and the number of wind turbines. A 6x13 matrix was setup using a range of 1 to 6 wind turbines and a range of 0 m/s to 6 m/s average wind speed increases over the baseline at 0.5 m/s intervals. The results can be seen in Figure 42.

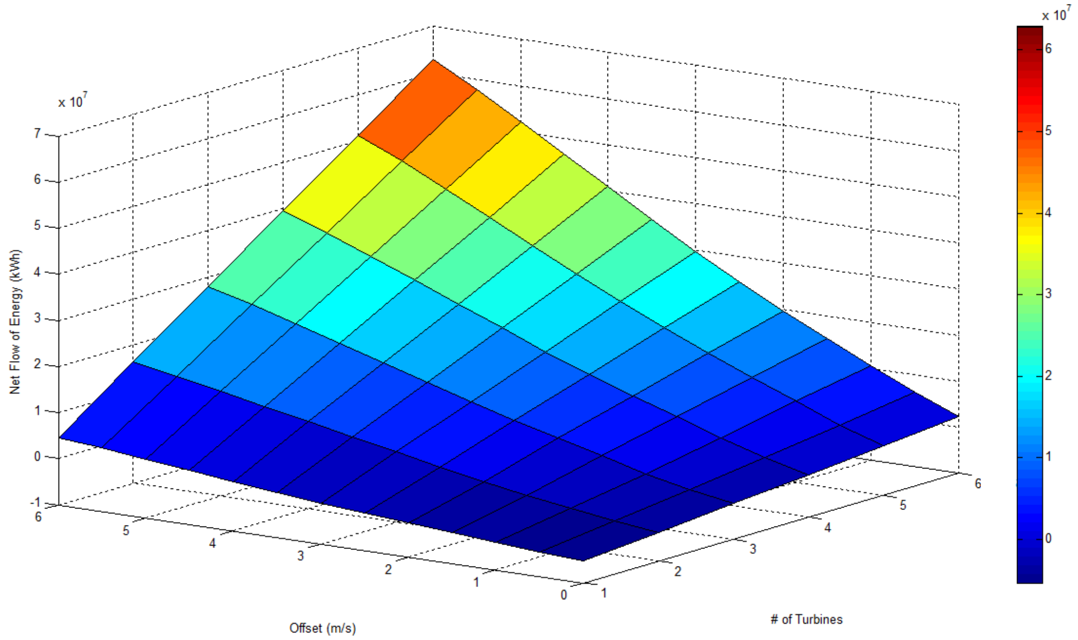


Figure 42: Net Energy Flow of the Facility Sensitivity to Wind Speed and Number of Turbines

Figure 42 shows how the Simulink system reacts to changing average wind speed as well as changing number of wind turbines. The results from Figure 42 are expected since higher wind speeds generate more power per turbine, while more turbines will generate more overall power.

With consideration of Figure 42 the more turbines will always be the better choice. This is incorrect because other factors haven't been taken into account in this result. Such factors include cost and size of system actually required, and more specifically land area. Looking at these other factors, especially with respect to what is actually needed, installing six turbines is not the best way to proceed.

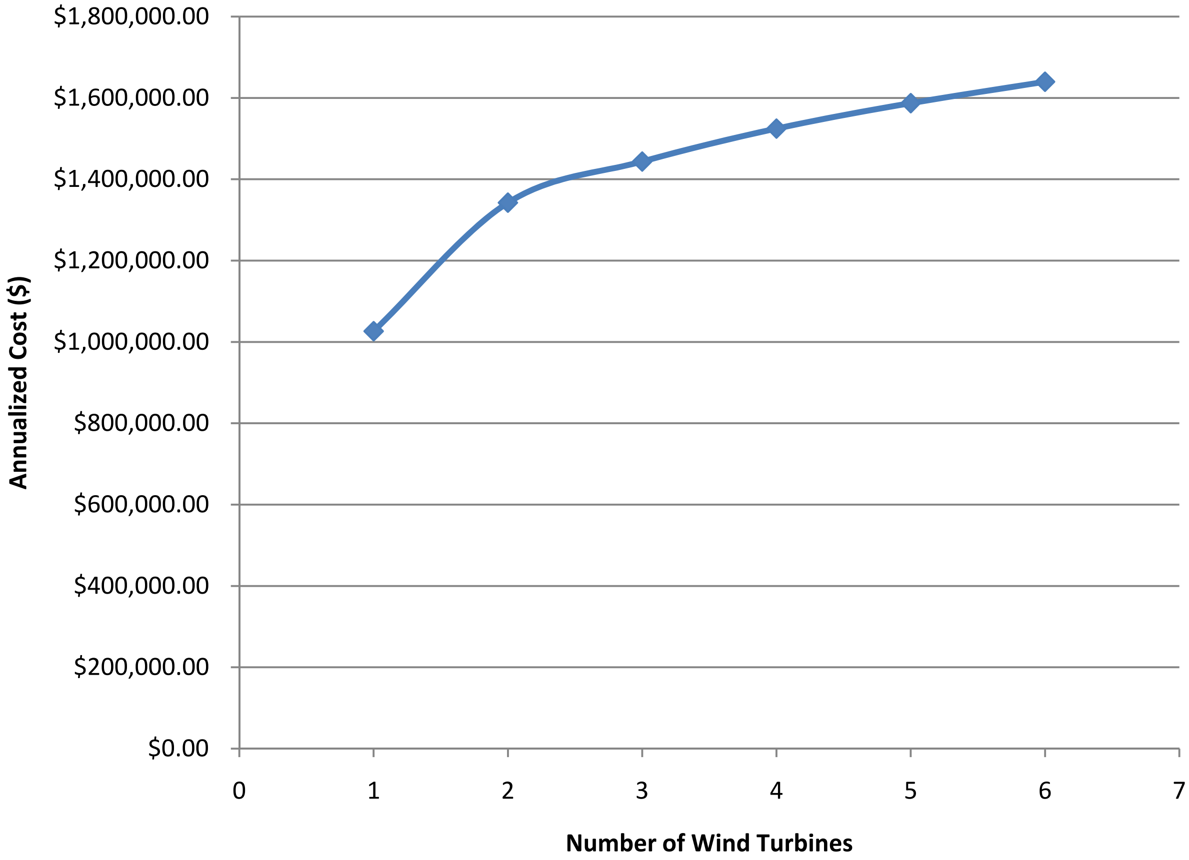


Figure 43: Annualized Cost with 0 m/s Average Wind Speed Increase, Varying Number of Wind Turbines

As expected, with normal wind speed, the annualized cost of the system increases with the increase in number of turbines. Similar to earlier, the other extreme must be analyzed in order to see the effect of wind speed increases.

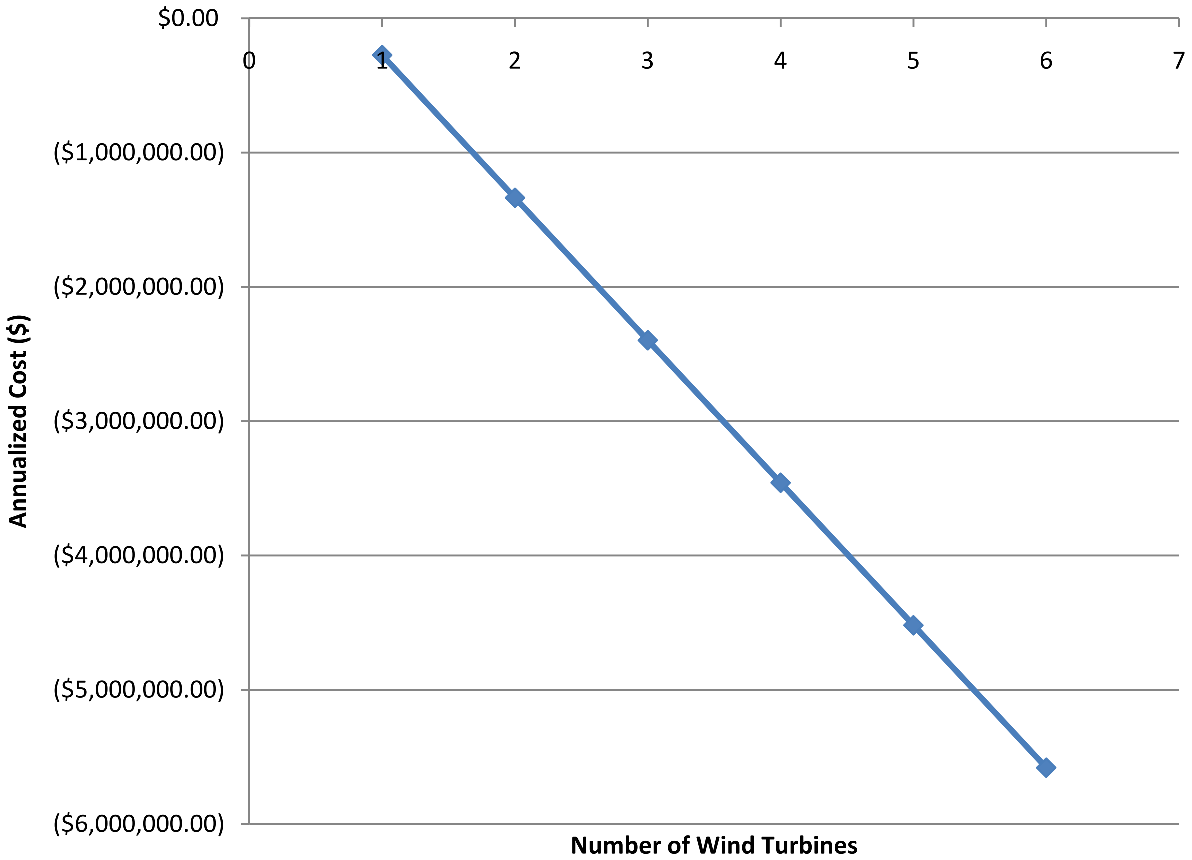


Figure 44: Annualized Cost with 6 m/s Average Wind Speed Increase, Varying Number of Wind Turbines

The annualized cost of the system illustrated in Figure 44 shows that the system has already begun and has exceeded the pay back amount by showing an annualized cost of below $0, to demonstrate the increased number of turbines generates revenue for the facility with the higher level of wind resources.

The same situation as earlier is had here as well; 6 m/s average wind speed increase is unreasonable to assume, therefore, the breaking point where the annualized cost reaches $0 must be found (while assuming one wind turbine).

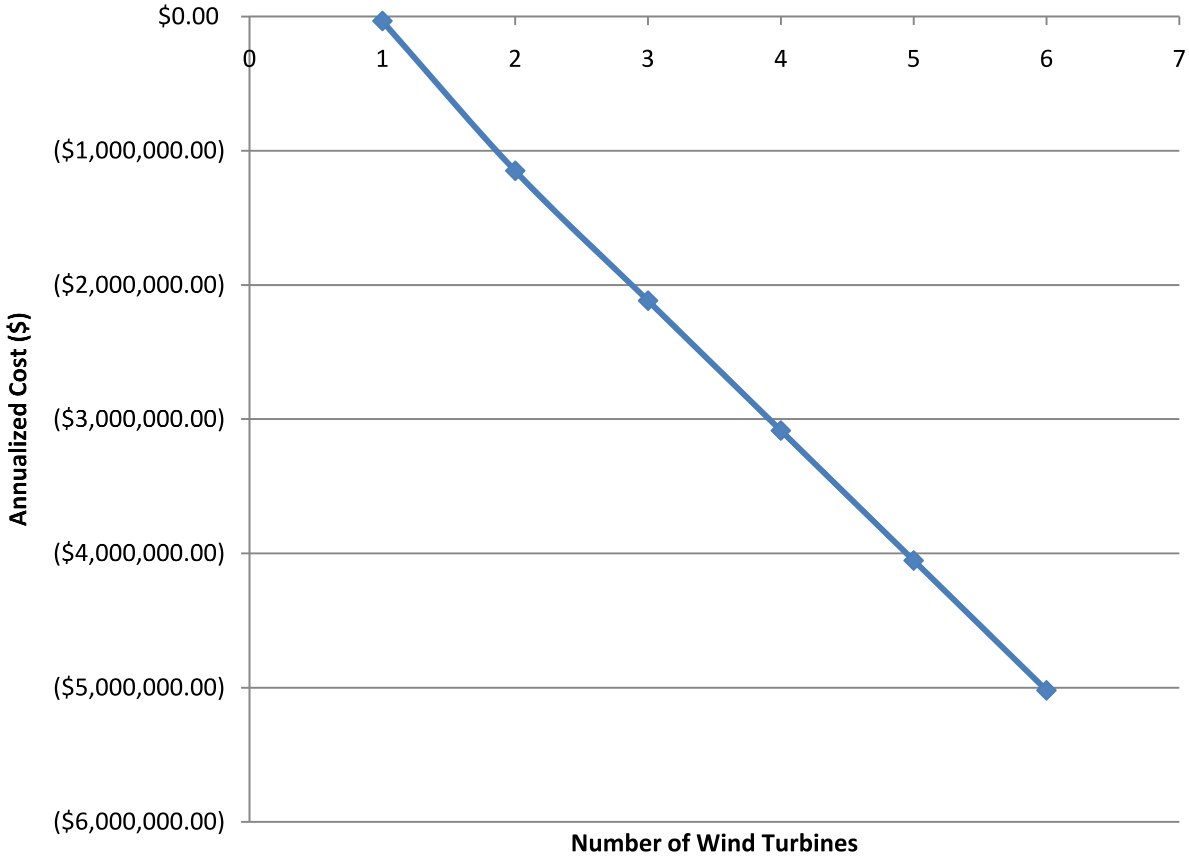


Figure 45: Annualized Cost with 5.5 m/s Average Wind Speed Increase, Varying Number of Wind Turbines

The point at where the annualized cost becomes $0 with one turbine was found to be at approximately 5.5 m/s average wind speed increase. An increase in average wind speed of 5.5 m/s is a little more favourable than 6 m/s, however, it is still unreasonable to hope for this kind of increase in the present location. In other more favourable locations, however, it may be possible for yearly fluctuations to reach this kind of increase.

The other side of the matrix must now be analyzed to see what the system has to offer.

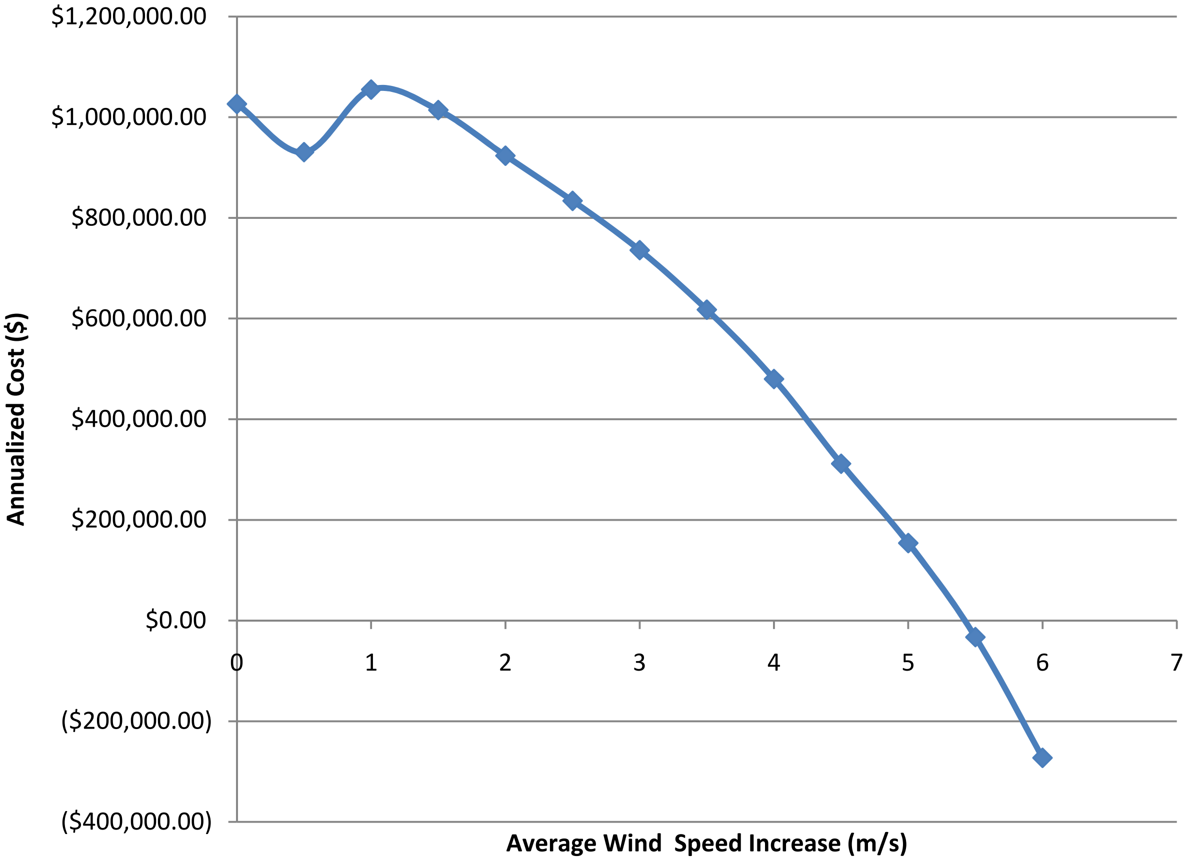


Figure 46: Annualized Cost with One Wind Turbine, Varying Average Wind Speed Increases

With faster wind speed, the general trend is that the annualized cost decreases with increases in speed due to the fact that the wind turbine can generate more power that can be sold to the grid.

As expected, the point at which the annualized cost reaches $0 is approximately had at 5.5 m/s average wind speed increase.

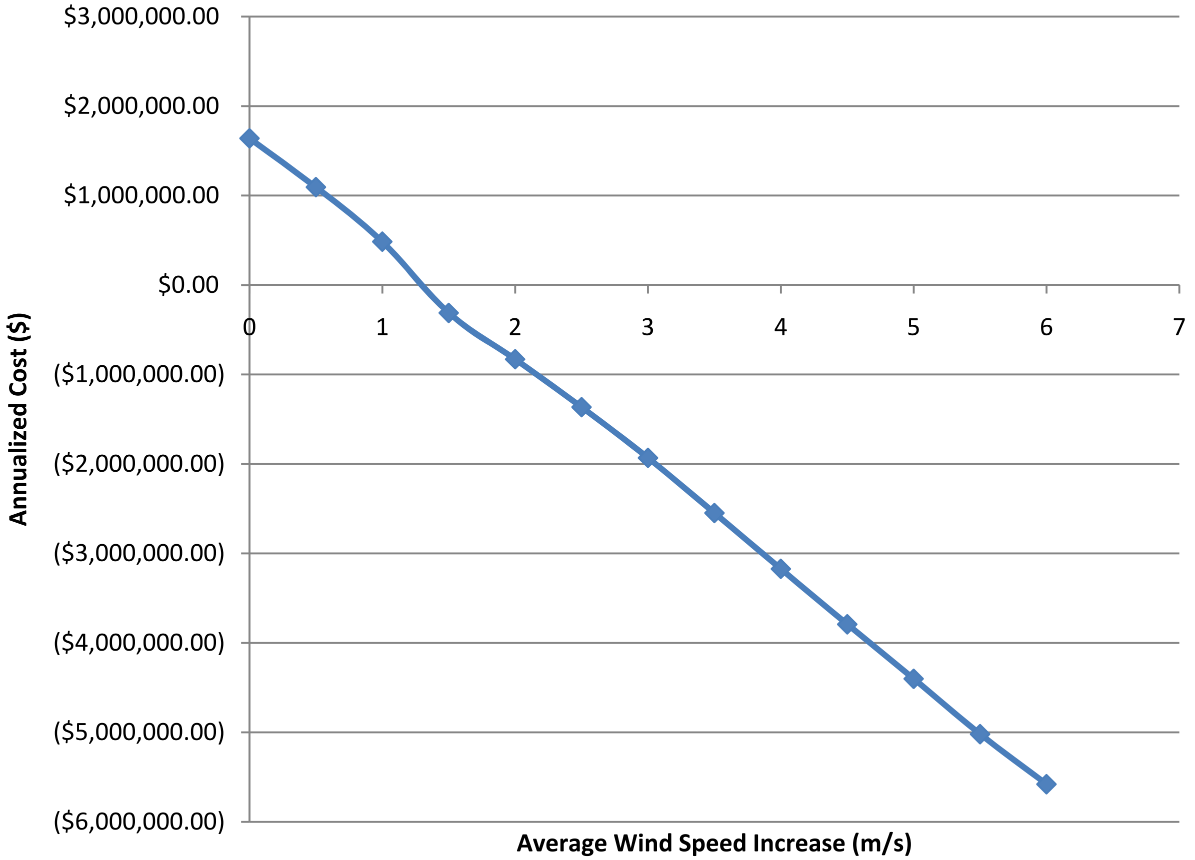


Figure 47: Annualized Cost with Six Wind Turbines, Varying Average Wind Speed Increases

At this extreme side of six wind turbines, $0 annualized cost can be found at approximately 1.5 m/s average wind speed increase. An average increase of 1.5 m/s is very reasonable, however, the need for six wind turbines for this system is not reasonable.

This analysis was put through the same 6x13 matrix that the energy flow analysis was put through. The results can be seen in Figure 48.

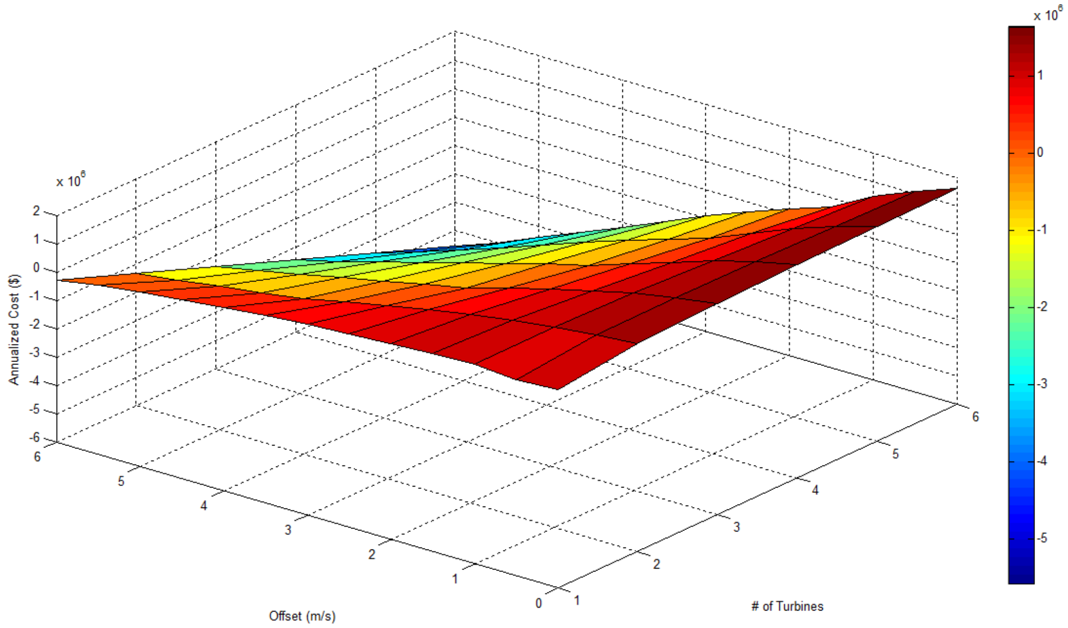


Figure 48: Annualized Cost Sensitivity with Average Wind Speed Increase and Number of Wind Turbines

As expected once again, increasing the wind speed decreases the annual cost of this system. The number of wind turbines, however, changes over from increasing cost to decreasing cost at about 1 m/s.

Although this annualized cost analysis agrees with the energy flow analysis, there is another parameter that does not agree; capital cost.

Table 7: Capital Cost Sensitivity Analysis

	Average Wind Speed Increase (m/s)						
Wind Turbines	***0.0***	***0.5***	***1.0***	***1.5***	***2.0***	***2.5***	***3.0***
1	$12.02M	$11.04M	$14.53M	$14.84M	$14.19M	$13.60M	$12.90M
2	$20.86M	$20.09M	$19.16M	$17.78M	$16.38M	$14.98M	$13.58M
3	$25.42M	$24.03M	$22.65M	$20.55M	$18.45M	$16.15M	$13.46M
4	$29.82M	$27.99M	$26.12M	$23.32M	$20.32M	$17.85M	$17.85M
5	$34.24M	$31.92M	$29.59M	$26.08M	$22.26M	$22.25M	$22.25M
6	$38.64M	$35.85M	$33.05M	$26.86M	$26.65M	$26.65M	$26.65M
	Average Wind Speed Increase (m/s)						
Wind Turbines	***3.5***	***4.0***	***4.5***	***5.0***	***5.5***	***6.0***	
1	$11.98M	$11.05M	$10.12M	$9.18M	$7.59M	$4.68M	
2	$11.52M	$9.06M	$9.05M	$9.05M	$9.05M	$9.05M	
3	$13.45M	$13.45M	$13.45M	$13.45M	$13.45M	$13.45M	
4	$17.85M	$17.85M	$17.85M	$17.85M	$17.85M	$17.85M	
5	$22.25M	$22.25M	$22.25M	$22.25M	$22.25M	$22.25M	
6	$26.65M	$26.65M	$26.65M	$26.65M	$26.65M	$26.65M	

Installing six wind turbines increases the capital cost by approximately $22M when compared to just one turbine.

If the capital cost of such a system is not an issue, assuming that all other factors (such as aesthetics) is not a factor, then the more wind turbines that are in the system, the better it is economically and for energy flow.

Since the capital cost is always a factor, it must be considered. Now the decision becomes a balance between annual cost and energy production with capital costs. Even though the decision is not clear, one still has to be made, and the final criteria will help in making the final decision; the Net Zero requirement.

Given the results from the energy flow analysis and keeping in mind the Net Zero criteria, between four and five wind turbines are required at normal wind speeds to achieve Net Zero. This results in a capital cost of $29.82M to $34.24M and an annualized cost of $1.52M to $1.59M. If there is a 1.5 m/s to 2.0 m/s increase in average wind speed, only two wind turbines will be enough to reach Net Zero. This decision comes with a capital cost of $16.38M to $17.78M and an annualized cost of $0.65M to $0.89M. With the increase in tropical activity around the world, it may be possible to realize a 1.5 m/s to 2.0 m/s average increase in wind speed, however, an actual wind speed analysis must be done for the specific area before any conclusions on wind speed can be had. Expecting the average wind speed to be 2.0 m/s is unlikely, therefore no results higher than 2.0 m/s over the baseline will be considered for this system.

Annualized costs were calculated over an equipment lifetime of approximately 20 years. In addition to the capital costs, electricity sales and purchases are taken into account also. The cost of electricity for commercial use (such as the University of Waterloo’s electricity cost) of $0.080/kWh was used as the purchase price. The sales price of electricity of $0.110/kWh was used. The price of $0.110/kWh of electricity is part of Ontario’s Standard Offer Program (SOP) that Ontario will buy electricity that is generated by wind turbines. The difference in yearly purchases and sales is added to the annualized cost in each result.

Within the capital cost of each system includes the cost of the batteries, hydrogen storage tank and the fuel cells. The size of each component is determined by the how the system reacts with respect to the number of wind turbines. Seen below is the breakdown of equipment for both results.

Table 8: Result 1 Cost Breakdown

Equipment	Size	Cost per Unit	Cost
Wind Turbines	4 - 5 x 1.8MW	$4.40M/ Turbine	$17.60M - $22.00M
Battery	921kW - 1,016kW with 2,000kWh Capacity	$150 / kW	$0.14M - $0.15M
Fuel Cell	1,220kW	$9,700 / kW	$11.83M
H2 Storage	504kg	$500 / kg	$0.25M
		Total Capital Cost	**$29.82M - $34.24M**

Table 9: Result 2 Cost Breakdown

Equipment	Size	Cost per Unit	Cost
Wind Turbines	2 x 1.8MW	$4.40M / Turbine	$8.80M
Battery	685kW - 794kW with 2,000kWh Capacity	$150 / kW	$0.10M - $0.12M
Fuel Cell	745kW - 887kW	$9,700 / kW	$7.23M - $8.60M
H2 Storage	504kg	$500 / kg	$0.25M
		Total Capital Cost	**$16.38M - $17.78M**

Seeing as the result for 0 m/s average wind speed increase costs approximately twice as much as the 1.5 m/s to 2.0 m/s average wind speed increase result, result 2 will be accepted as the final result.

With two wind turbines at an average wind speed increase of 1.5 m/s to 2.0 m/s, the system is able to sustain up to three vehicles without severely changing the results of energy flow and annualized costs. This is because the vehicles can only actually be operated while the system is producing a net positive amount of hydrogen while storing enough excess for the system to have enough hydrogen in reserve to power the facility. The system can be modified to increase the production of hydrogen, however, it will negatively impact the overall system, and that is not the focus of the project.

9.0 Conclusions

There are many technologies available for distributed generation, and the selection of specific technology depends largely on the application and the location. The application of fuel cells is probably the most complicated, yet fuel cells show promise as a viable energy storage technology and will aid in a specific energy hub or facility achieving Net Zero with respect to energy generation and use. The complication isn't how the fuel cell operates as a single entity, but how it operates in conjunction with other power sources and also from where it will receive its hydrogen supply.

Distributed generation is a necessity in today's urban societies. Grid congestion is a growing problem for utilities that must be addressed quickly and successfully. Distributed generation does not have to be a problem for large utility companies; utilities can be the facilitator of distributed generation. That being said, utilities-run distributed generation systems will undoubtedly be grid-tied. This concept has its advantages and disadvantages where intermittency of sources will become a non-issue while it also means that utilities will still have control of the cost of electricity and the operation of the system.

The Experiential and Innovation Technology Centre is large enough to be able to use wind power effectively. The results that yielded the best compromise between cost and energy production while meeting the Net Zero requirement can be seen in the summary table below.

Table 10: Summary of Final Results

Equipment	Size	Cost per Unit	Cost
Wind Turbines	2 x 1.8MW	$4.40M / Turbine	$8.80M
Battery	685kW - 794kW with 2,000kWh Capacity	$150 / kW	$0.10M - $0.12M
Fuel Cell	745kW - 887kW	$9,700 / kW	$7.23M - $8.60M
H2 Storage	504kg	$500 / kg	$0.25M
		Total Capital Cost	**$16.38M - $17.78M**

The energy hub system as proposed realizes the benefit of having a Net Zero commercial facility located in a technologically advanced city, Waterloo, Ontario. The EITC will be the first of its kind to showcase this kind of system as well as attract many countries and corporations to conduct state-of-the-art research in a Canadian facility. Although the economics of this energy system alone is not a favourable one, an overall economic analysis including all factors (such as fees to use facility, residential fees, etc.) must be done in order to realize the full economic potential of this facility.

Economics aside, the EITC brings many other benefits to both the City of Waterloo, as well as to Canada as a country since it will attract international collaboration of various technological research projects from around the world.

The following is a list of possible future work should this project be taken further.

Work	**Brief Description**
Transient Models	To incorporate reaction time of each piece of equipment
Fleet of Vehicles	Most in depth analysis of fleet of vehicles. Incorporate the vehicles into the building to displace stationary fuel cells.
Full Optimization of System	To determine best models and best system
Use Other Forms of Renewable Technology	Feasibility study of other sources of renewable energy
Thermal Analysis of Facility	A thermal analysis of the facility will complete the overall analysis of the facility

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Appendix A – MATLAB/Simulink Model and Code

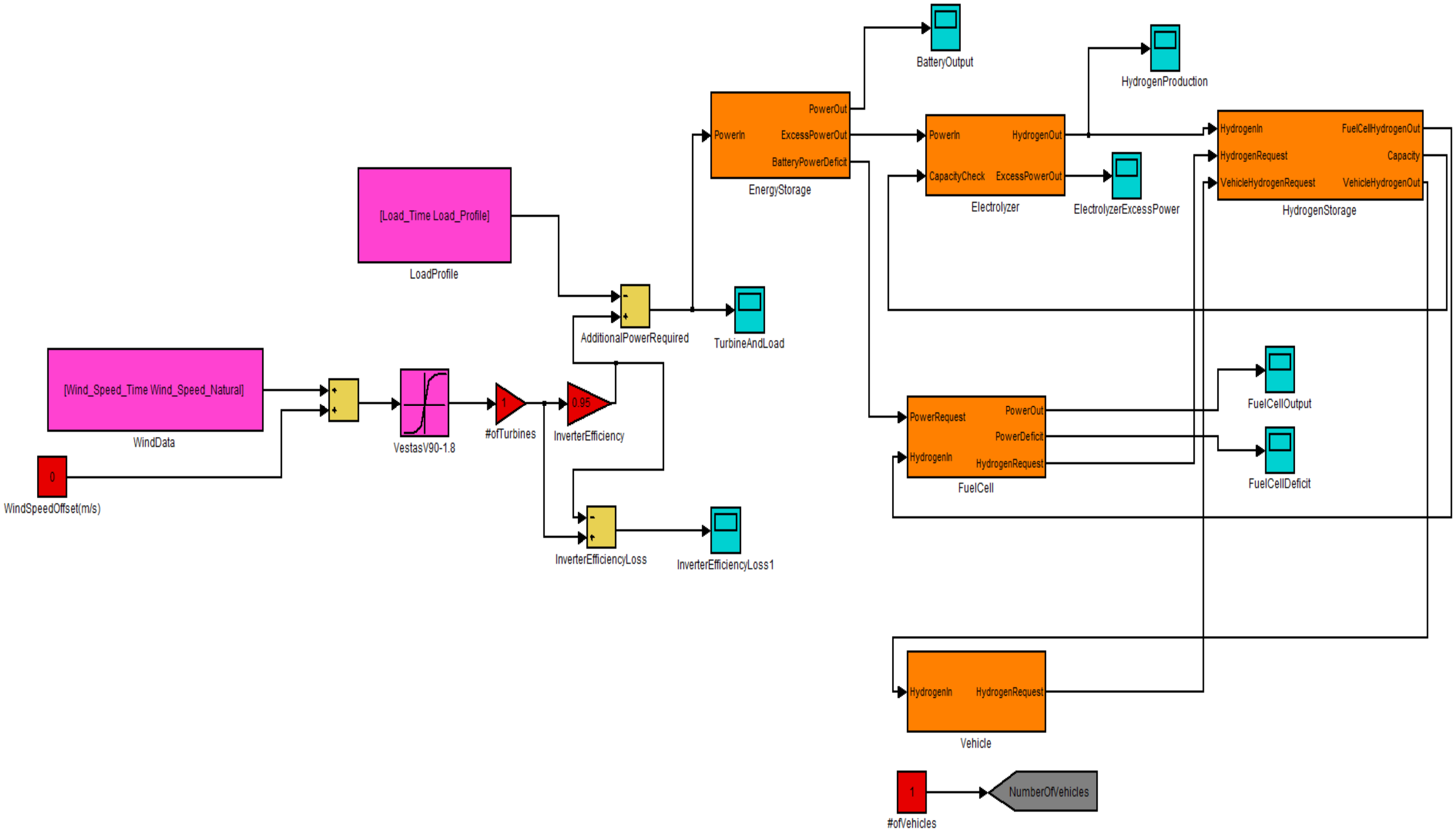

Figure 49: Overall MATLAB/Simulink Model for EITC Facility

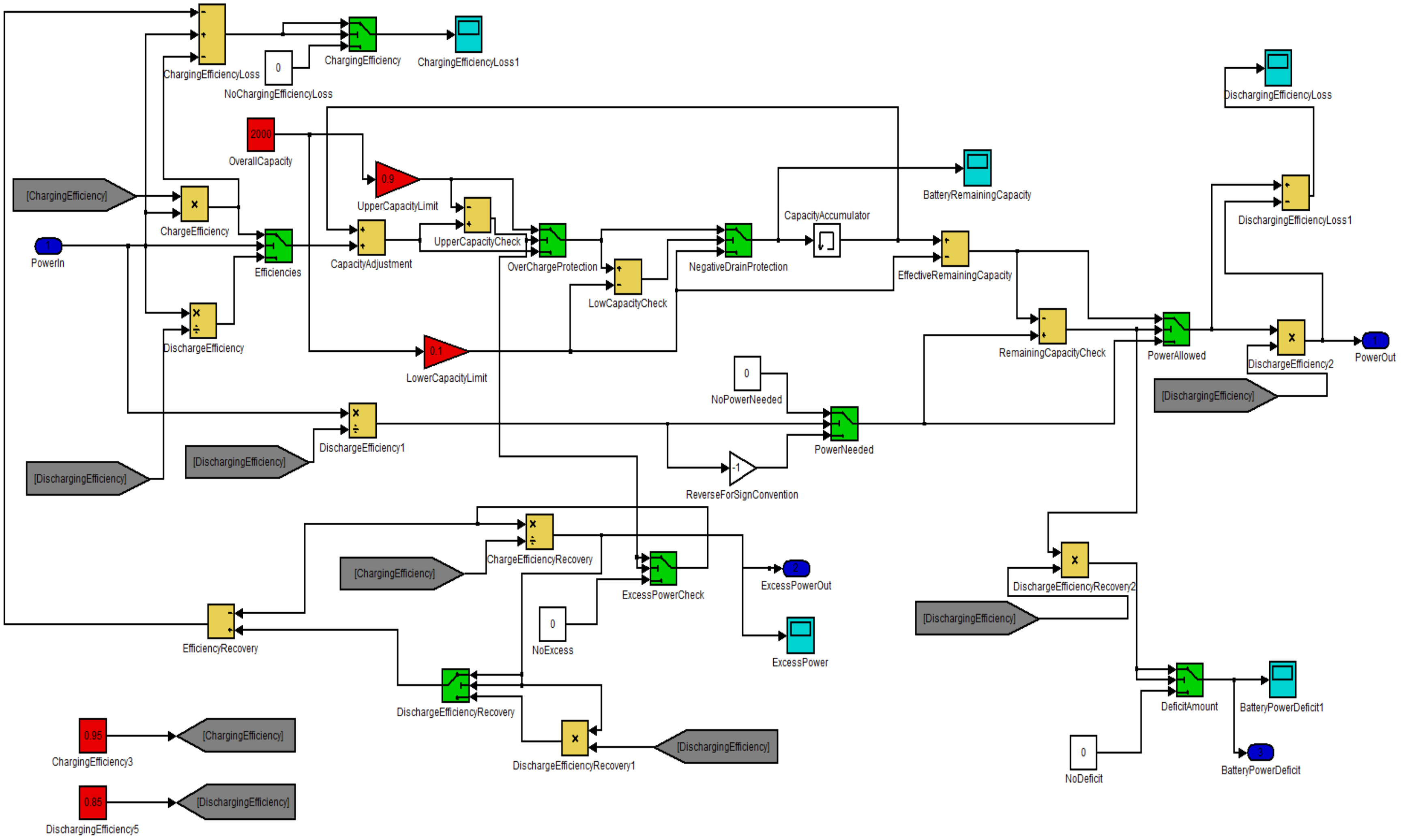

Figure 50: MATLAB/Simulink Battery Model for EITC Facility

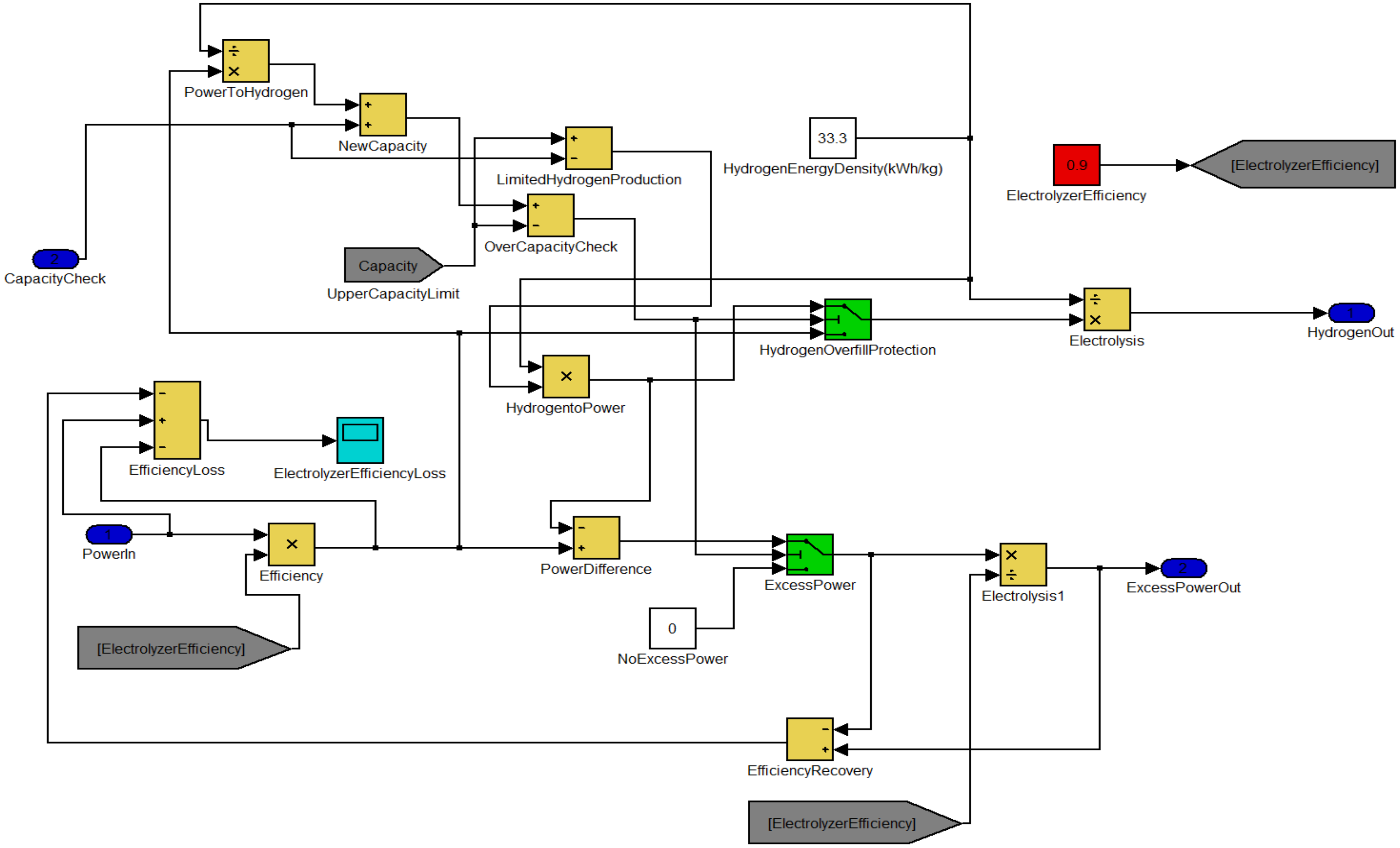

Figure 51: MATLAB/Simulink Electrolyzer Model for EITC Facility

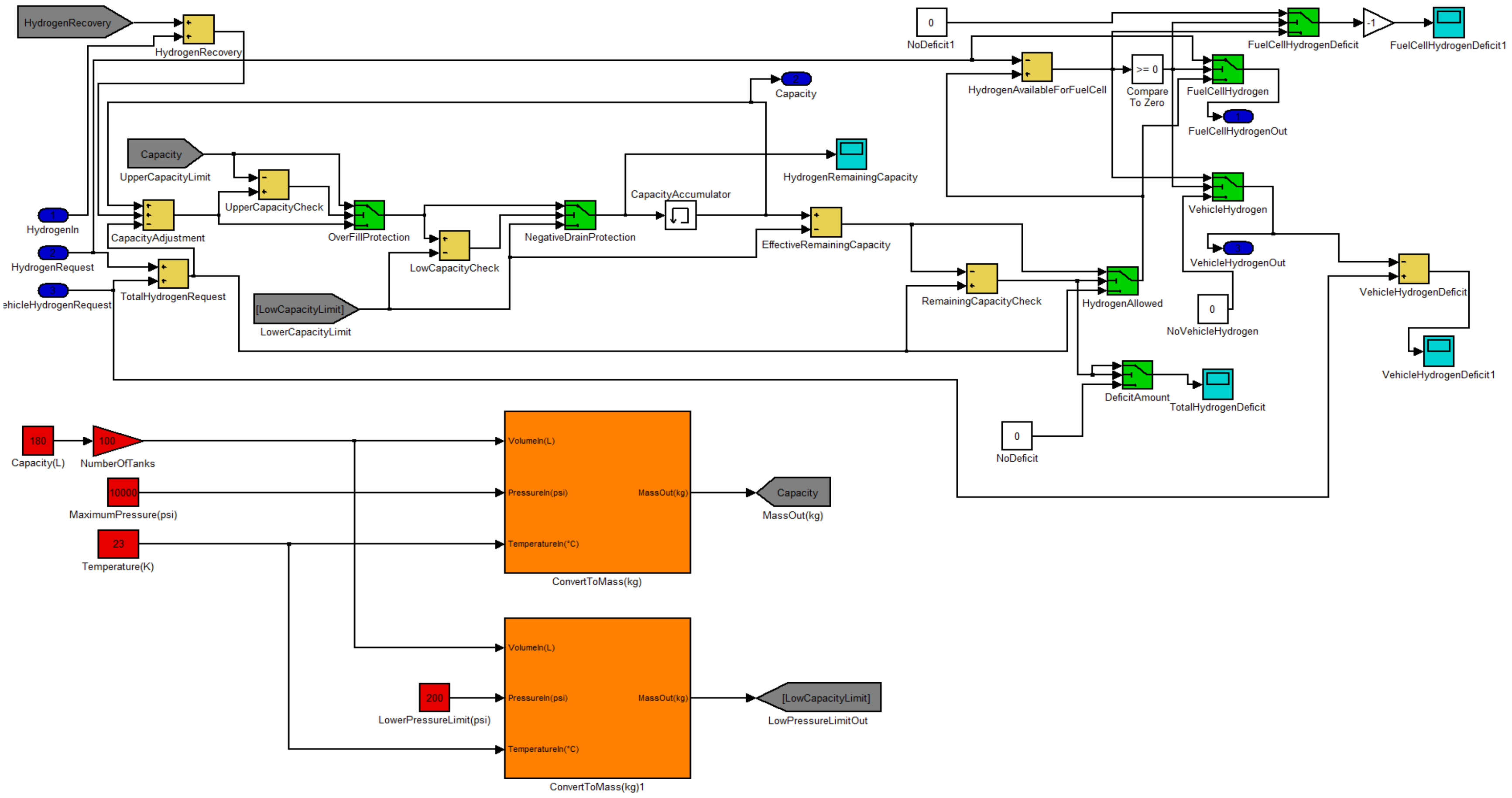

Figure 52: MATLAB/Simulink Hydrogen Storage Model for EITC Facility

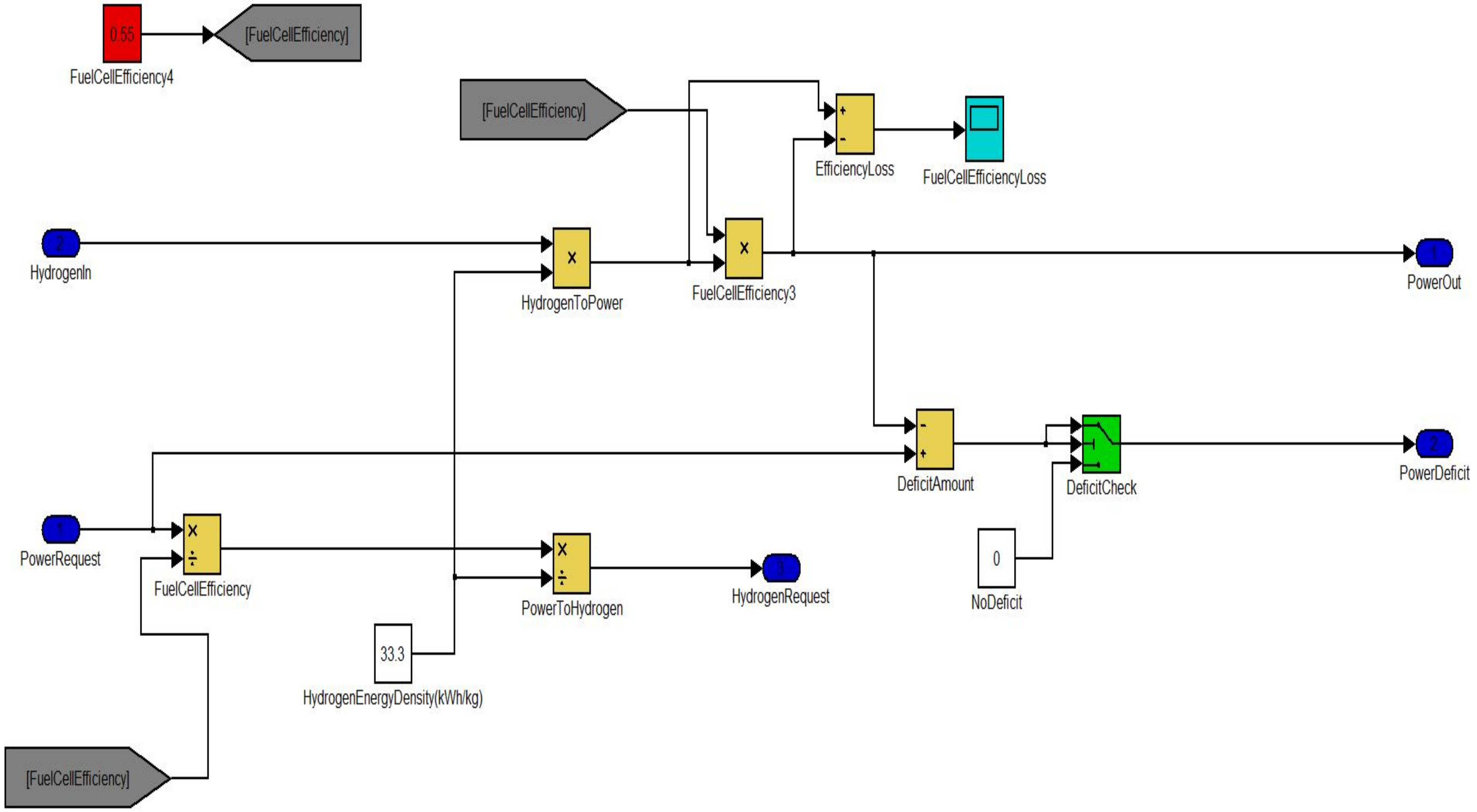

Figure 53: MATLAB/Simulink Fuel Cell Model for EITC Facility

Exporting Data to Excel for Analysis Code

```
display ('Exporting TurbineAndLoad')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', TurbineAndLoad, 'Sheet1', 'A2')
display('Exporting BatteryOutput')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', BatteryOutput(:,2), 'Sheet1', 'C2')
display('Exporting BatteryCapacity')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', BatteryCapacity(:,2), 'Sheet1', 'D2')
display('Exporting BatteryPowerDeficit')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', BatteryPowerDeficit(:,2), 'Sheet1', 'E2')
display('Exporting BatteryExcessPower')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', BatteryExcessPower(:,2), 'Sheet1', 'F2')
display('Exporting HydrogenProduction')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', HydrogenProduction(:,2), 'Sheet1', 'G2')
display('Exporting HydrogenCapacity')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', HydrogenCapacity(:,2), 'Sheet1', 'H2')
display('Exporting TotalHydrogenDeficit')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', TotalHydrogenDeficit(:,2), 'Sheet1', 'I2')
display('Exporting ElectrolyzerExcessPower')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', ElectrolyzerExcessPower(:,2), 'Sheet1', 'J2')
display('Exporting FuelCellOutput')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', FuelCellOutput(:,2), 'Sheet1', 'K2')
display('Exporting FuelCellDeficit')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', FuelCellDeficit(:,2), 'Sheet1', 'L2')
display('Exporting InverterEfficiencyLoss')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', InverterEfficiencyLoss(:,2), 'Sheet1', 'M2')
display('Exporting BatteryChargingEfficiencyLoss')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', BatteryChargingEfficiencyLoss(:,2), 'Sheet1', 'N2')
display('Exporting BatteryDischargingEfficiencyLoss')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', BatteryDischargingEfficiencyLoss(:,2), 'Sheet1', 'O2')
display('Exporting ElectrolyzerEfficiencyLoss')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', ElectrolyzerEfficiencyLoss(:,2), 'Sheet1', 'P2')
display('Exporting FuelCellEfficiencyLoss')
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display('Exporting FuelCellHydrogenDeficit')
```

```
xlswrite('\Results\Preliminary Results - 04-20-08.xls', FuelCellHydrogenDeficit(:,2), 'Sheet1', 'R2')
display('Exporting VehicleHydrogenDeficit')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', VehicleHydrogenDeficit(:,2), 'Sheet1', 'S2')
display('Exporting VehiclesRequested')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', VehiclesRequested(:,2), 'Sheet1', 'T2')
display('Exporting VehiclesOperating')
xlswrite('\Results\Preliminary Results - 04-20-08.xls', VehiclesOperating(:,2), 'Sheet1', 'U2')
```

Initializing Variables and Parameters

```
% Read Wind Data contained in an excel spreadsheet
display ('Loading Wind Data');
Wind_Speed_Time = xlsread('Wind_Data\Adjusted_Wind_Speed_Data_2004.xls', 'Time_Data');
Wind_Speed_Natural = xlsread('Wind_Data\Adjusted_Wind_Speed_Data_2004.xls', 'Wind_Data');

% Read Turbine Power Profile contained in an excel spreadsheet
display ('Loading Wind Turbine Profile');
Turbine_Wind_Speed = xlsread('Turbine_Power_Profile\Turbine_Power_Profile.xls', 'Wind_Speed');
Turbine_Power = xlsread('Turbine_Power_Profile\Turbine_Power_Profile.xls', 'Power_Output');

% Read Building Load Profile contained in an excel spreadsheet
display ('Loading Building Load Profile');
Load_Time = xlsread('Load_Profile\Load_Profile.xls', 'Time_Load');
Load_Profile = xlsread('Load_Profile\Load_Profile.xls', 'Load_Data');

% Read Vehicle Load Profile contained in an excel spreadsheet
display ('Loading Vehicle Load Profile');
Load_Vehicle_Profile = xlsread('Vehicle_Load_Profile\Vehicle_Load_Profile.xls','Vehicle_Load_Data');
```

Appendix B – MATLAB/Simulink Results

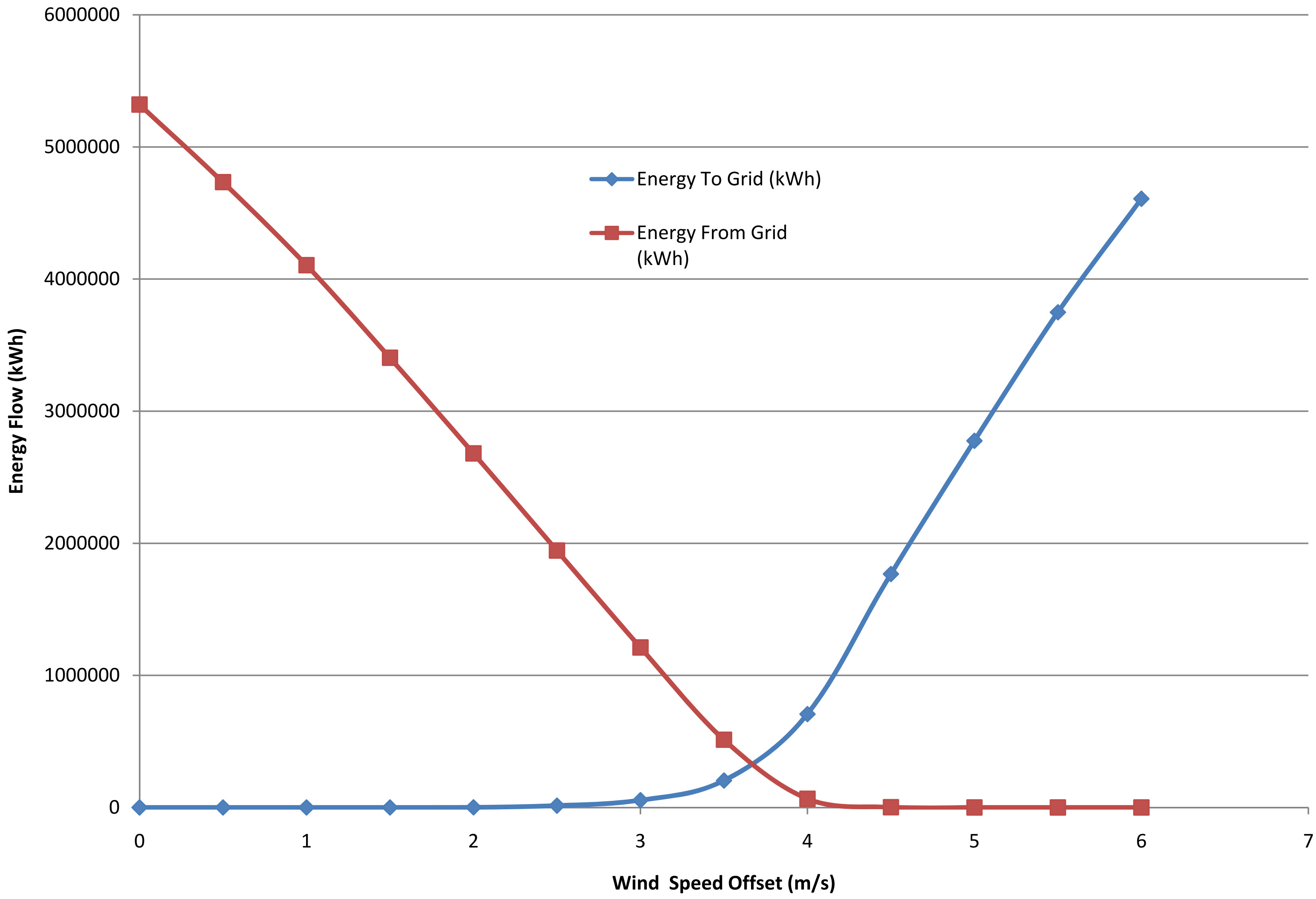

Figure 54: Energy Flow with One Wind Turbine, Varying Wind Speed Offset from Average

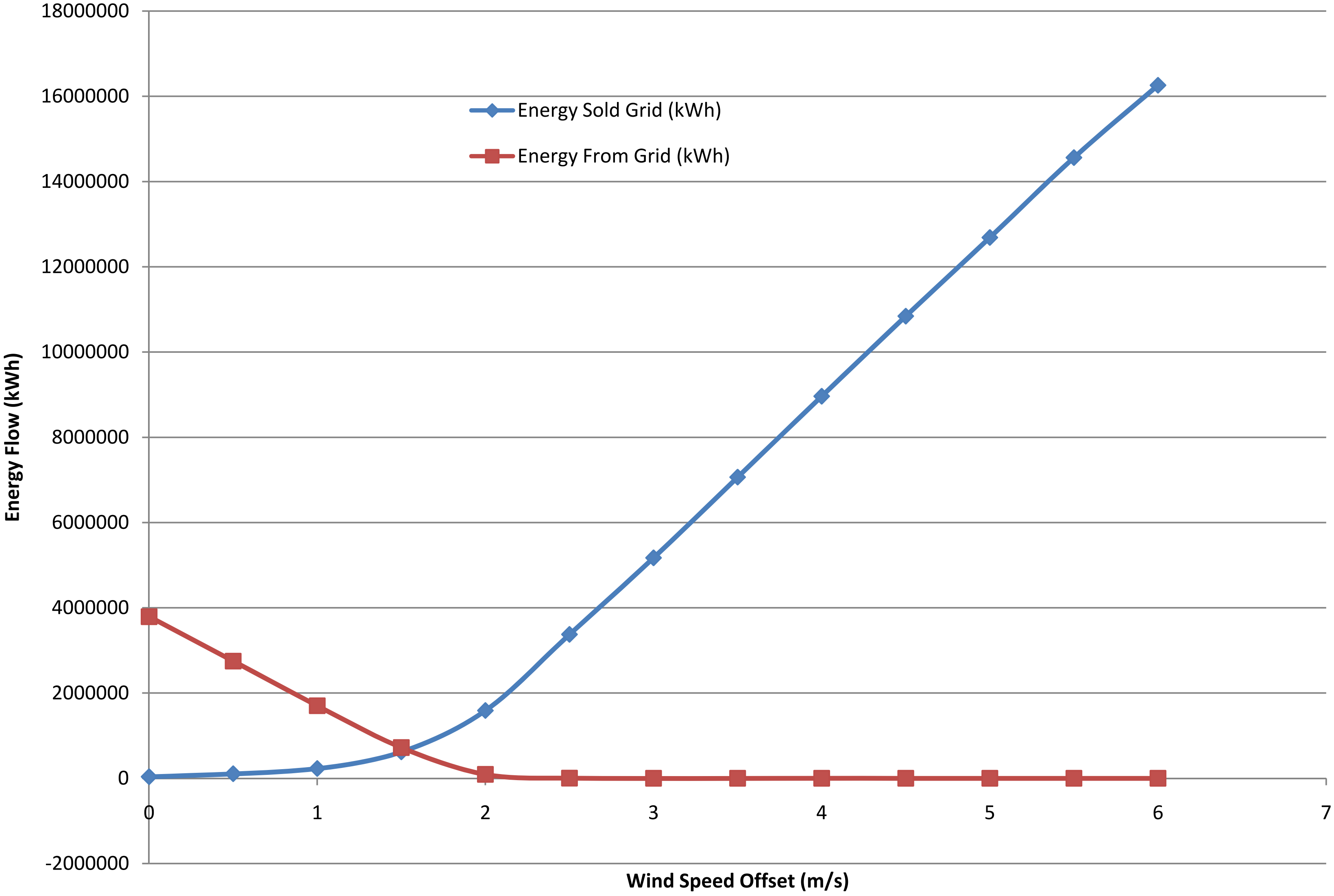

Figure 55: Energy Flow with Two Wind Turbines, Varying Wind Speed Offset from Average

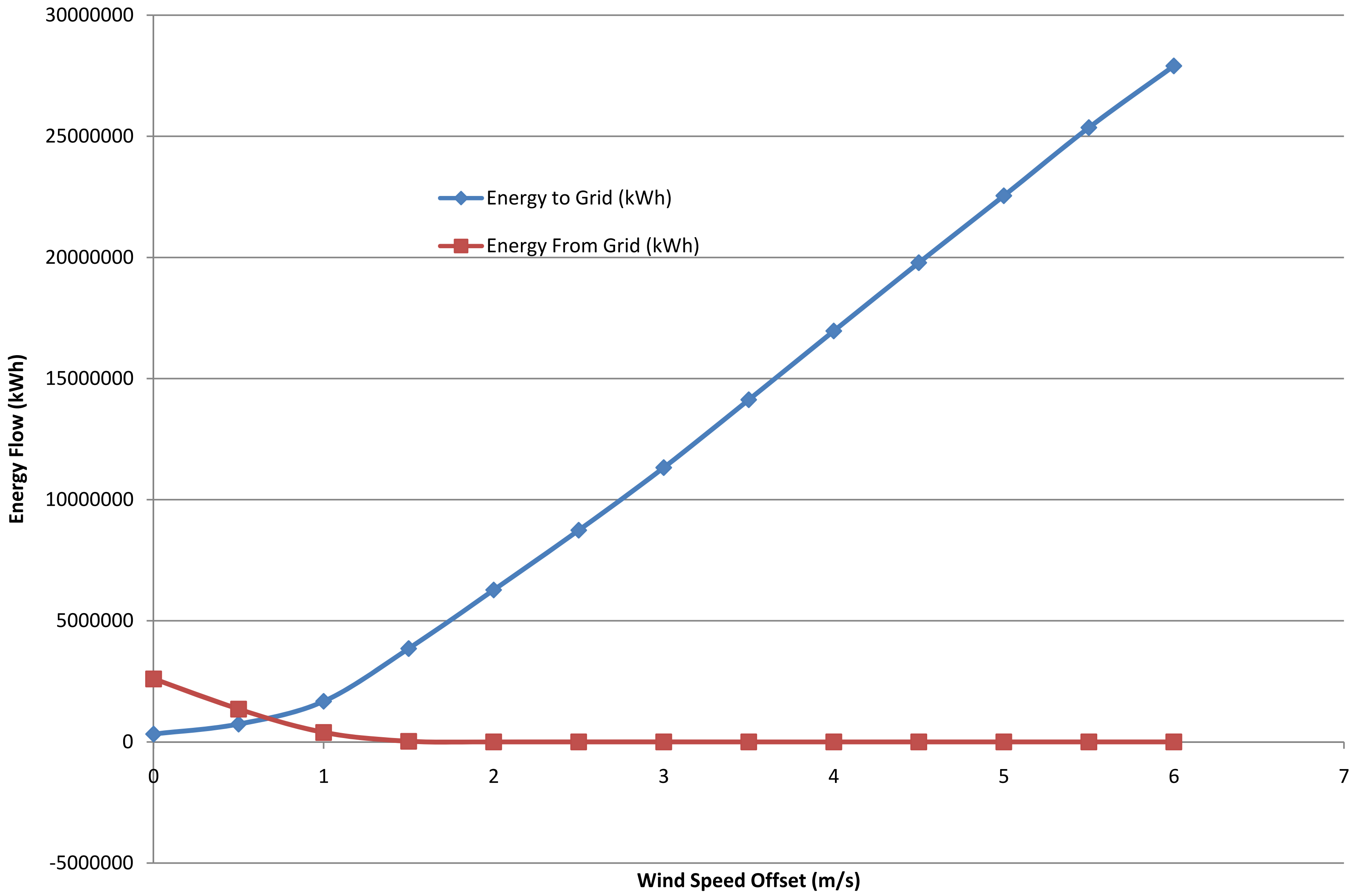

Figure 56: Energy Flow with Three Wind Turbines, Varying Wind Speed Offset from Average

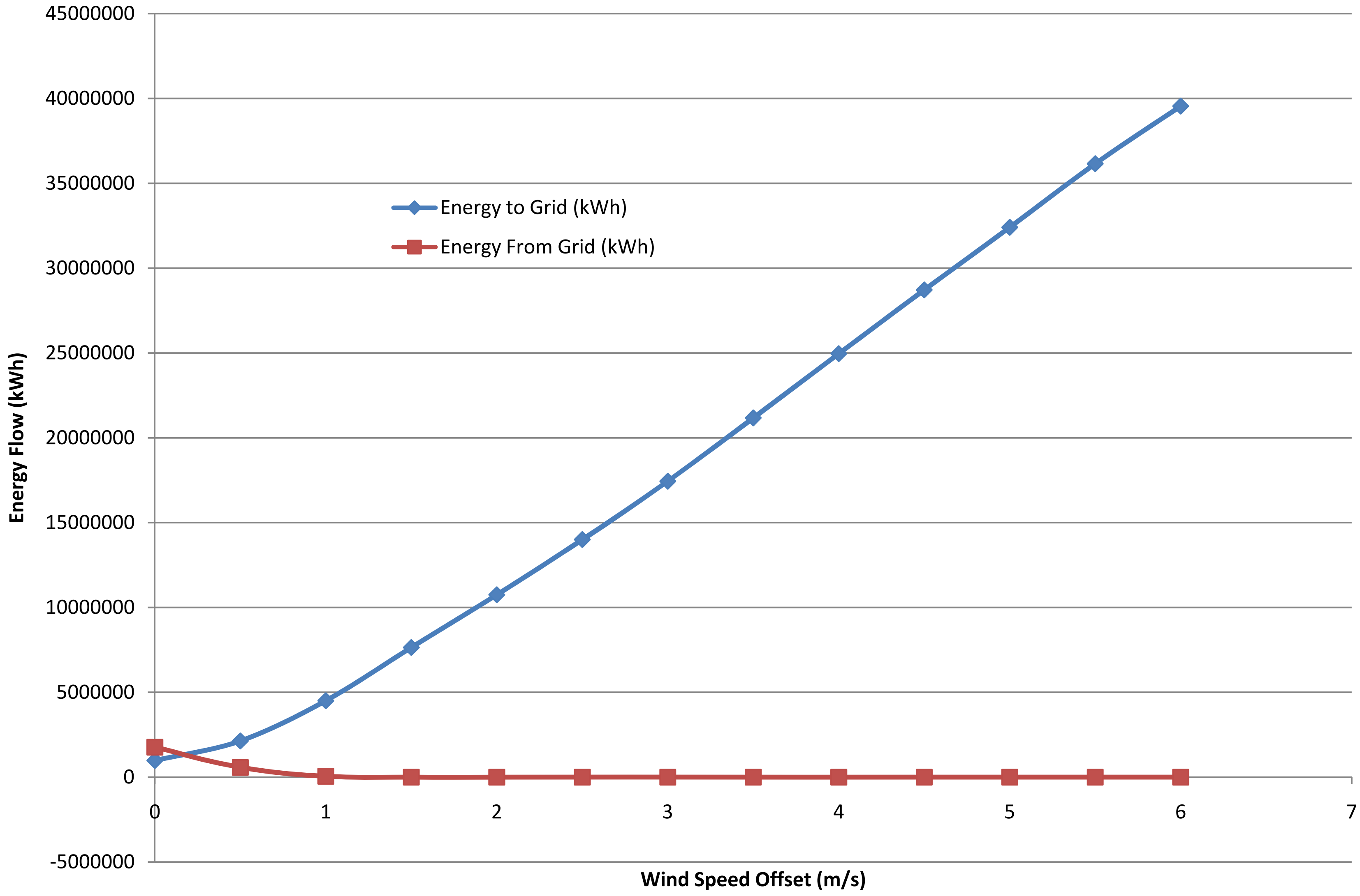

Figure 57: Energy Flow with Four Wind Turbines, Varying Wind Speed Offset from Average

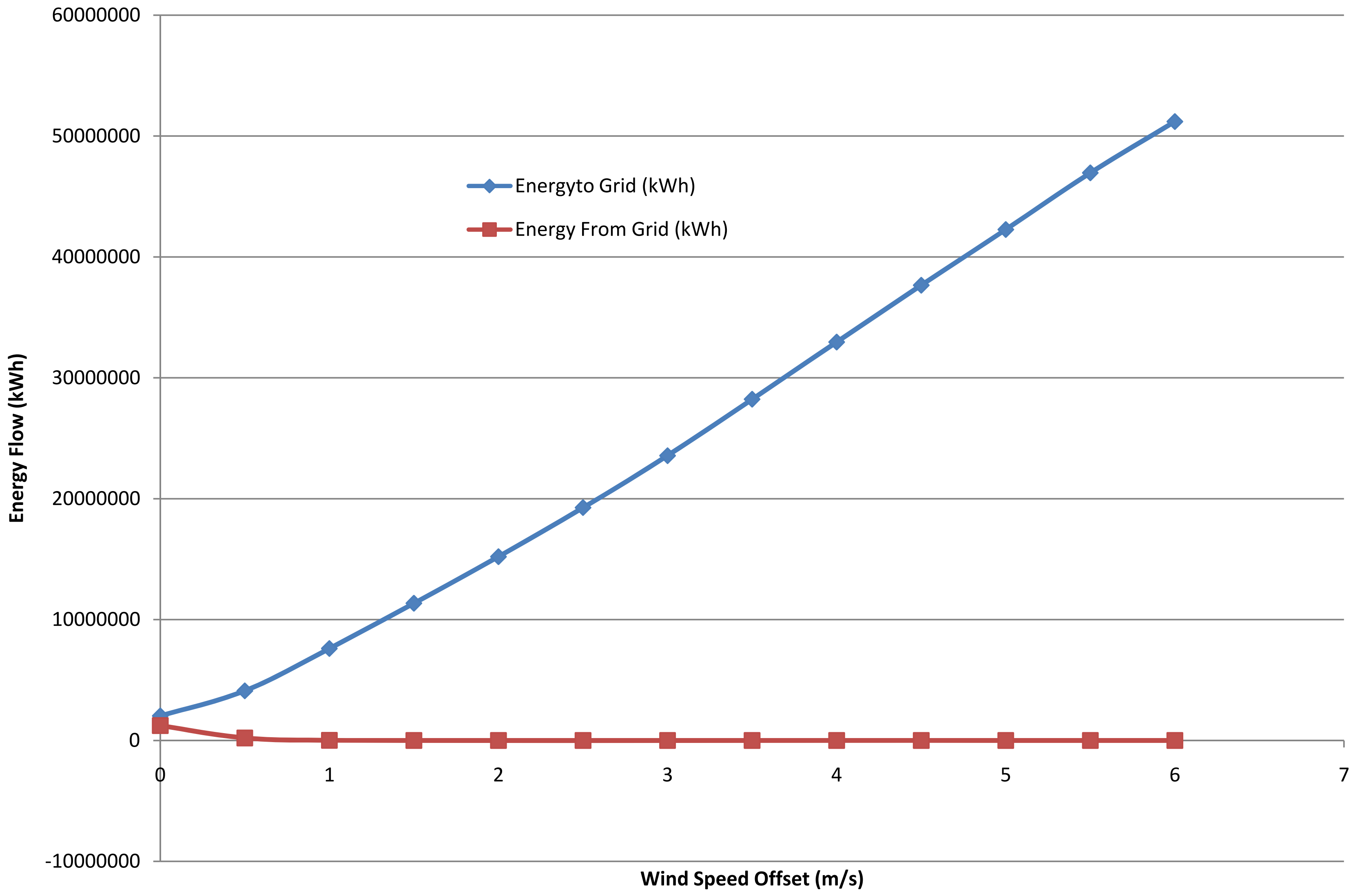

Figure 58: Energy Flow with Five Wind Turbines, Varying Wind Speed Offset from Average

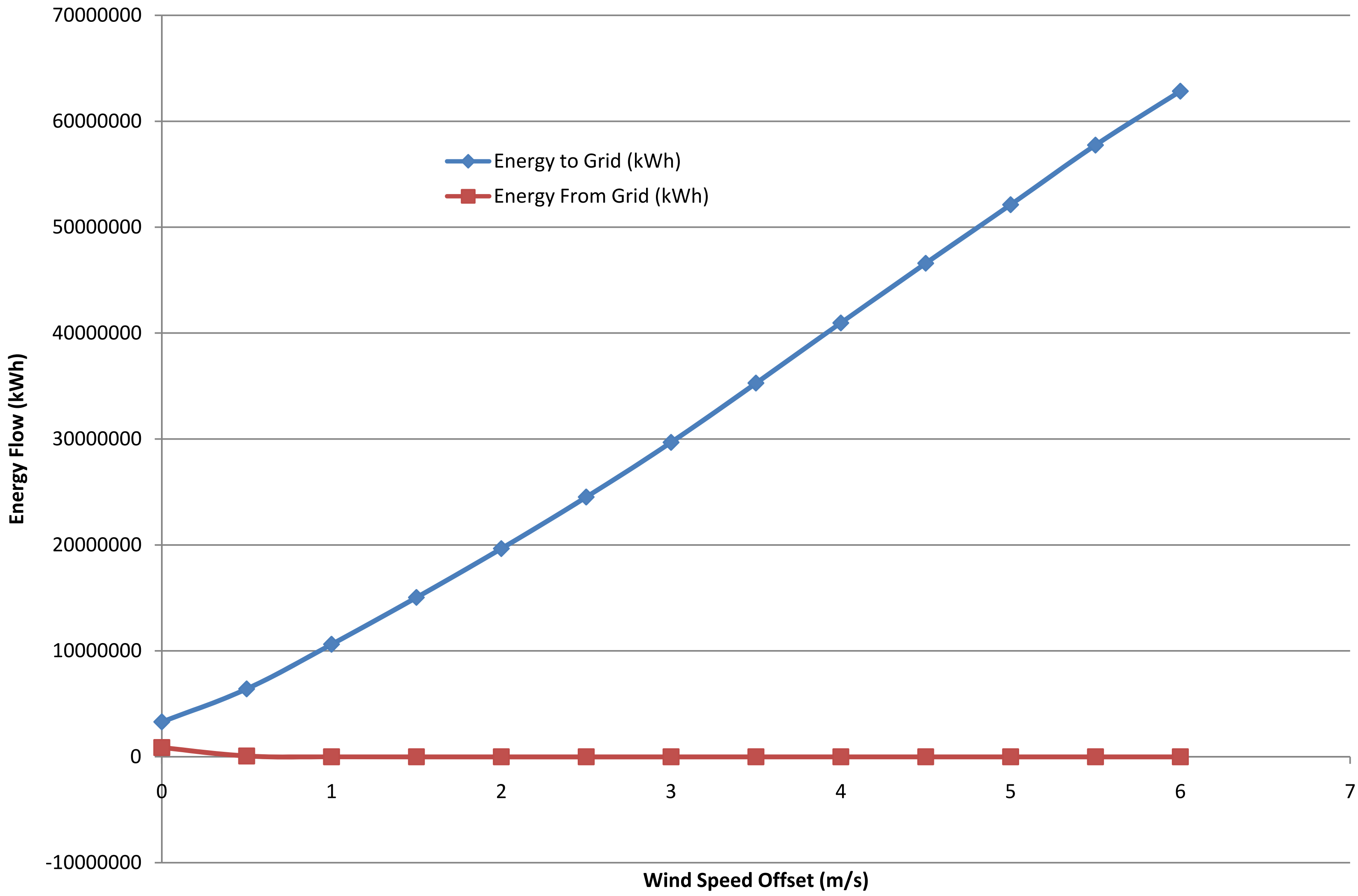

Figure 59: Energy Flow with Six Wind Turbines, Varying Wind Speed Offset from Average

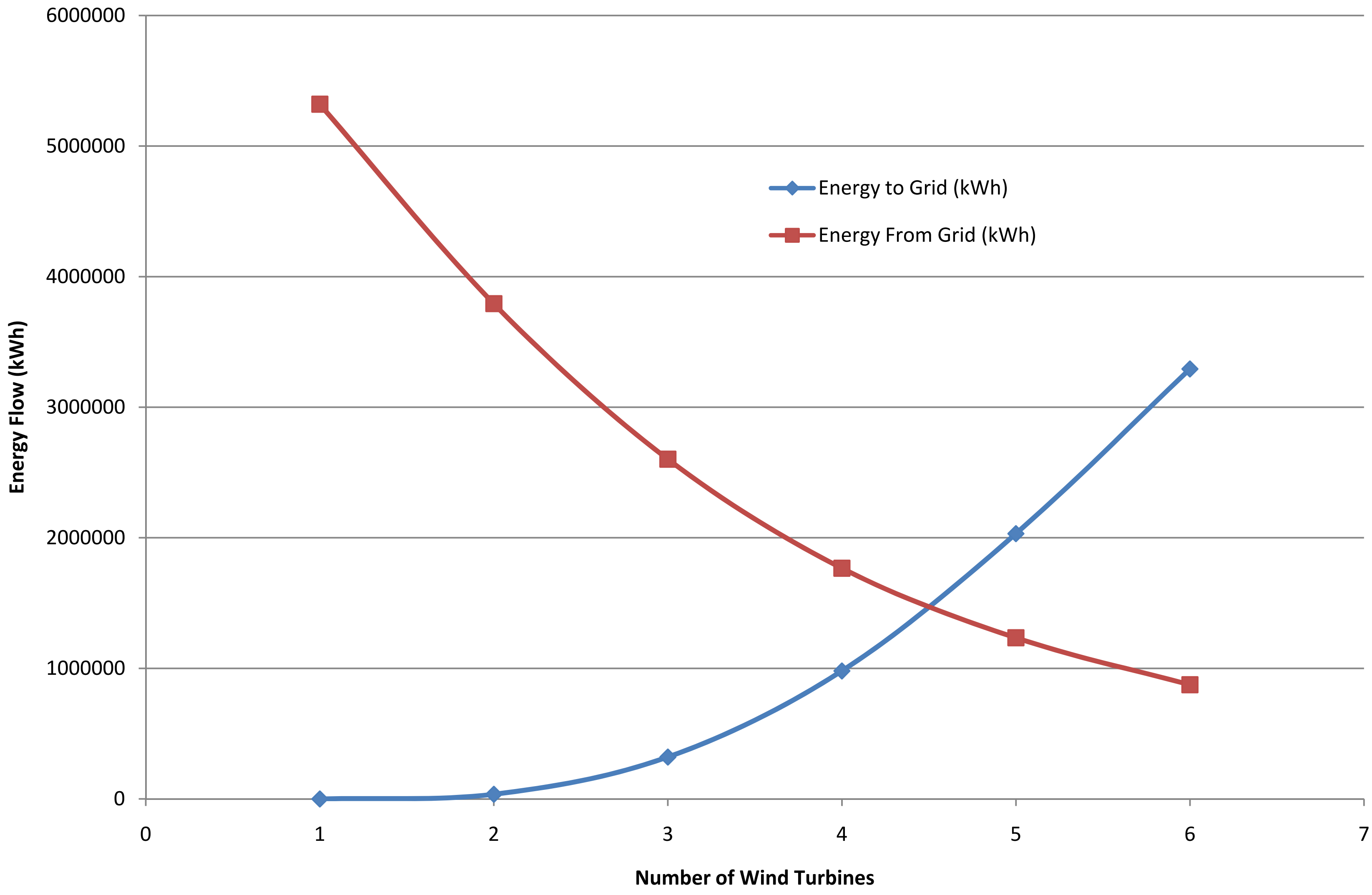

Figure 60: Energy Flow with 0 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

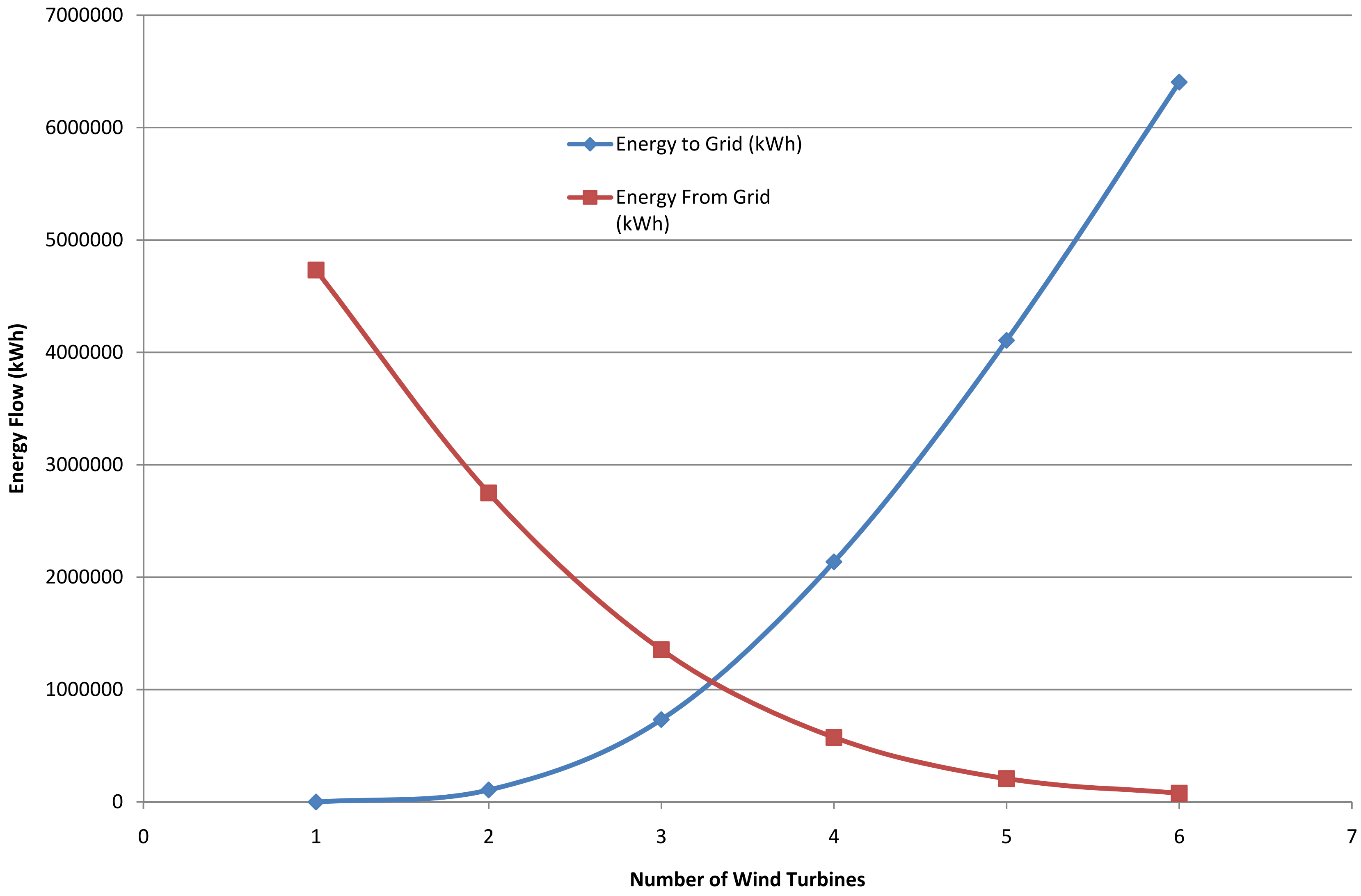

Figure 61: Energy Flow with 0.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

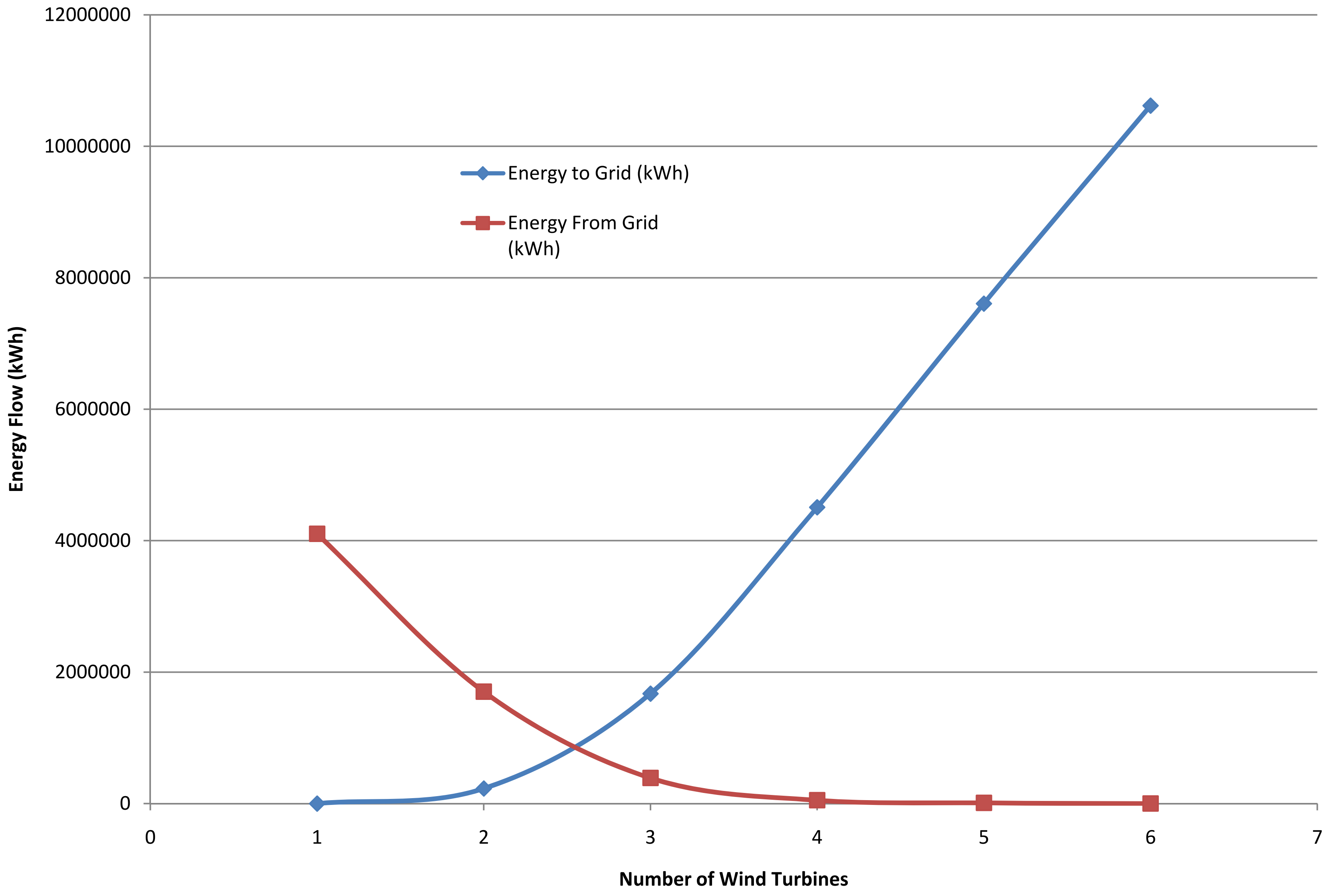

Figure 62: Energy Flow with 1 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

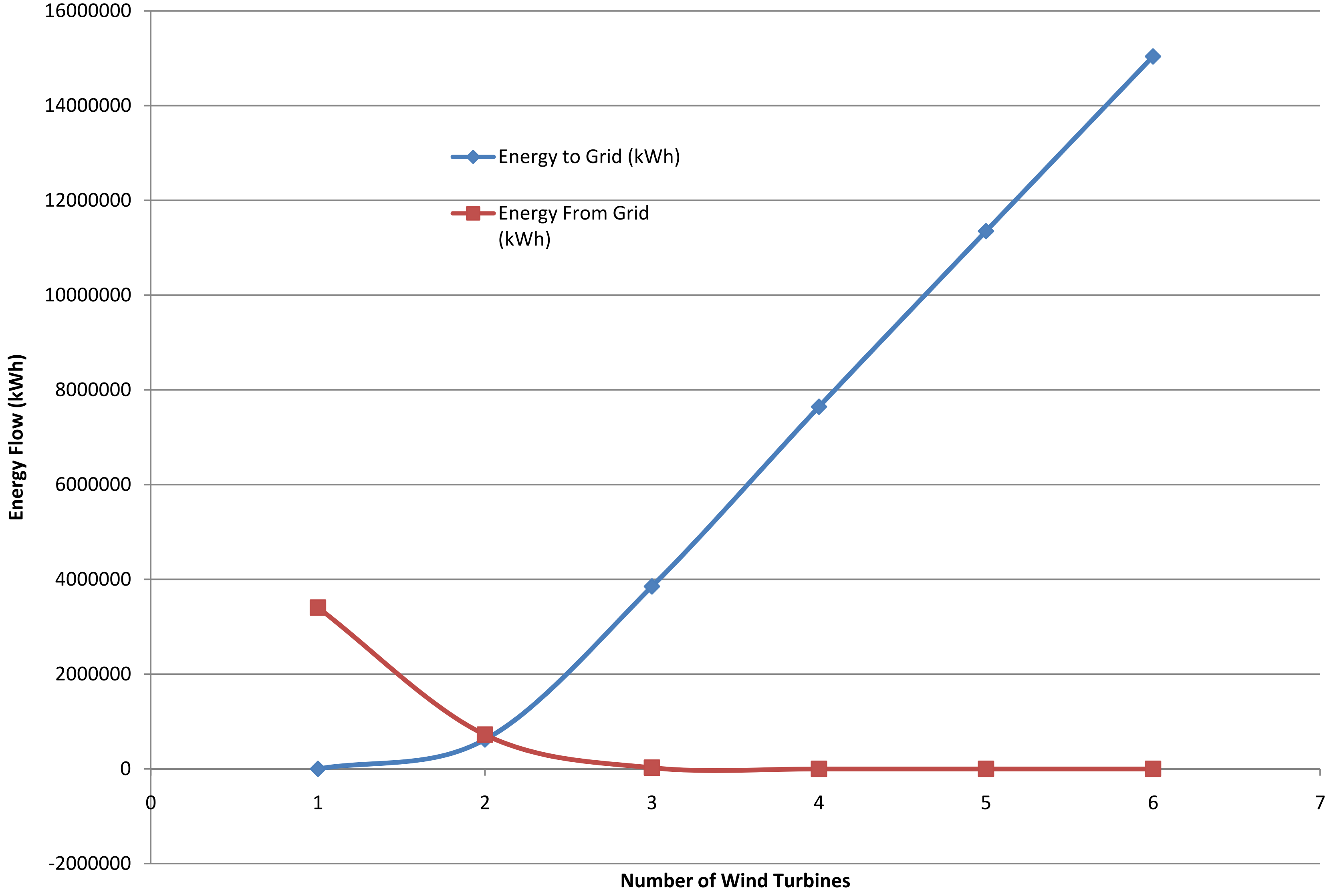

Figure 63: Energy Flow with 1.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

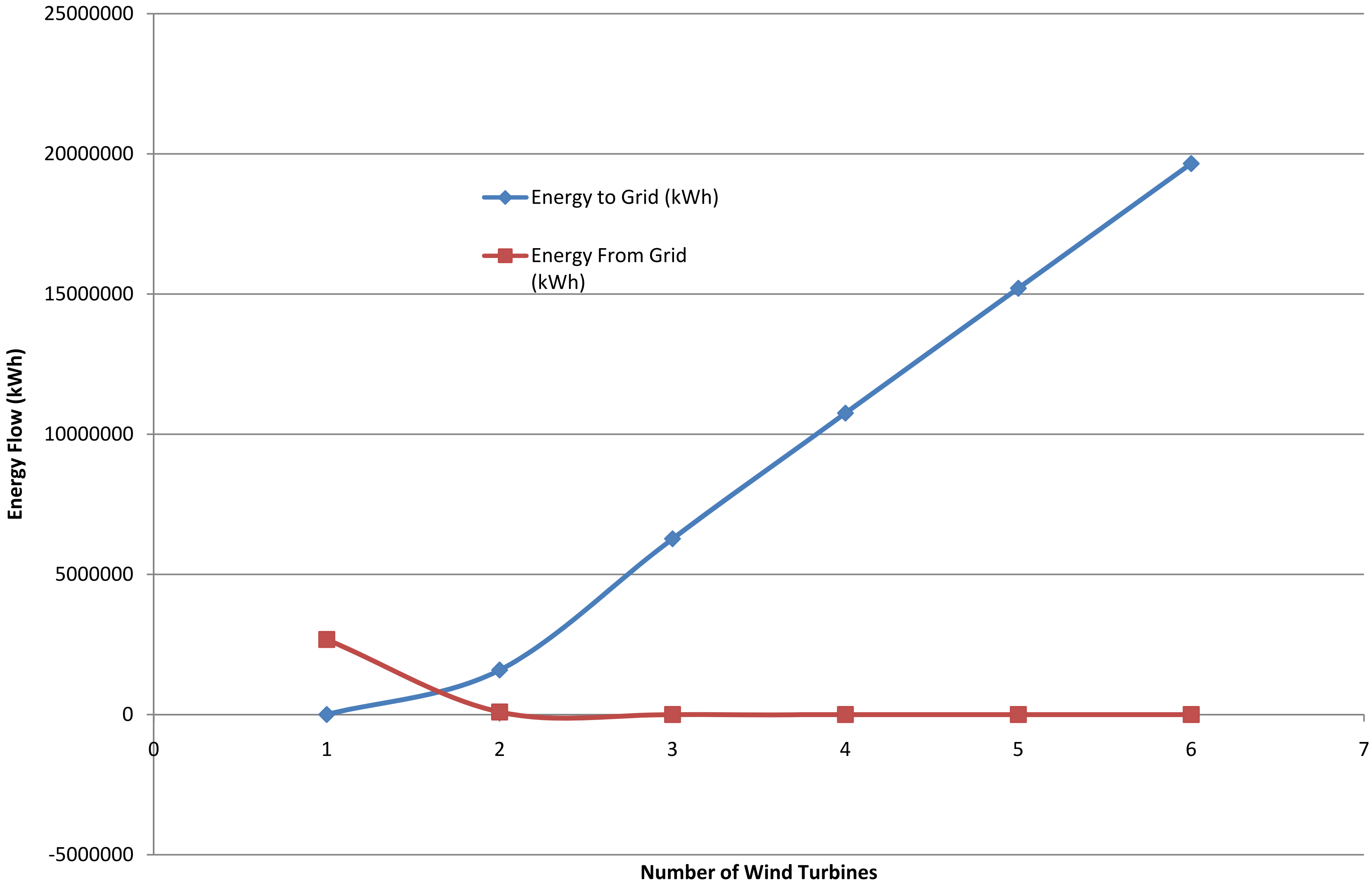

Figure 64: Energy Flow with 2 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

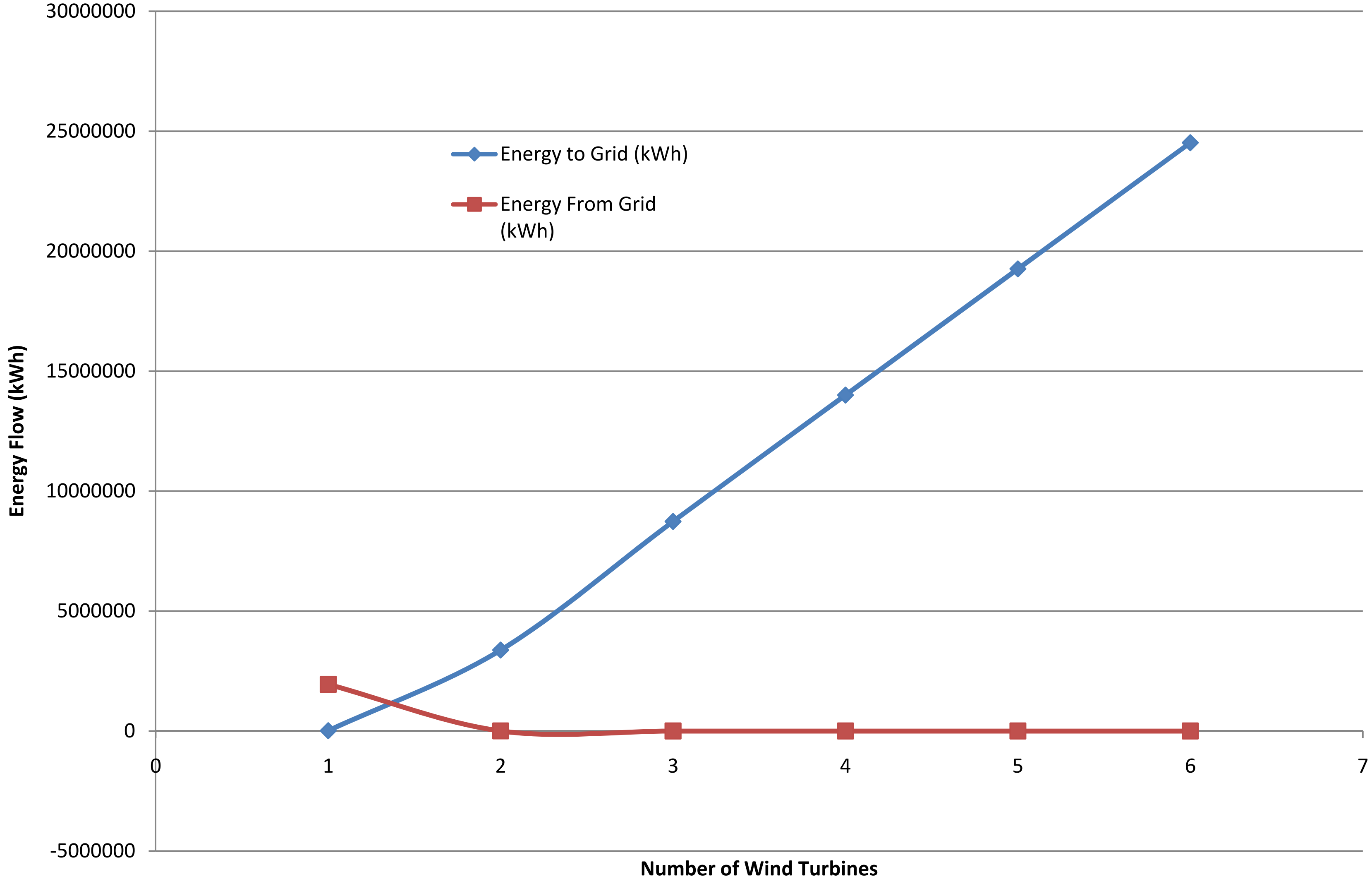

Figure 65: Energy Flow with 2.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

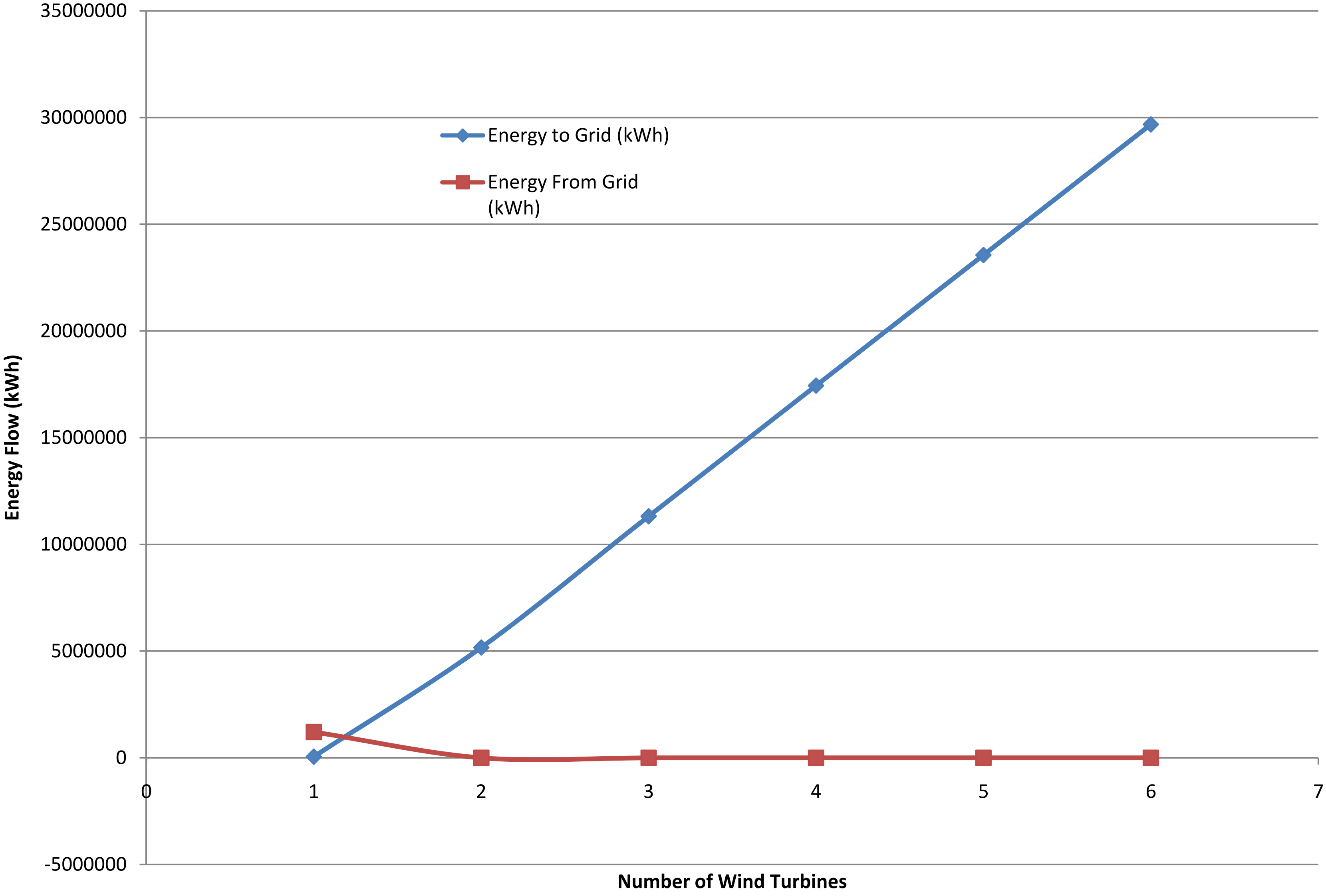

Figure 66: Energy Flow with 3 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

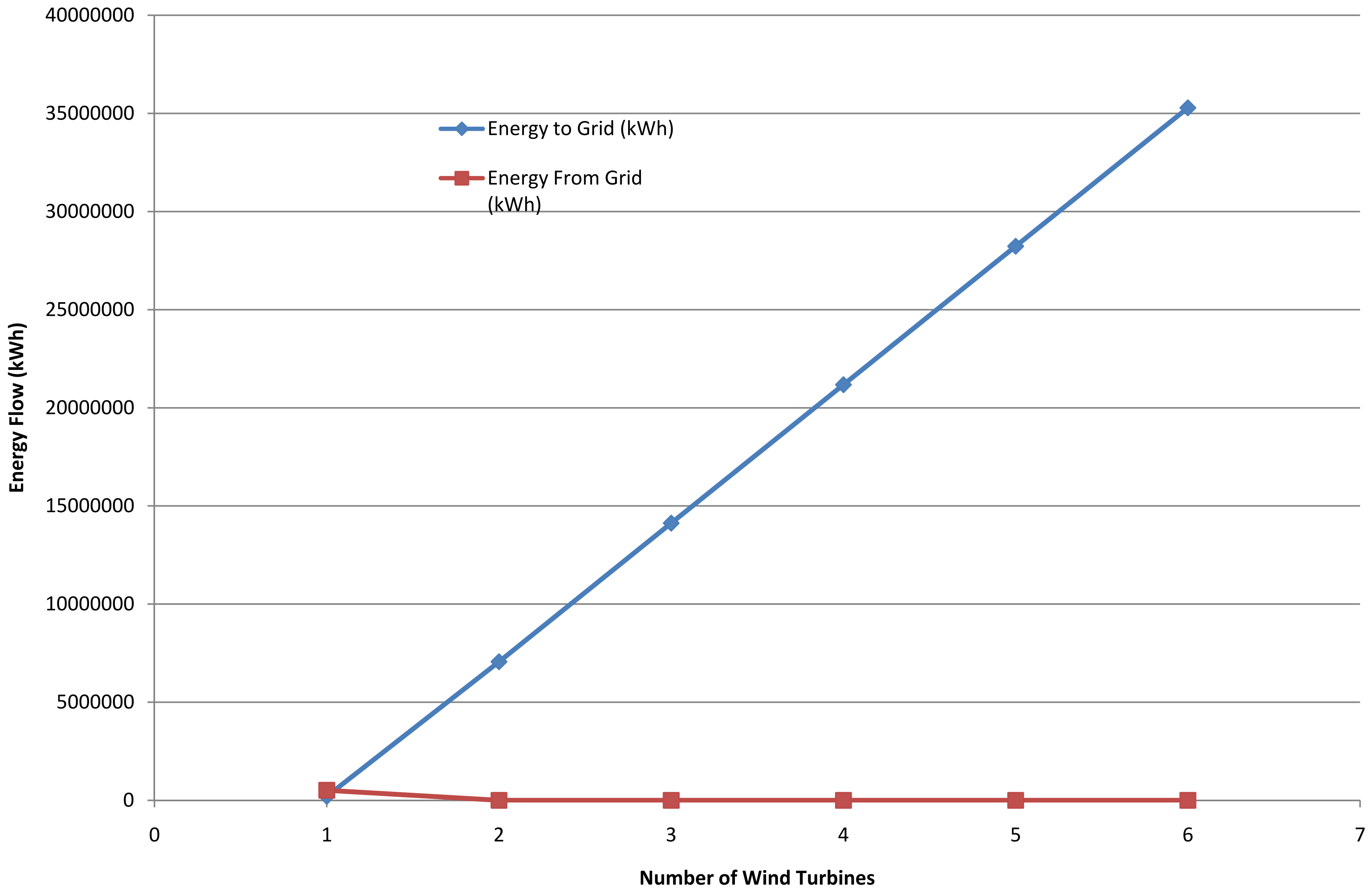

Figure 67: Energy Flow with 3.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

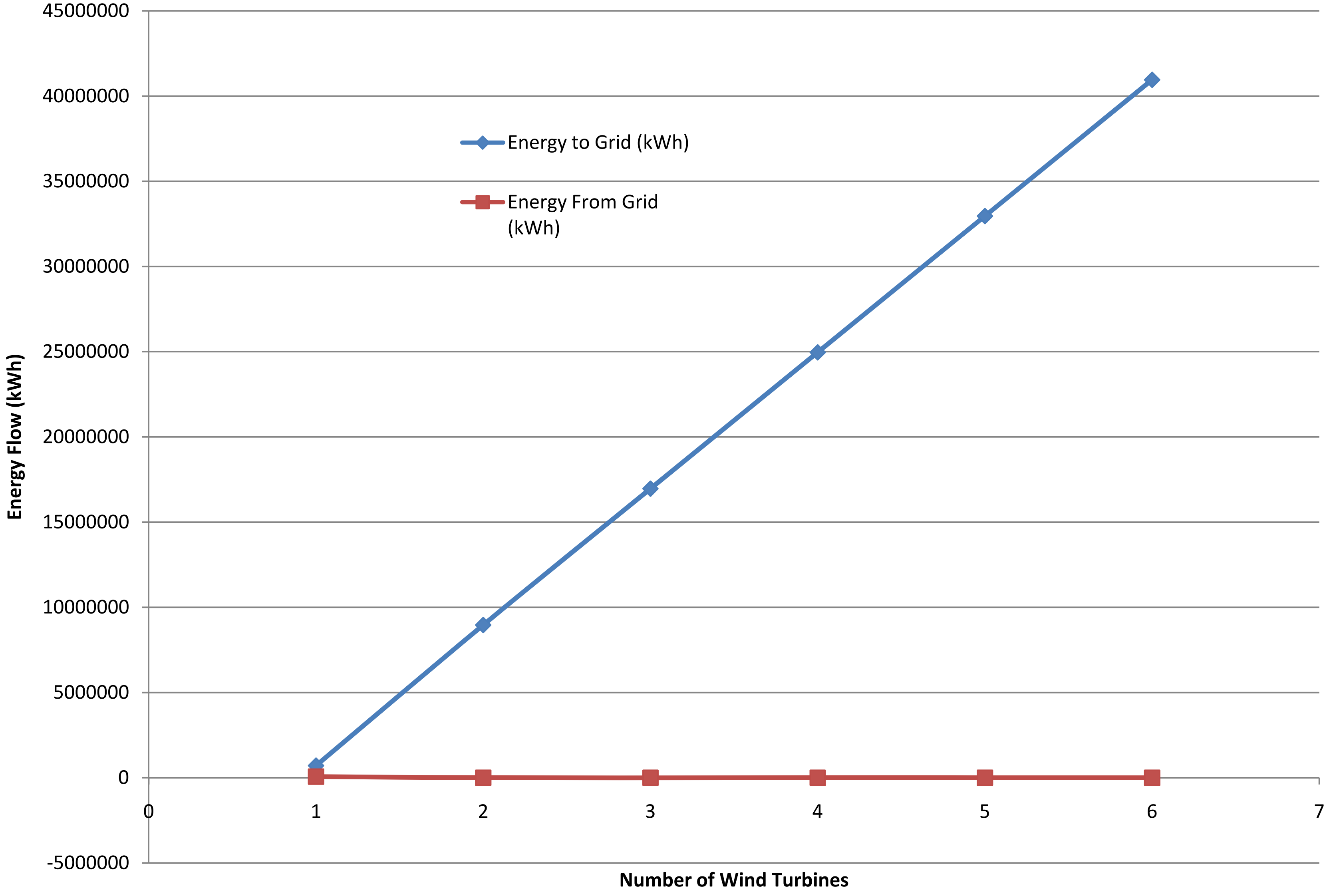

Figure 68: Energy Flow with 4 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

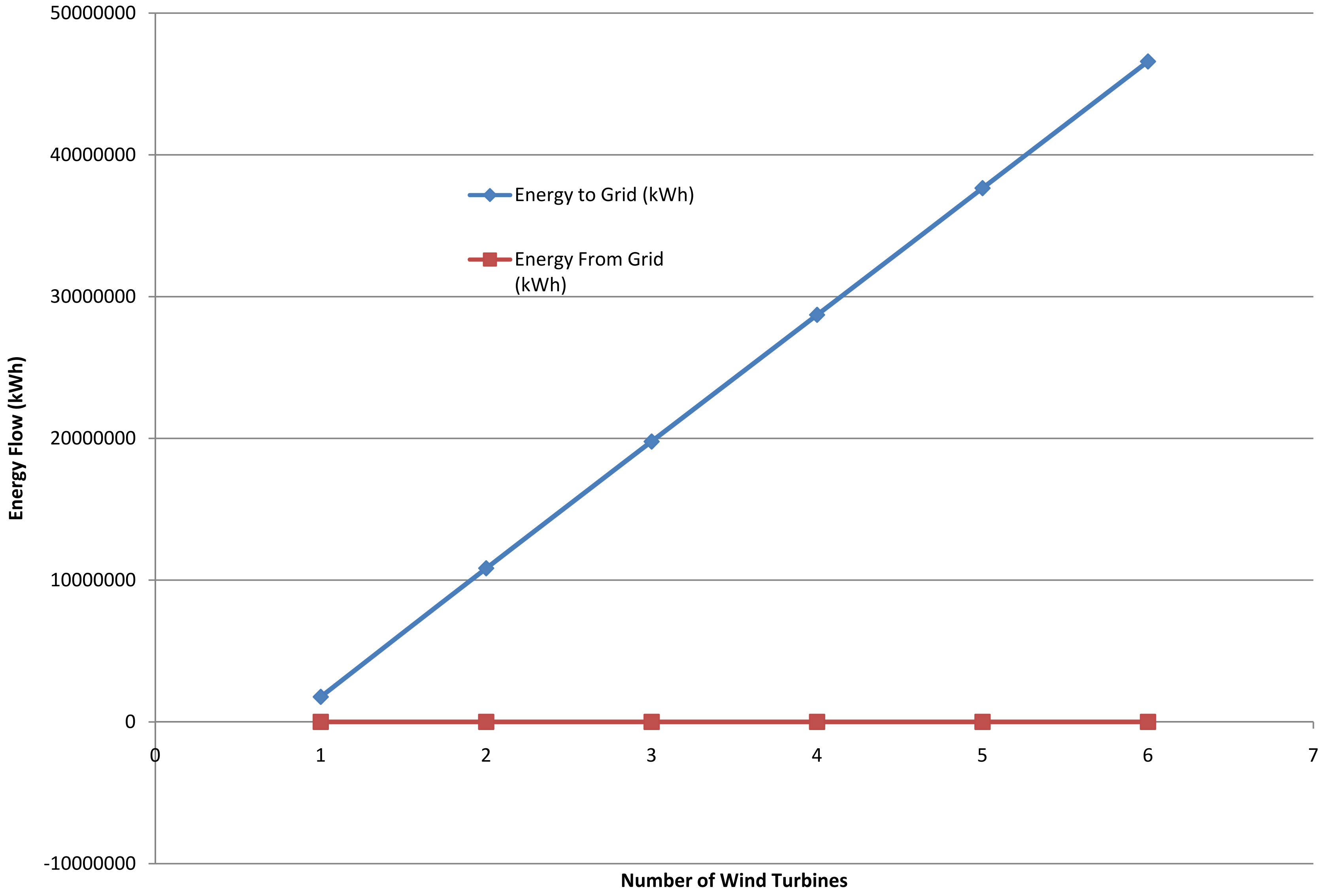

Figure 69: Energy Flow with 4.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

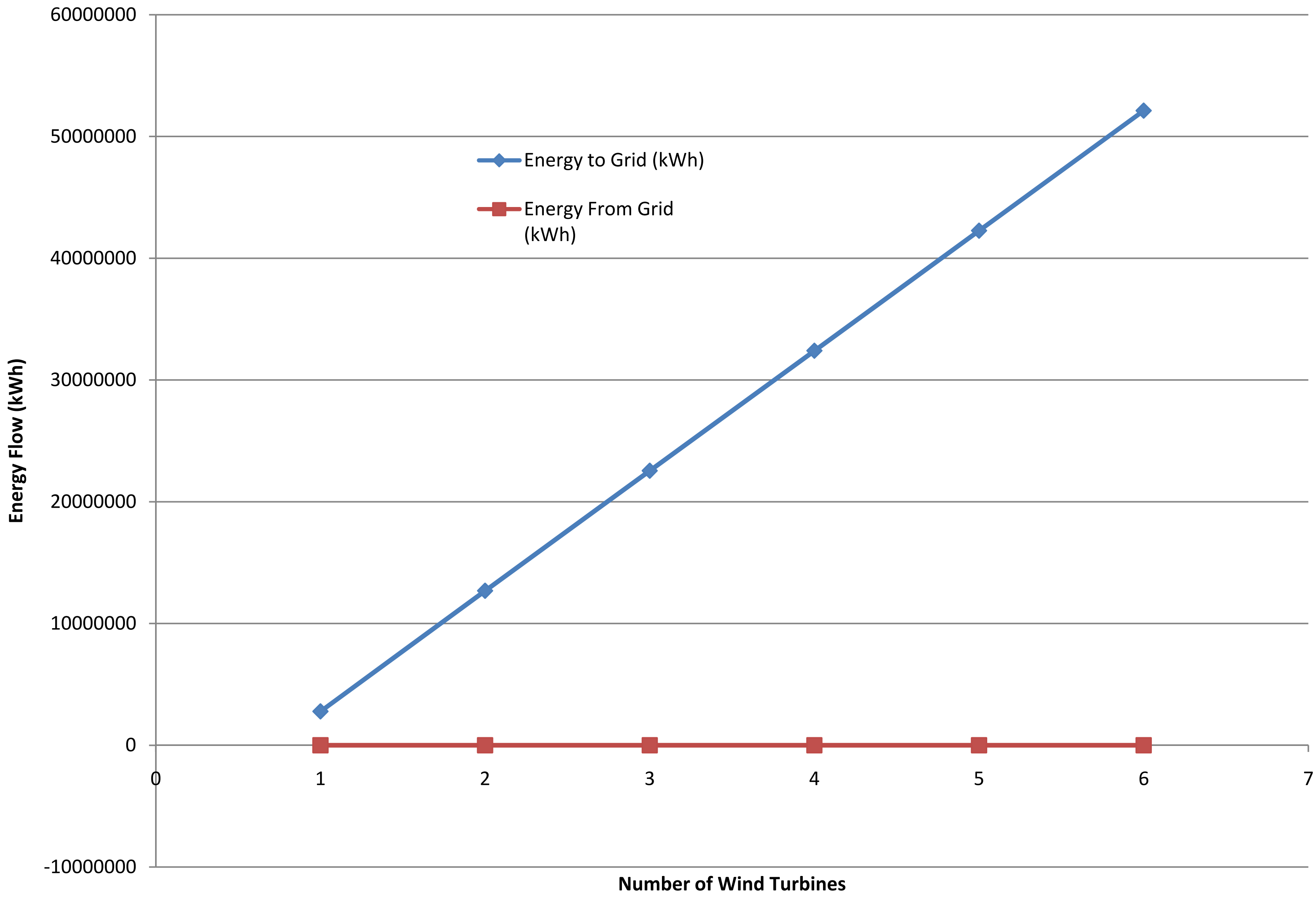

Figure 70: Energy Flow with 5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

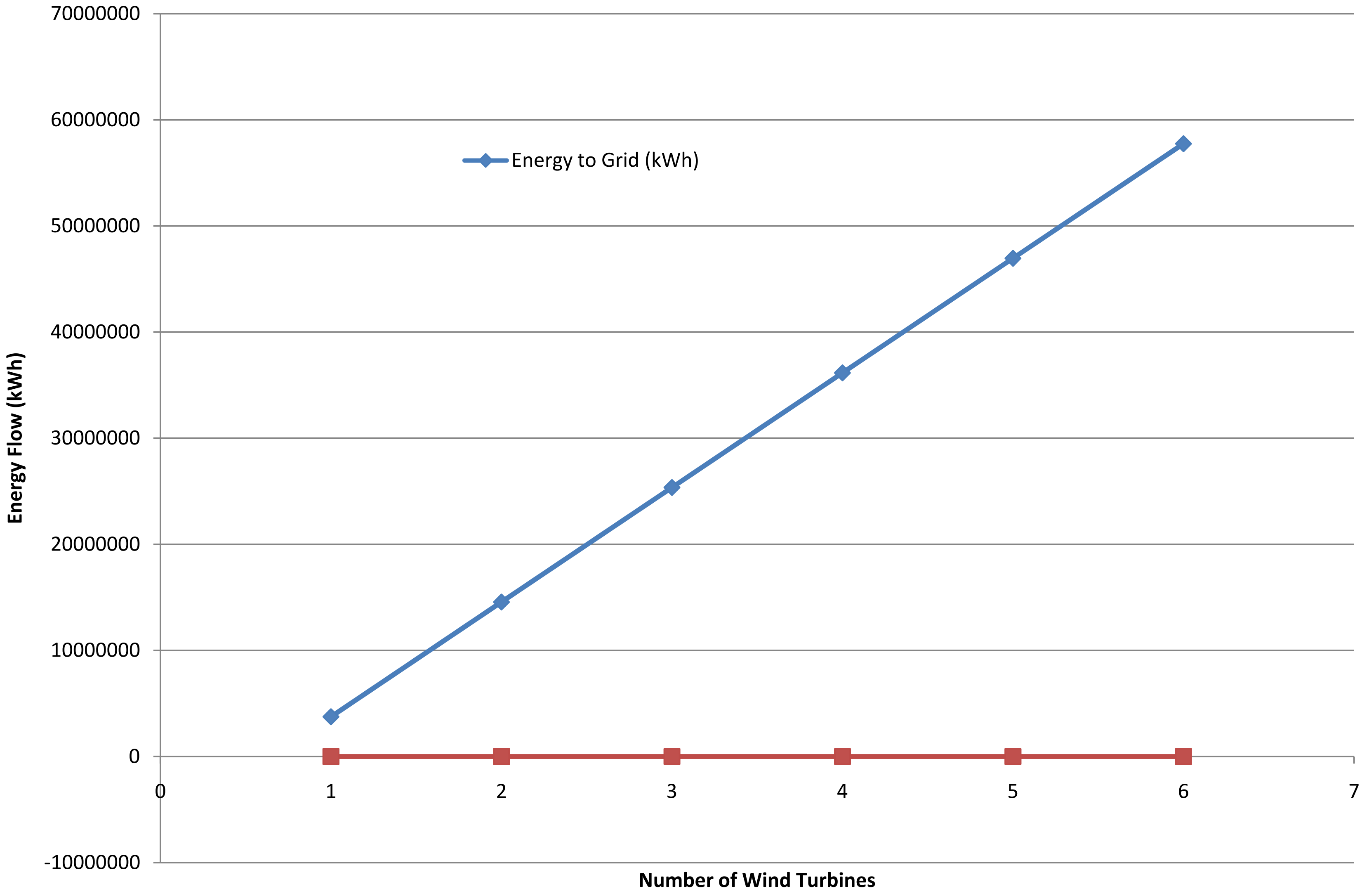

Figure 71: Energy Flow with 5.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

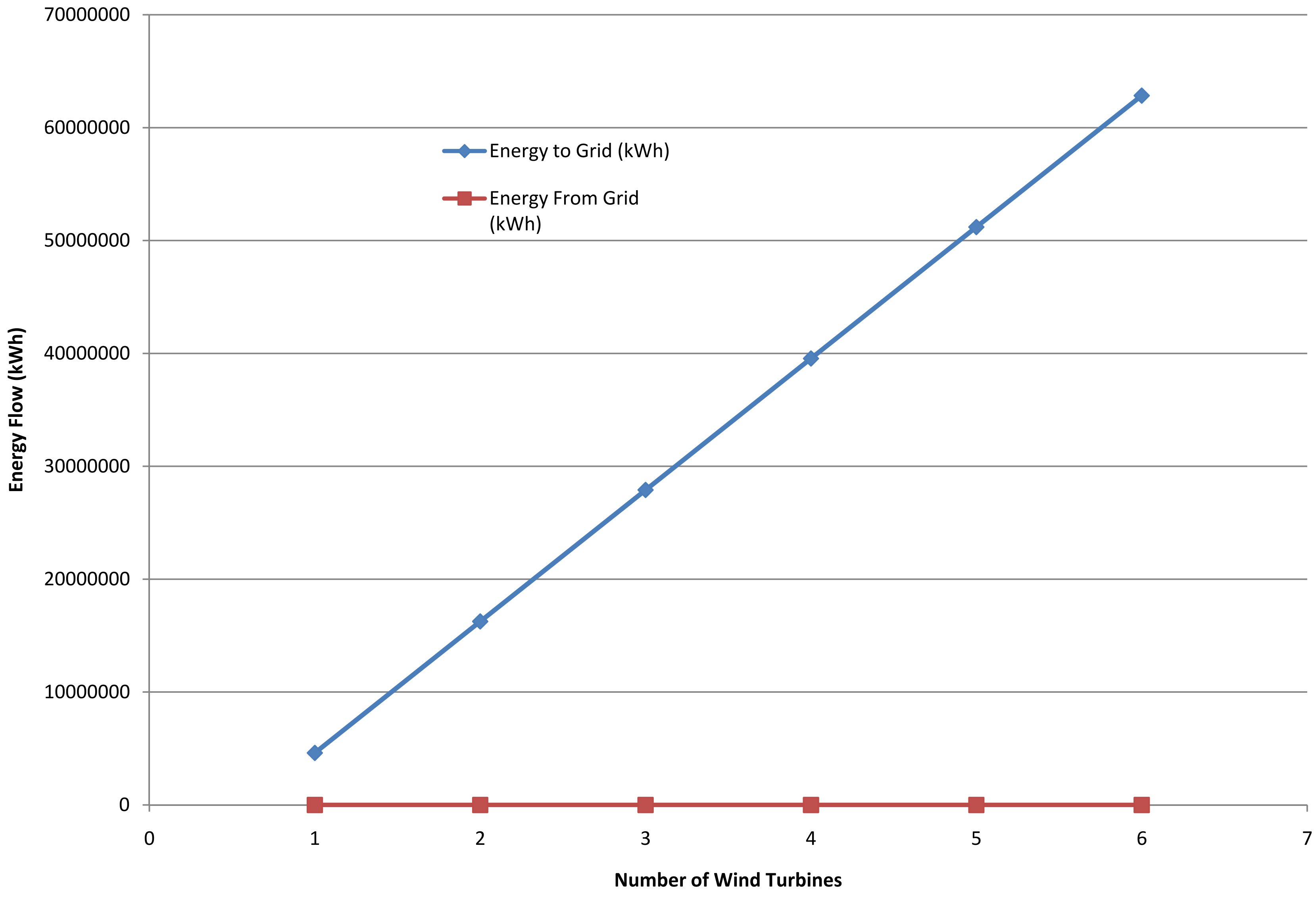

Figure 72: Energy Flow with 6 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

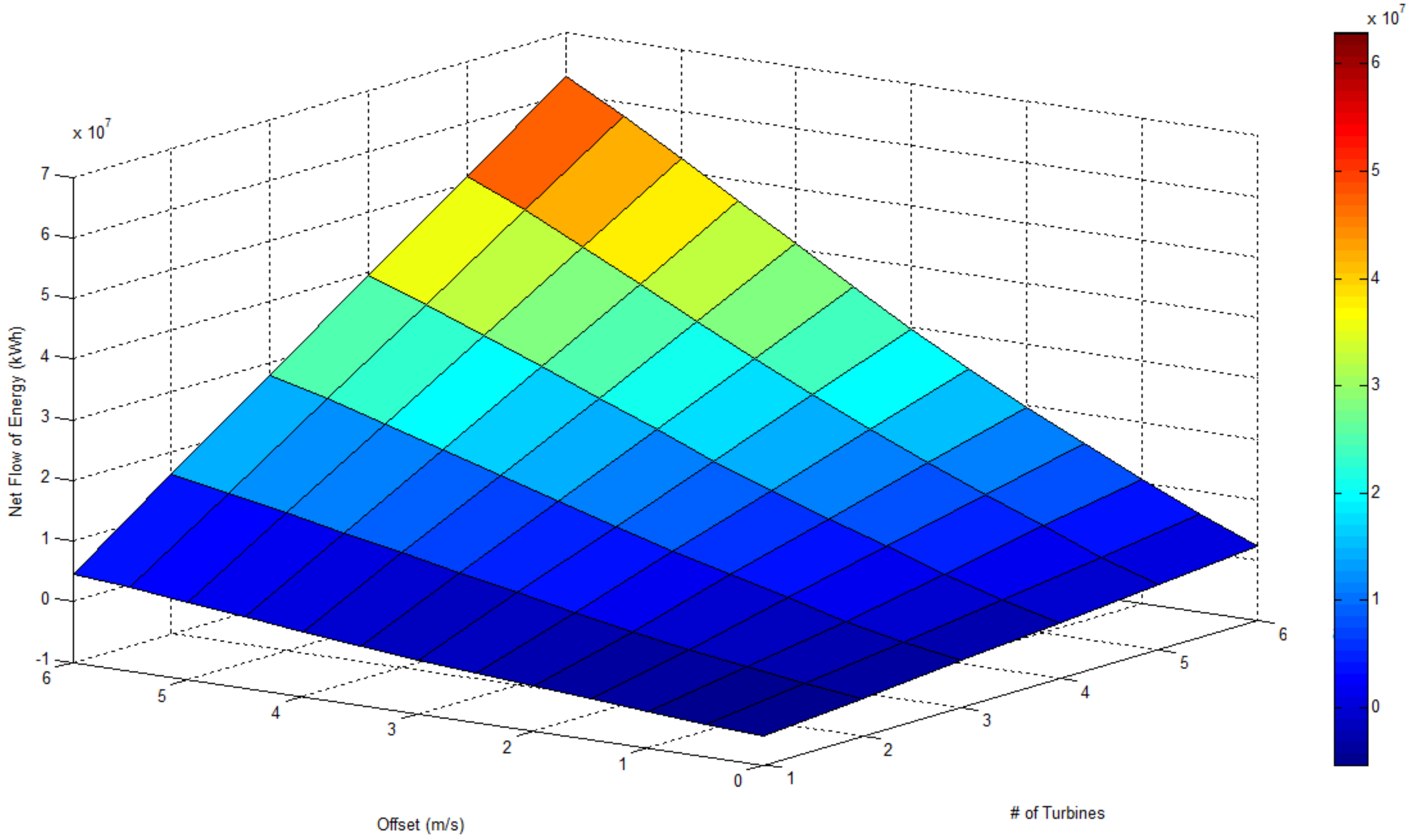

Figure 73: 3D Graph of Energy Flow Sensitivity Analysis

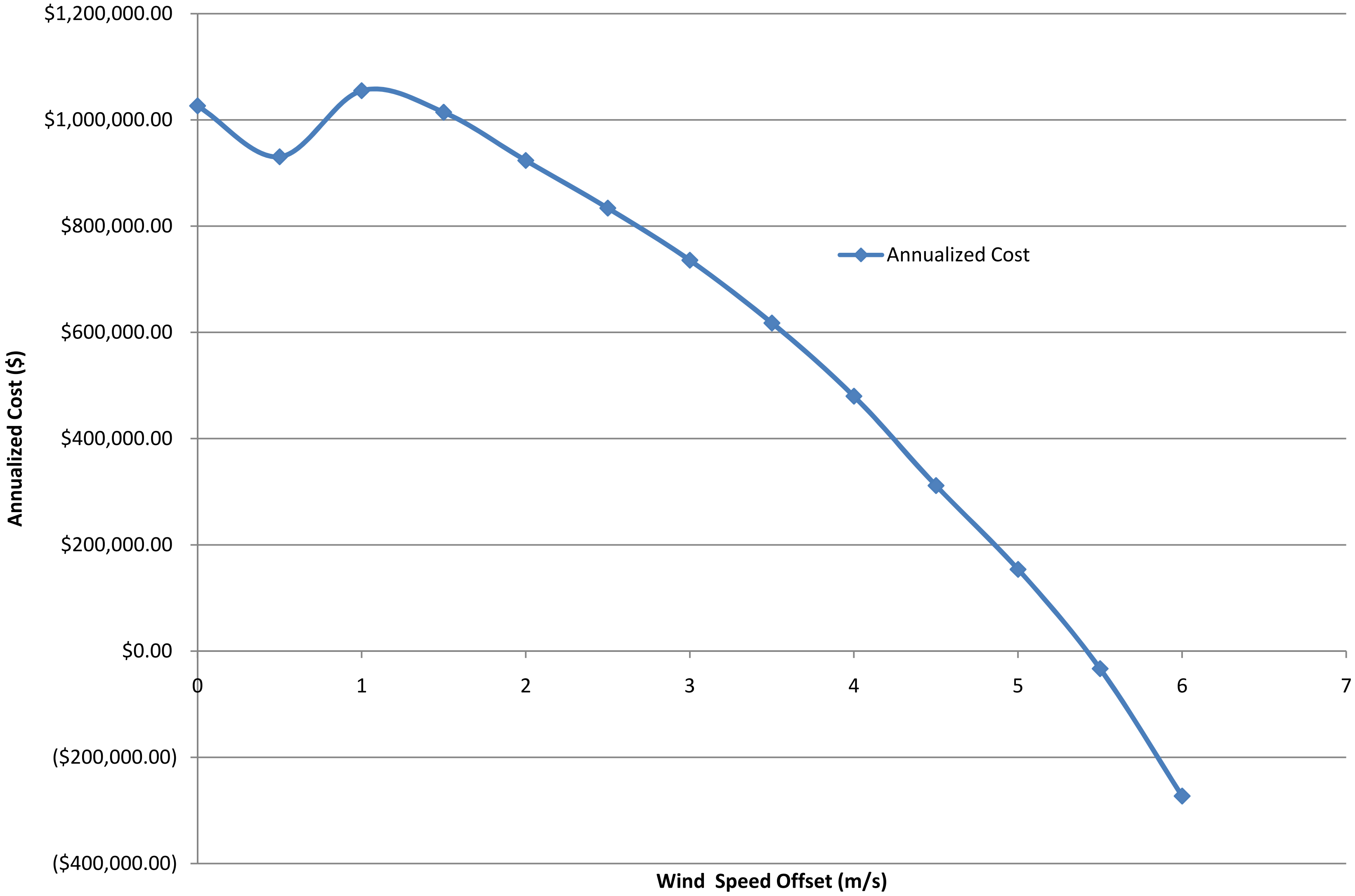

Figure 74: Annualized Cost with One Wind Turbine, Varying Wind Speed Offset from Average

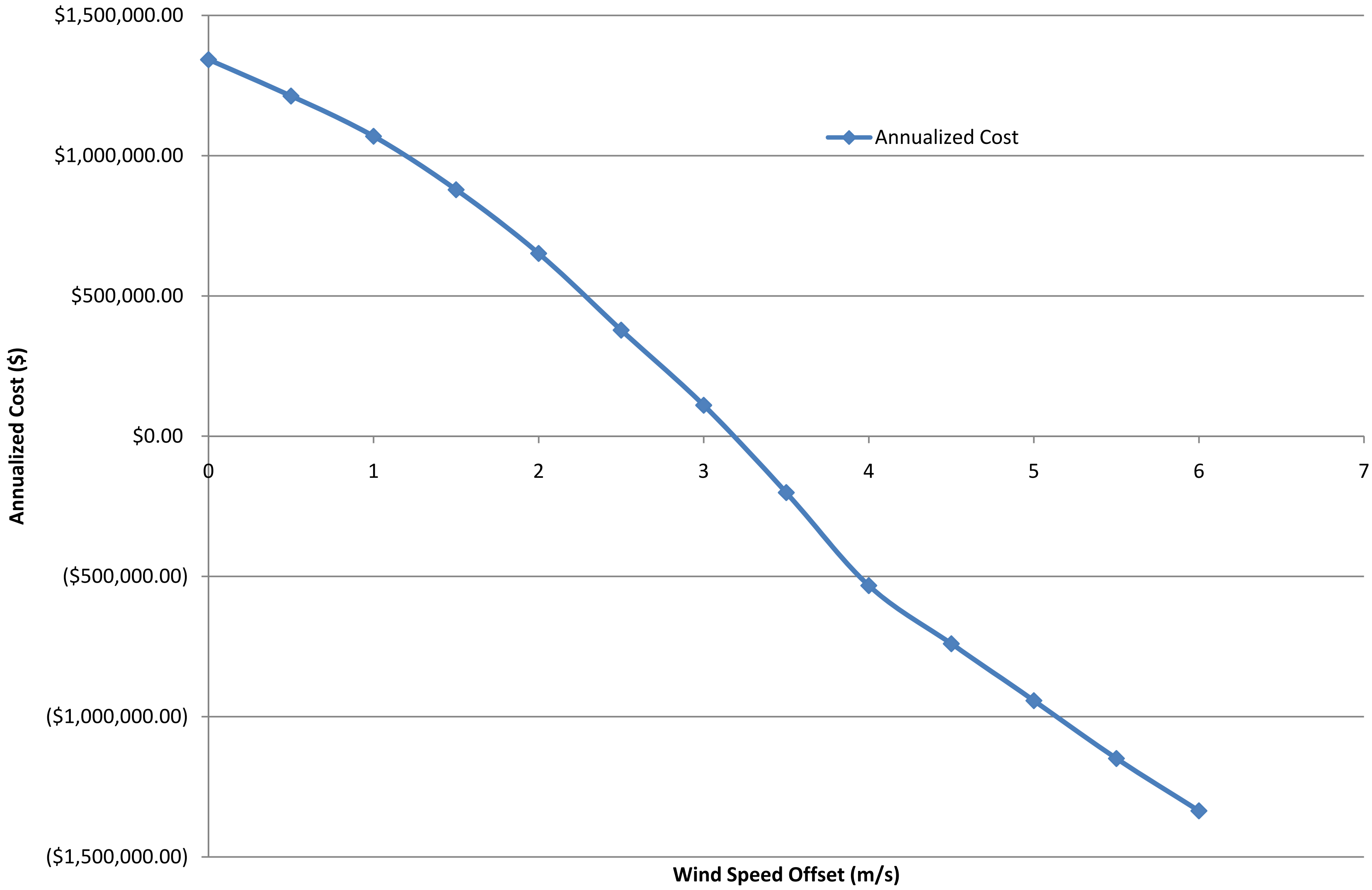

Figure 75: Annualized Cost with Two Wind Turbines, Varying Wind Speed Offset from Average

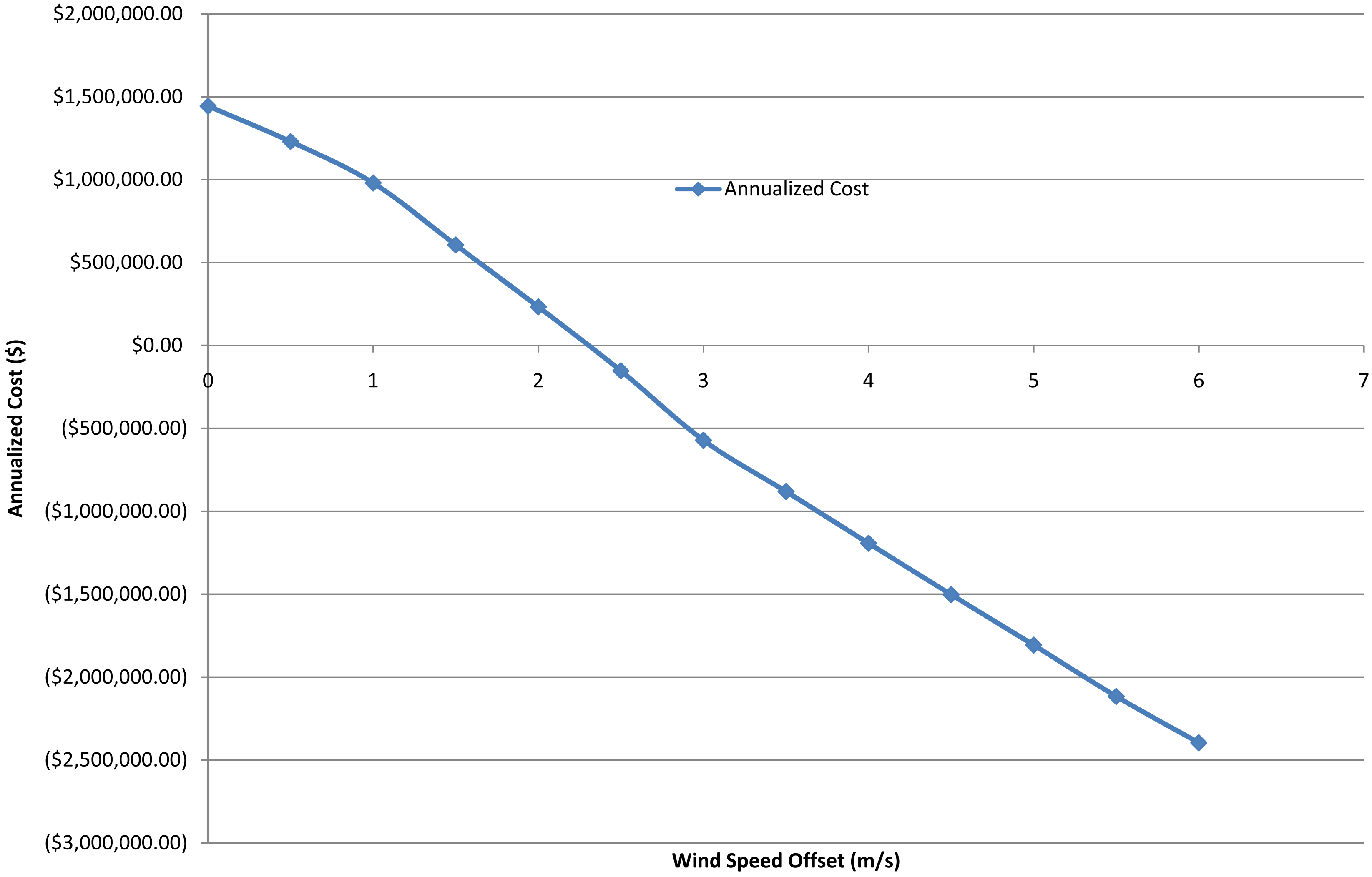

Figure 76: Annualized Cost with Three Wind Turbines, Varying Wind Speed Offset from Average

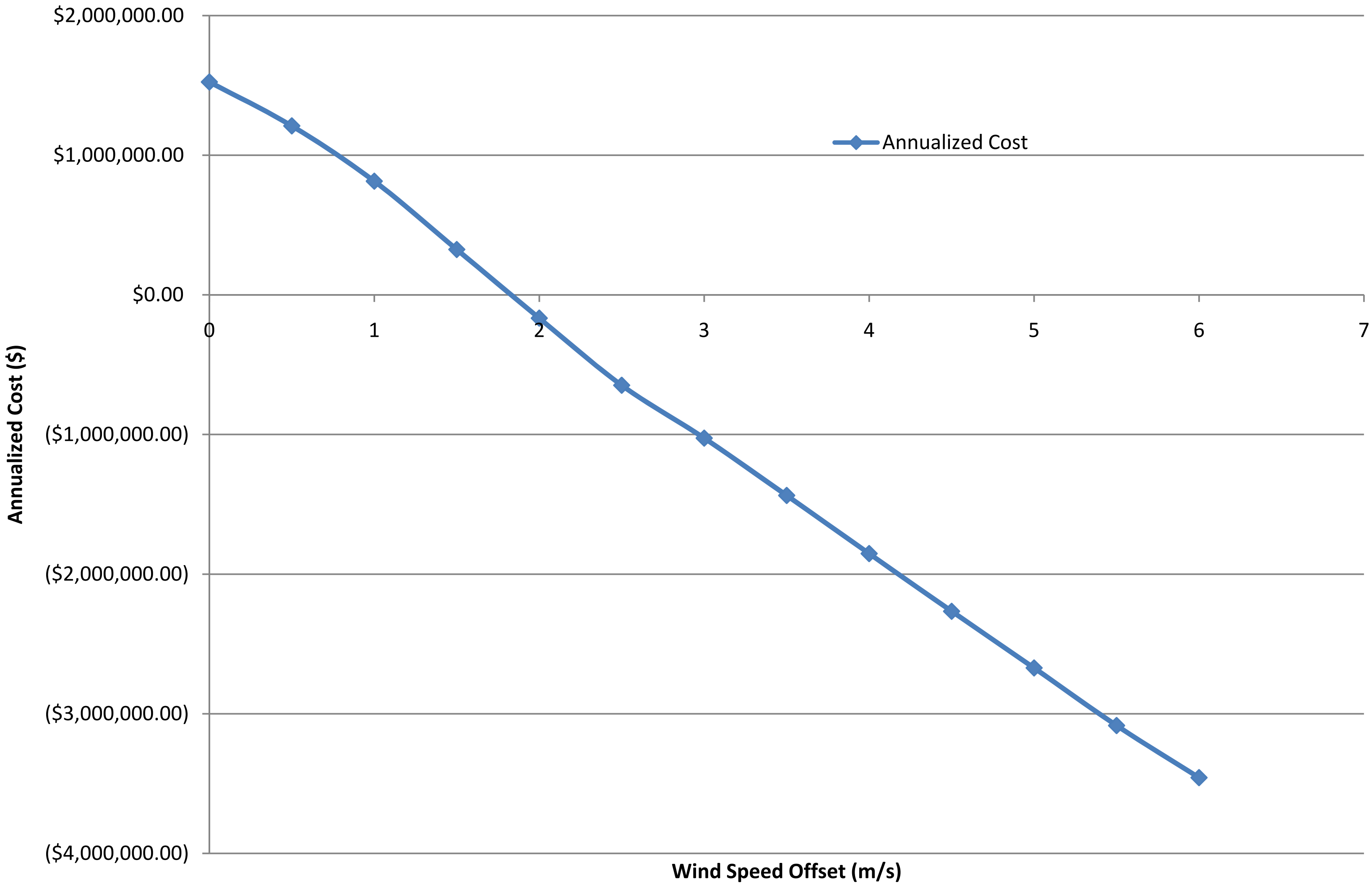

Figure 77: Annualized Cost with Four Wind Turbines, Varying Wind Speed Offset from Average

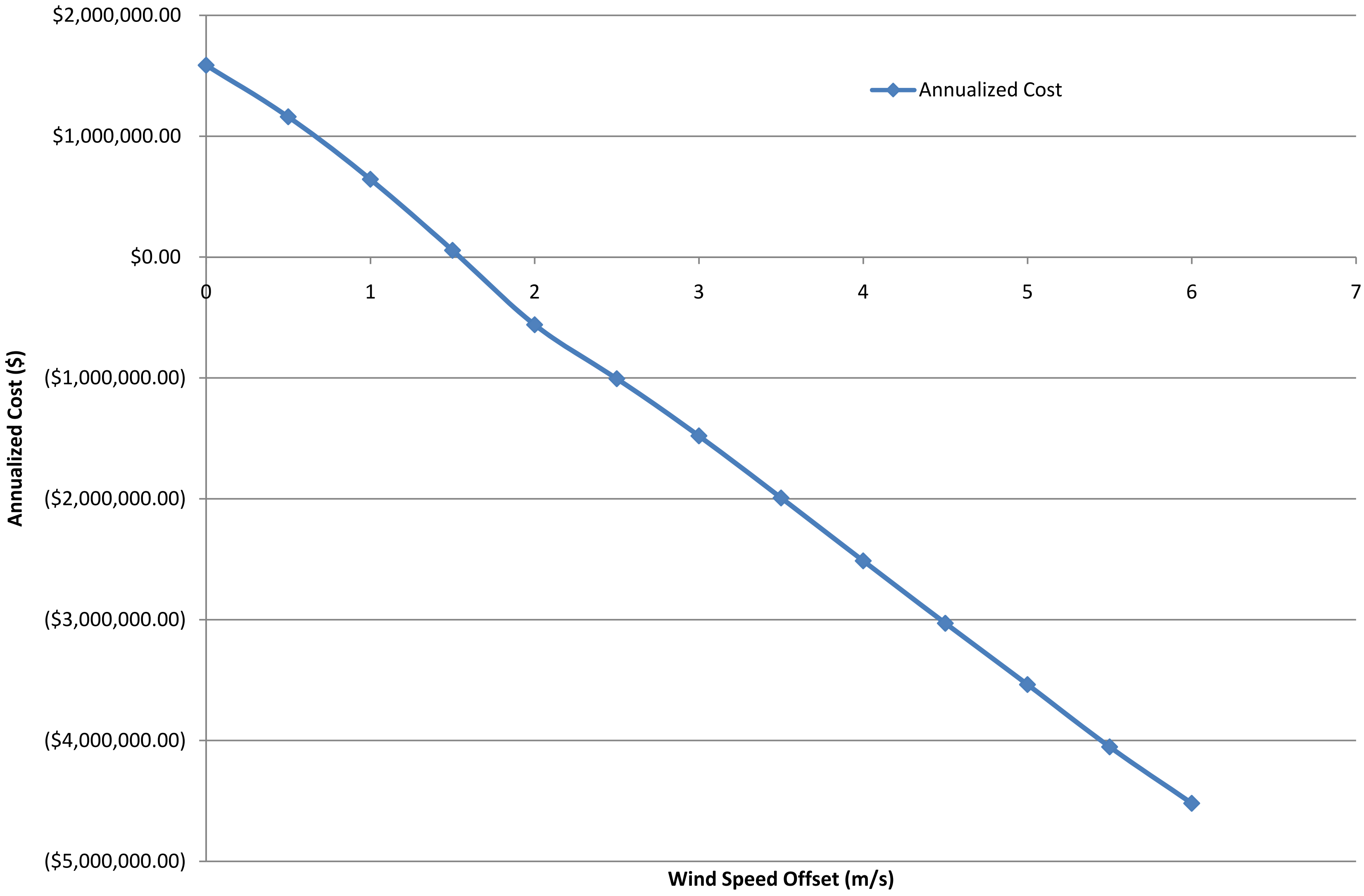

Figure 78: Annualized Cost with Five Wind Turbines, Varying Wind Speed Offset from Average

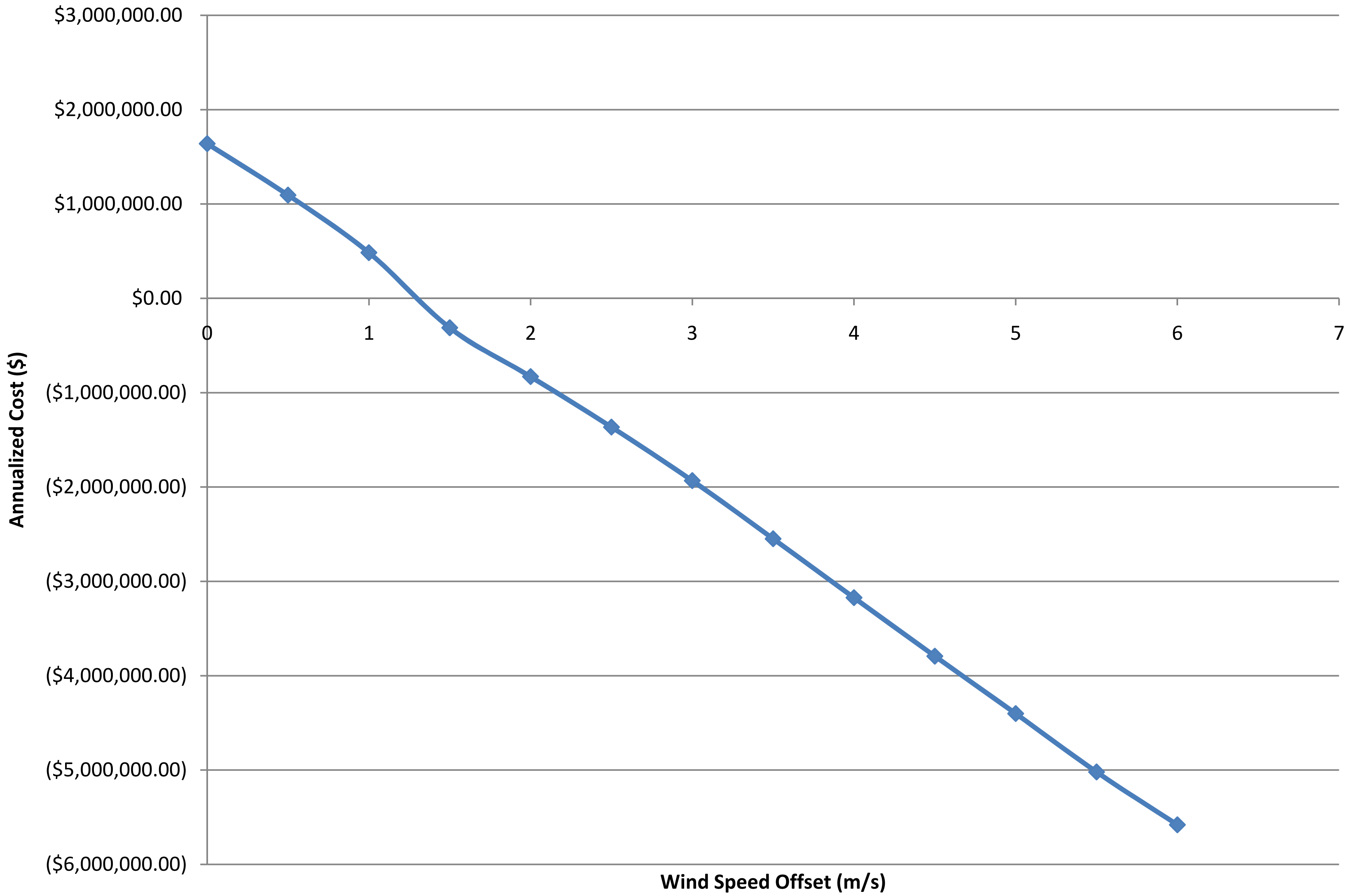

Figure 79: Annualized Cost with Six Wind Turbines, Varying Wind Speed Offset from Average

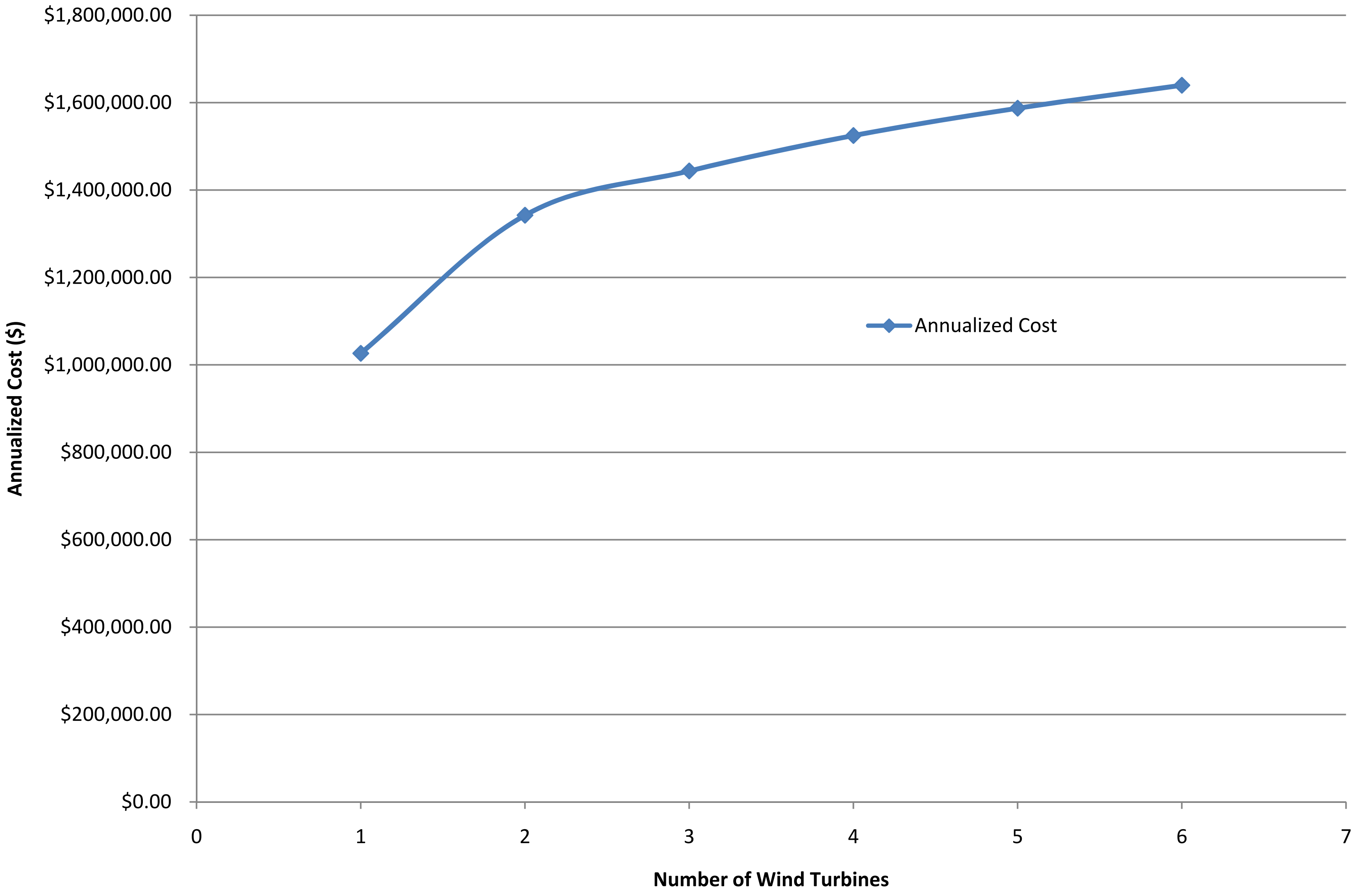

Figure 80: Annualized Cost with 0 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

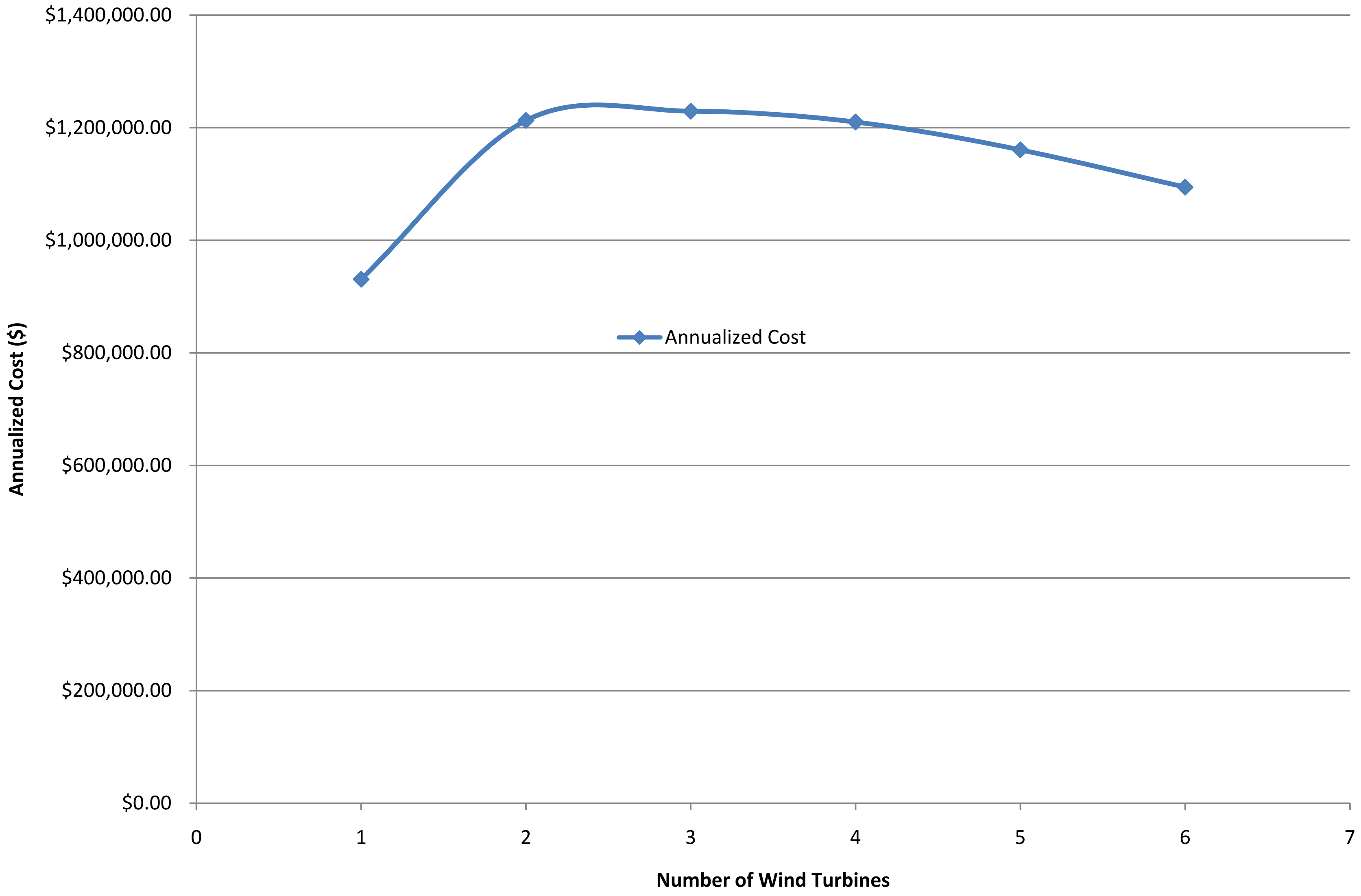

Figure 81: Annualized Cost with 0.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

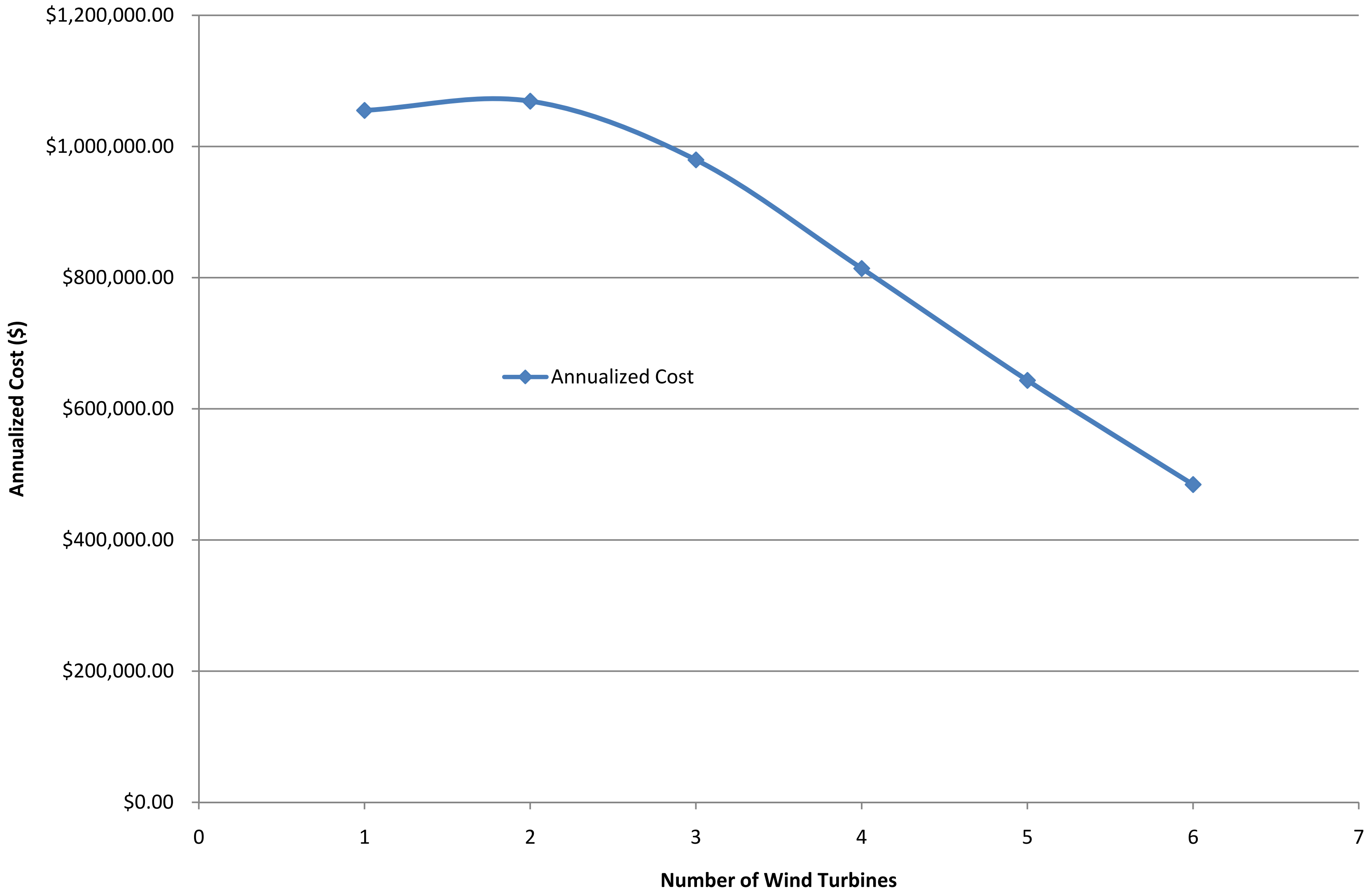

Figure 82: Annualized Cost with 1 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

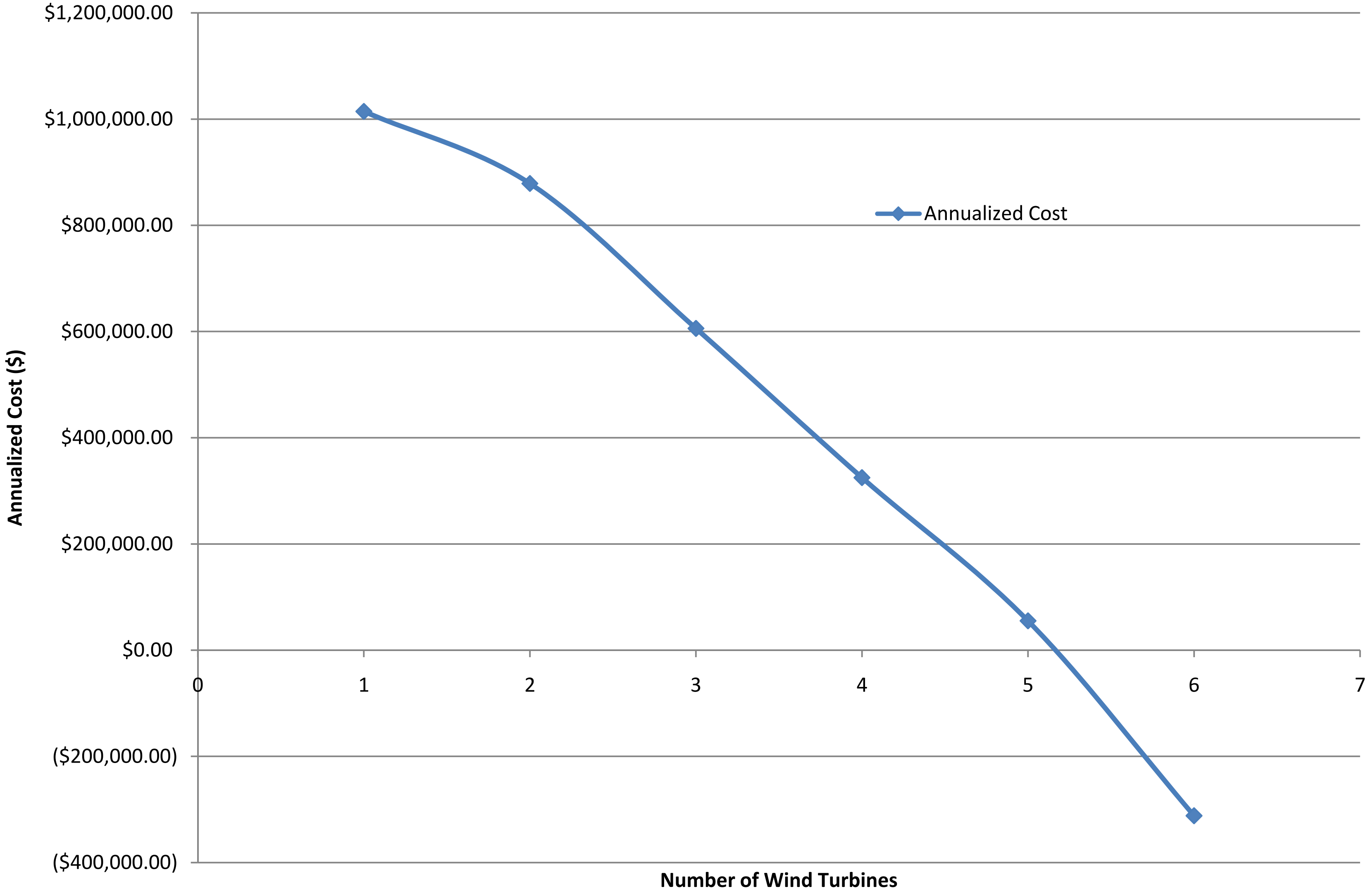

Figure 83: Annualized Cost with 1.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

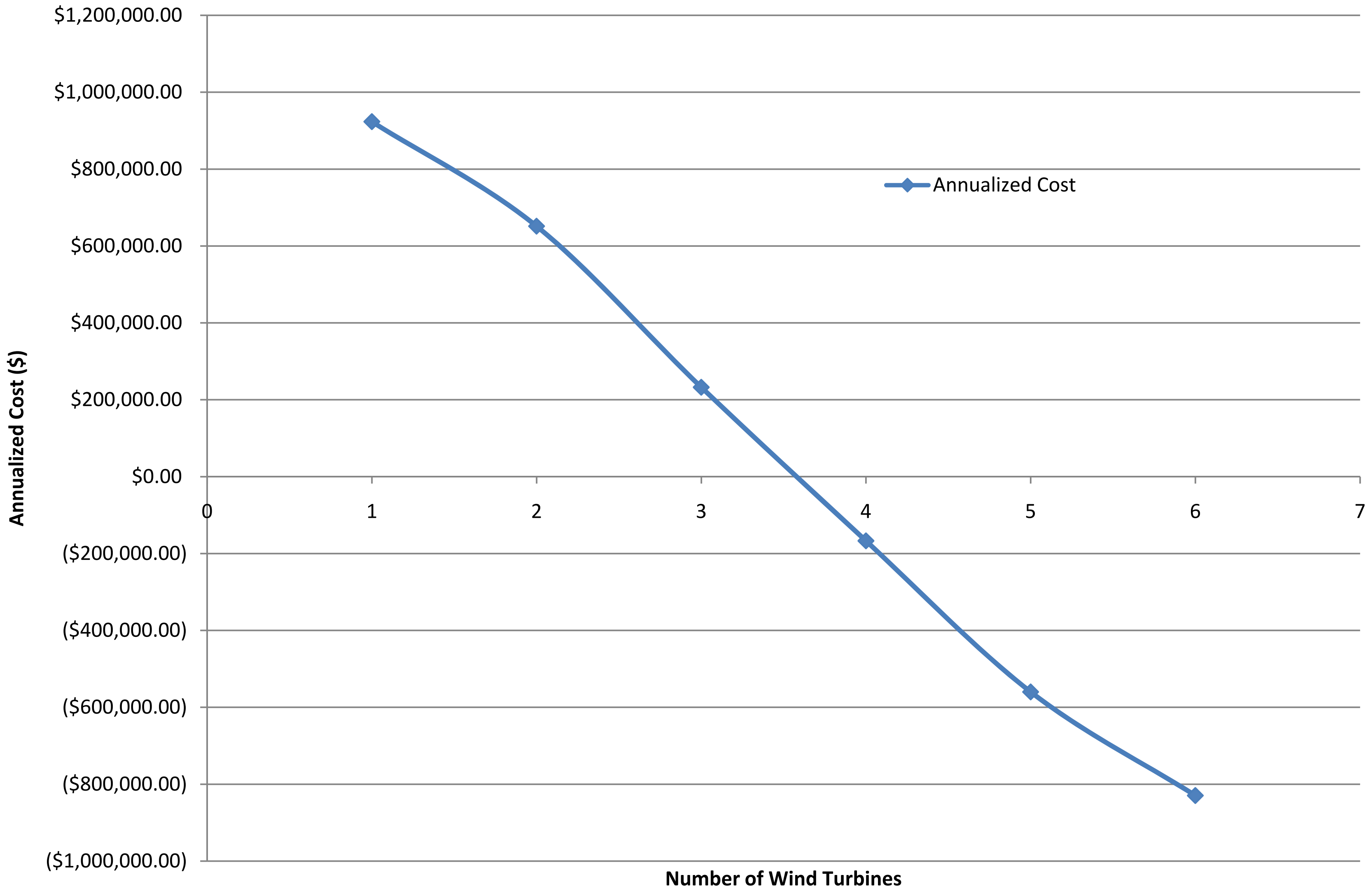

Figure 84: Annualized Cost with 2 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

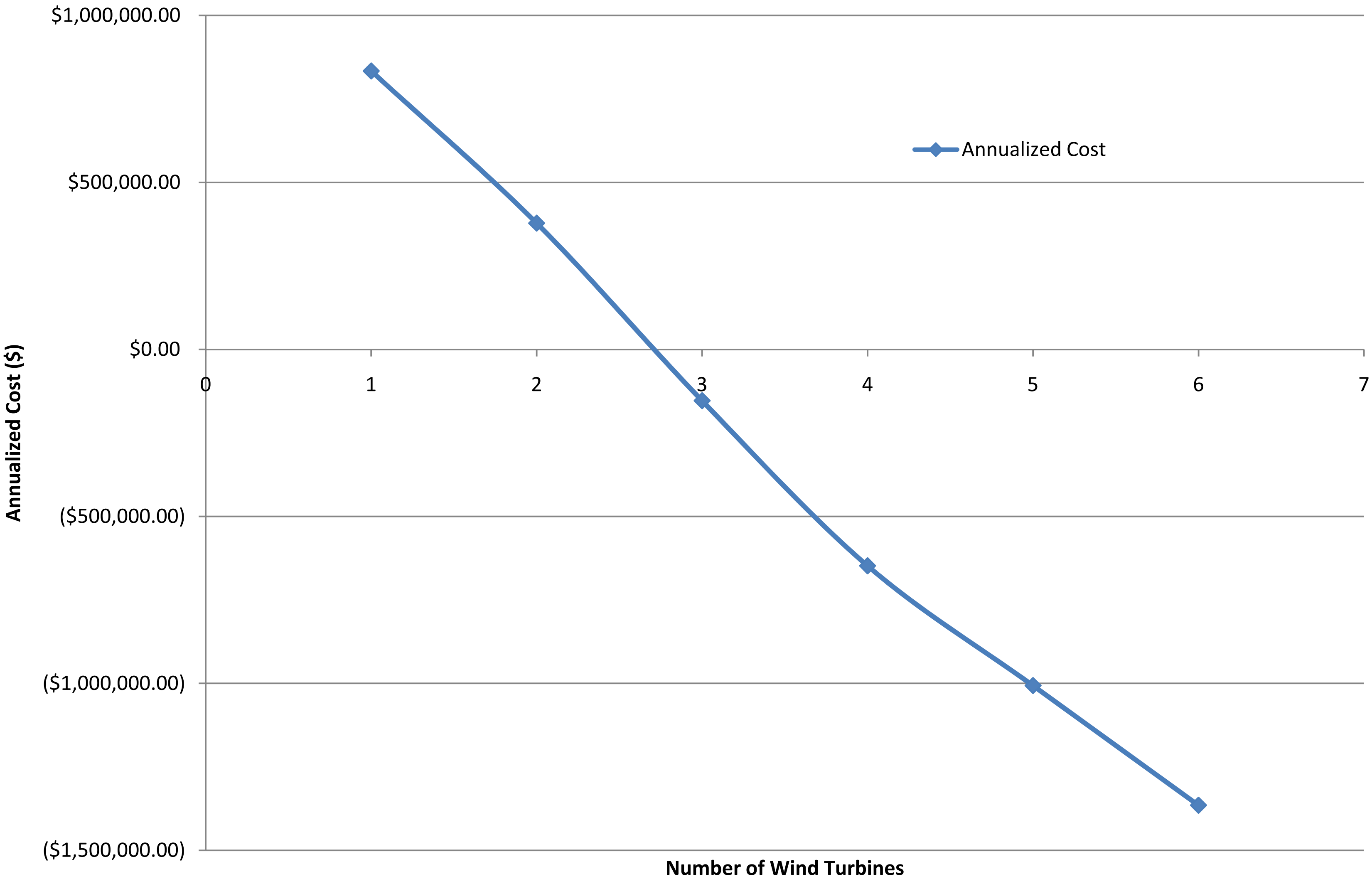

Figure 85: Annualized Cost with 2.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

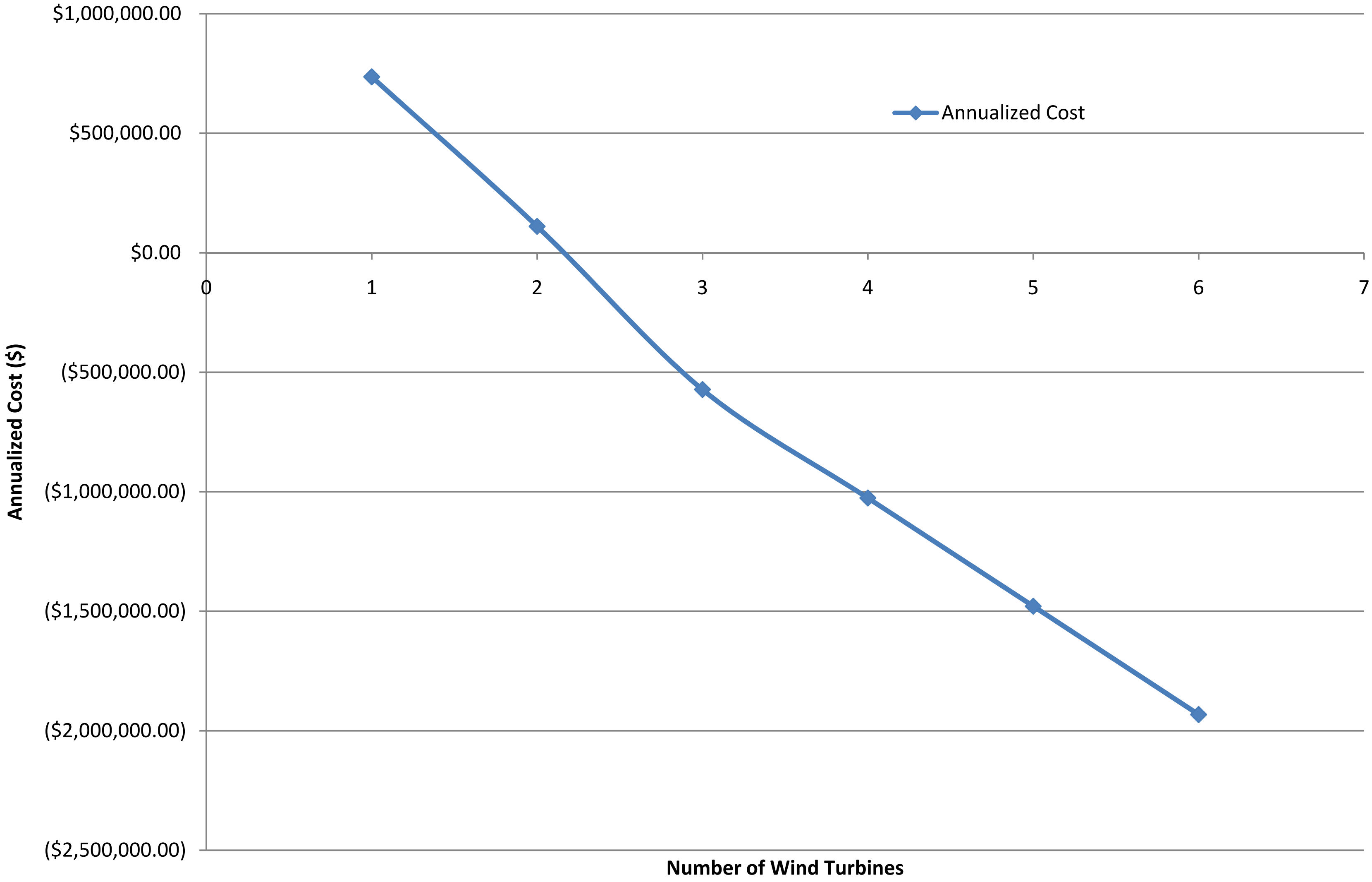

Figure 86: Annualized Cost with 3 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

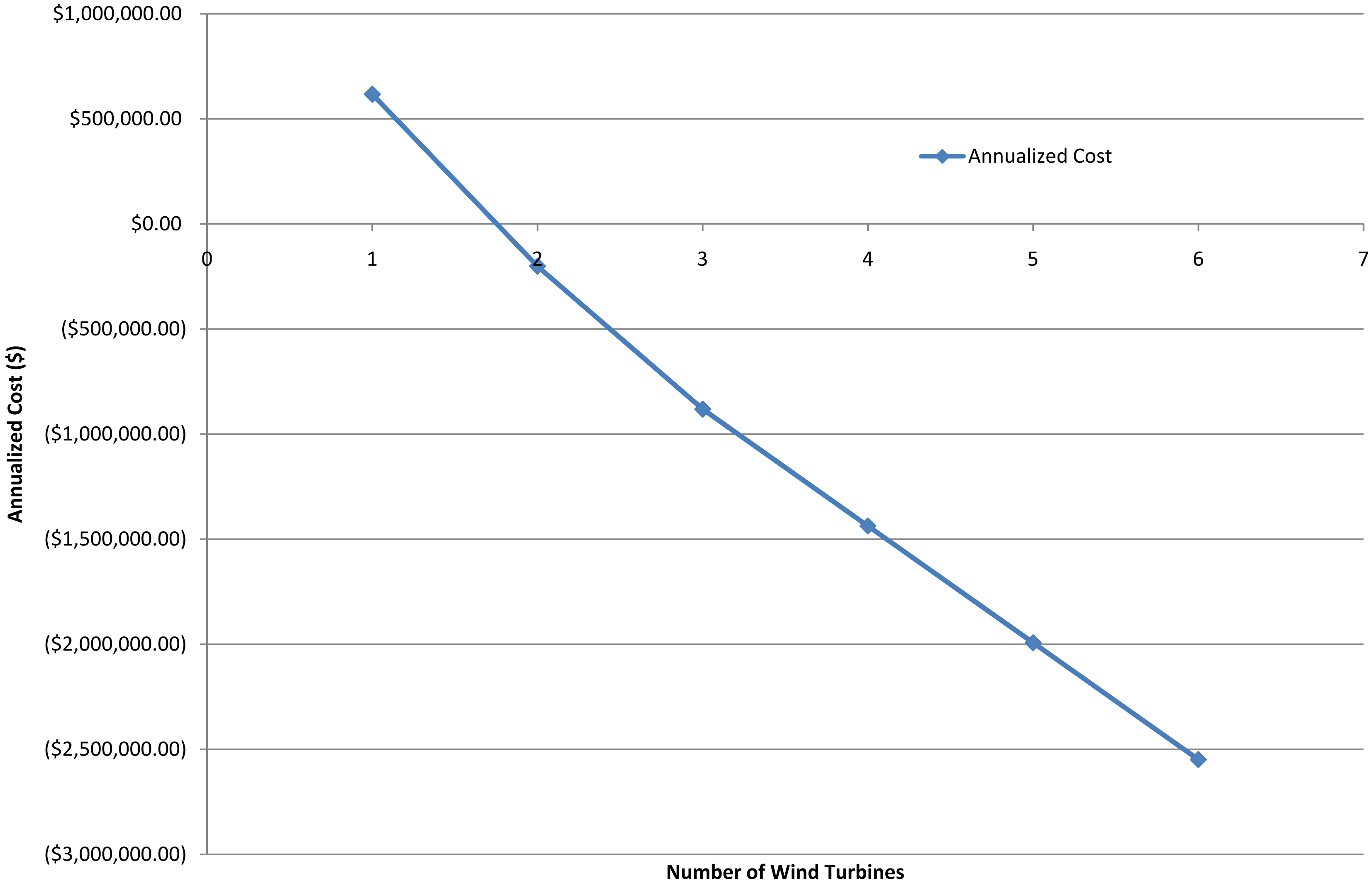

Figure 87: Annualized Cost with 3.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

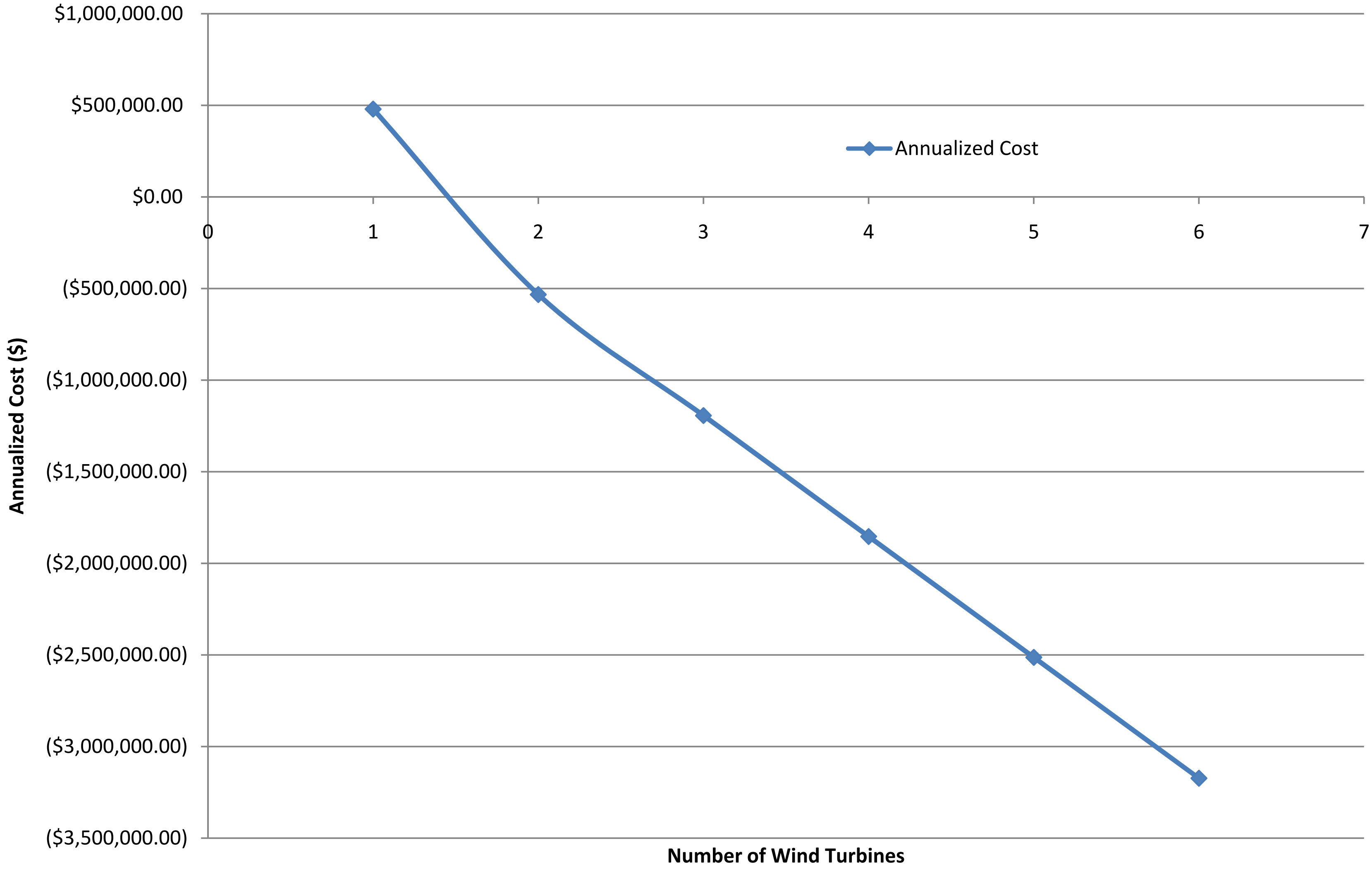

Figure 88: Annualized Cost with 4 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

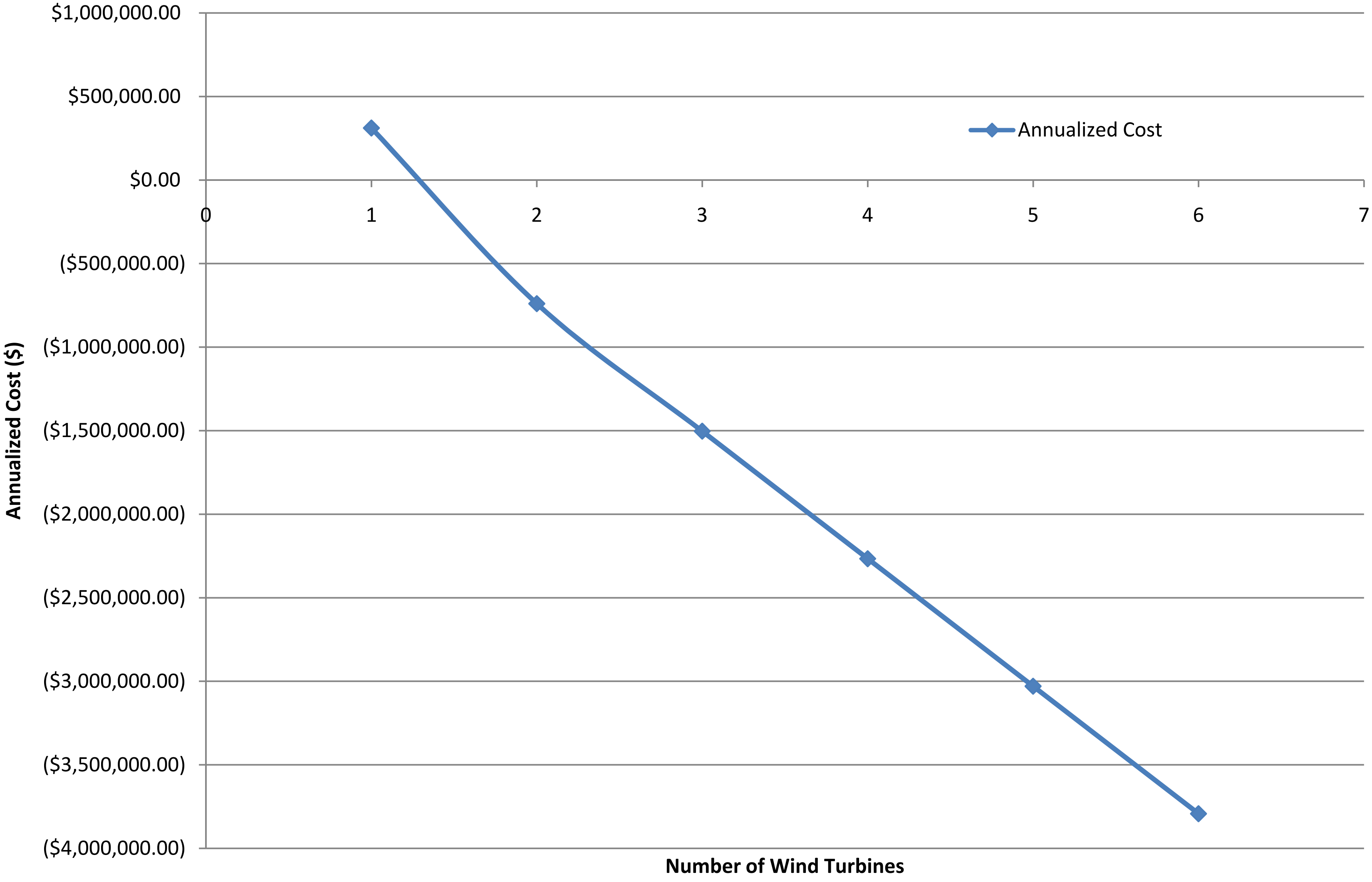

Figure 89: Annualized Cost with 4.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

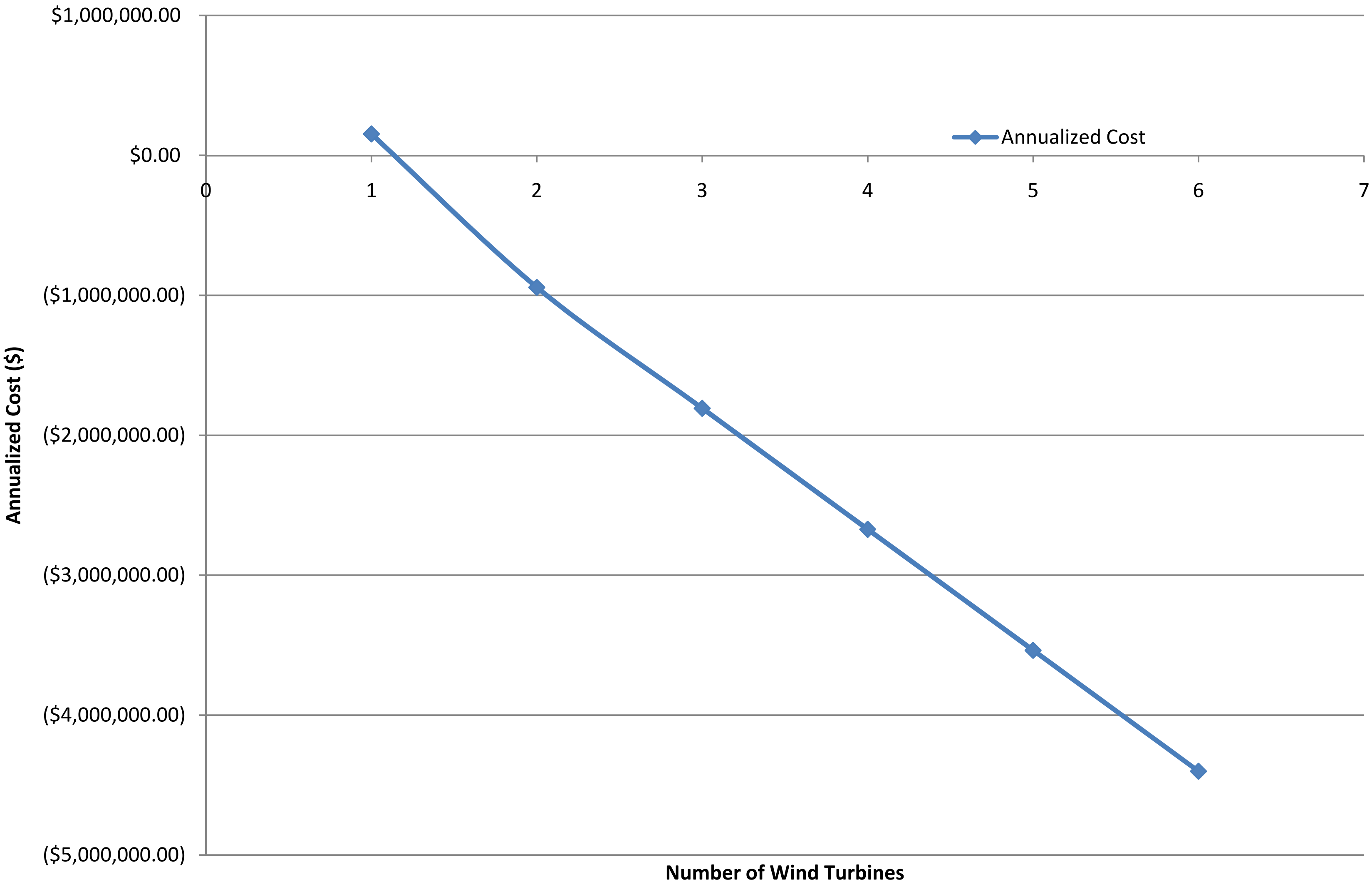

Figure 90: Annualized Cost with 5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

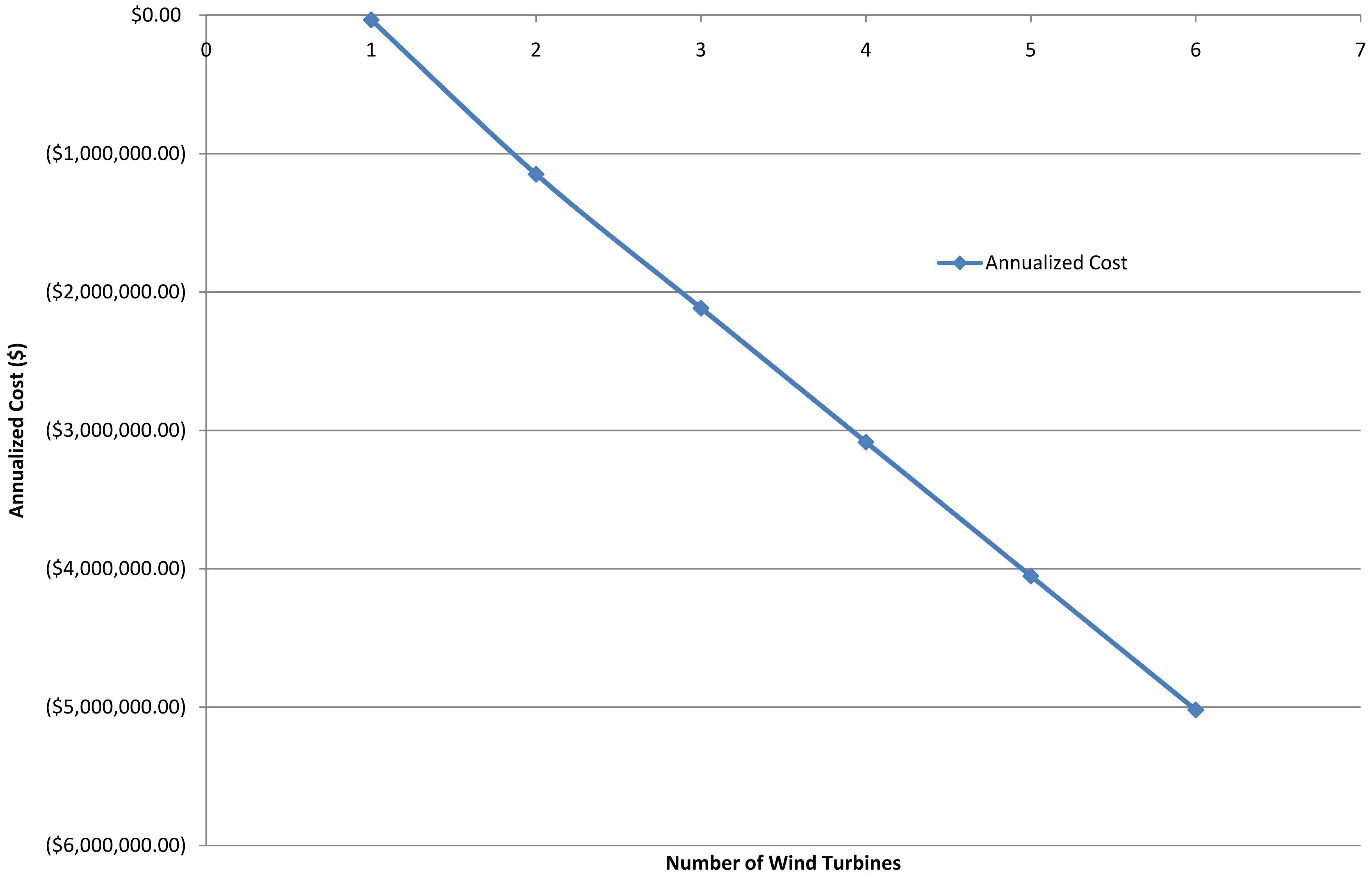

Figure 91: Annualized Cost with 5.5 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

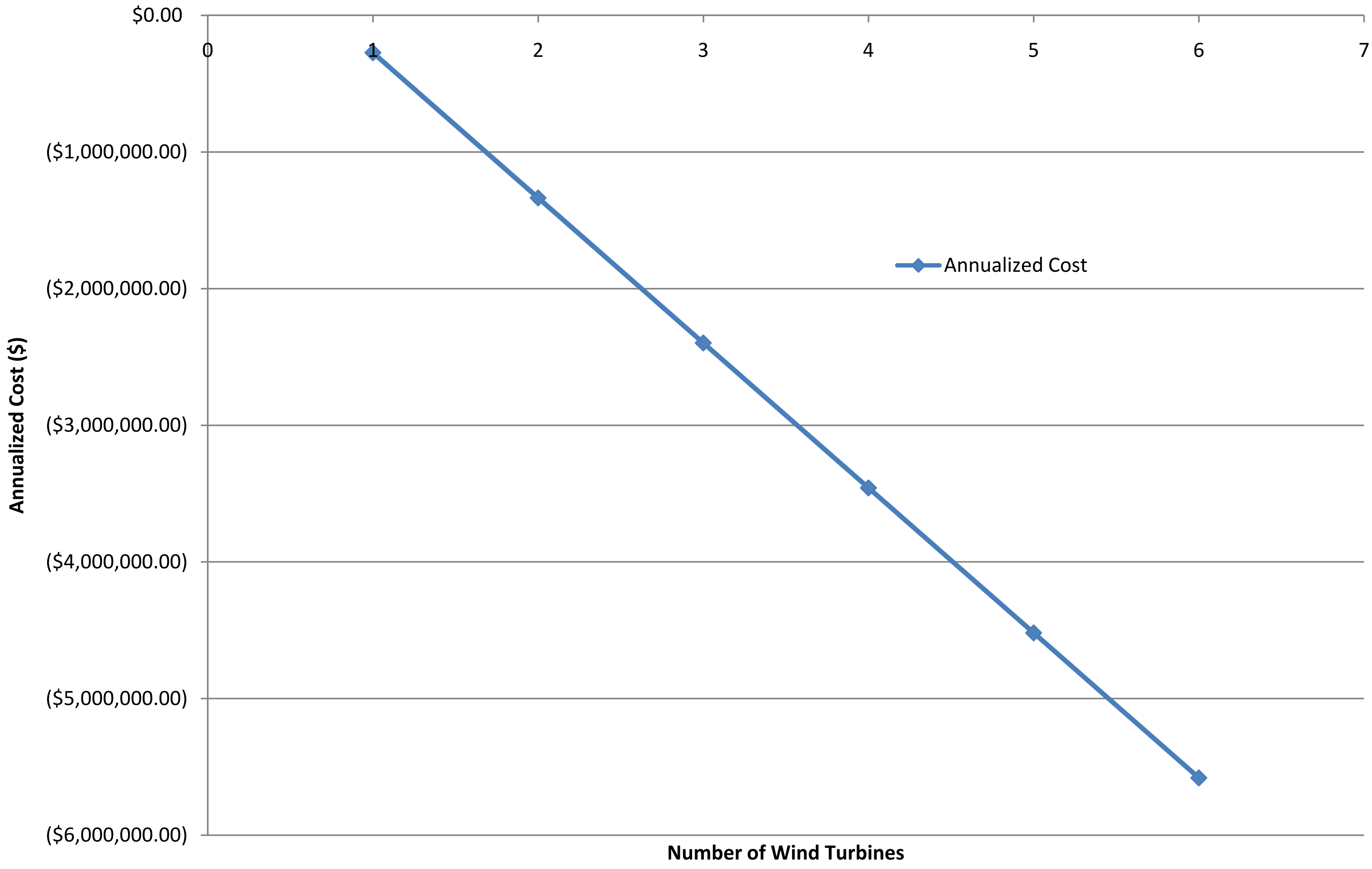

Figure 92: Annualized Cost with 6 m/s Wind Speed Offset from Average, Varying Number of Wind Turbines

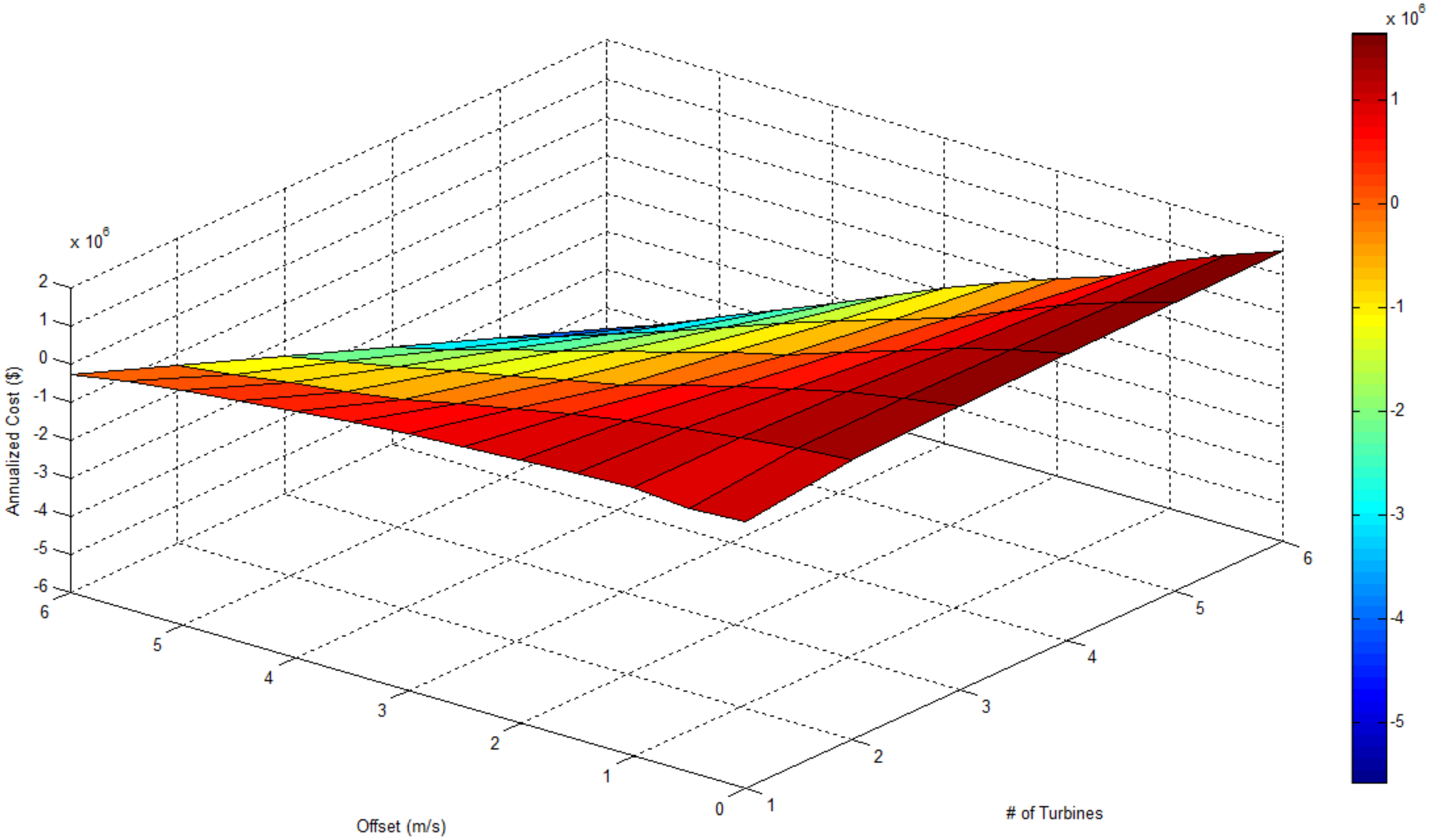

Figure 93: 3D Graph of Annualized Cost Sensitivity Analysis

Appendix C – Miscellaneous

Table 11: Comparison of Fuel Cell Technologies

Fuel Cell Type	Common Electrolyte	Operating Temperature	System Output	Electrical Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)*	Solid organic polymer poly-perfluorosulfonic acid	50 - 100°C 122 - 212°F	<1kW – 250kW	53-58% (transportation) 25-35% (stationary)	▪ Backup power ▪ Portable power ▪ Small distributed generation ▪ Transportation	▪ Solid electrolyte reduces corrosion & electrolyte management problems ▪ Low temperature ▪ Quick start-up	▪ Requires expensive catalysts ▪ High sensitivity to fuel impurities ▪ Waste heat temperature not suitable for combined heat and power (CHP)
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90 - 100°C 194 - 212°F	10kW – 100kW	60%	▪ Military ▪ Space	▪ Cathode reaction faster in alkaline electrolyte, leads to higher performance	▪ Expensive removal of CO$_2$ from fuel and air streams required (CO$_2$ degrades the electrolyte)
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	150 - 200°C 302 - 392°F	50kW – 1MW (250kW module typical)	>40%	▪ Distributed generation	▪ Higher overall efficiency with CHP ▪ Increased tolerance to impurities in hydrogen	▪ Requires expensive platinum catalysts ▪ Low current and power ▪ Large size/weight
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600 - 700°C 1112 - 1292°F	<1kW – 1MW (250kW module typical)	45-47%	▪ Electric utility ▪ Large distributed generation	▪ High efficiency ▪ Fuel flexibility ▪ Can use a variety of catalysts ▪ Suitable for CHP	▪ High temperature speeds corrosion and breakdown of cell components ▪ Complex electrolyte management ▪ Slow start-up
Solid Oxide (SOFC)	Yttria stabilized zirconia	600 - 1000°C 1202 - 1832°F	<1kW – 3MW	35-43%	▪ Auxiliary power ▪ Electric utility ▪ Large distributed generation	▪ High efficiency ▪ Fuel flexibility ▪ Can use a variety of catalysts ▪ Solid electrolyte reduces electrolyte management problems ▪ Suitable for CHP ▪ Hybrid/GT cycle	▪ High temperature enhances corrosion and breakdown of cell components ▪ Slow start-up ▪ Brittleness of ceramic electrolyte with thermal cycling

**Direct Methanol Fuel Cells (DMFC) are a subset of PEM typically used for small portable power applications with a size range of about a subwatt to 100W and operating at 60 - 90°C.*

Sources: U.S. Department of Energy – Energy Efficiency and Renewable Energy

Table 12: Geothermal Electrical Generation Worldwide, (Geothermal Education Office, 2008)

Country	**Amount of Geothermal Power (MW in 1999)**
United States	2850
Philippines	1848
Italy	768.5
Mexico	743
Indonesia	589.5
Japan	530
New Zealand	345
Iceland	140
Costa Rica	120
El Salvador	105
Nicaragua	70
Kenya	45
China	32
Turkey	21
Russia	11
Portugal (Azores)	11
Guatemala	5
France (Guadeloupe)	4
Taiwan	3
Thailand	0.3
Zambia	0.2
TOTAL	**8217**

Table 13: Geothermal Direct Usage Worldwide, (Geothermal Education Office, 2008)

Country	**Thermal Capacity (MW in 1999)**
Austria	21.1
Belgium	3.9
Demark	0.1
France	309
Germany	307
Greece	22.6
Ireland	0.7
Italy	314
Portugal	0.8
Sweden	47
United Kingdom	2
European Union Countries Total	**1031.4**
Bosnia and Herzegovina	33
Bulgaria	94.5
Croatia	11
Czech Republic	2
Georgia	245
Iceland	1443
Israel	42
Hungary	750
Macedonia	75
Poland	44
Romania	137
Russia	210
Serbia	86
Slovakia	75
Slovenia	37
Switzerland	190

Turkey	160
Other European Countries Total	**3602**
TOTAL EUROPE	**4633**
Canada	3
USA	1905
America Total	**1908**
China	1913
Asia Total	**3075**
New Zealand	5
Oceana Total	**5**
Algeria	1
Tunisia	70
Africa Total	**71**
TOTAL WORLD	**9692**