NDOT Research Report

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Assessment of Alternative Energy Applications at the Nevada Department of Transportation

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Disclaimer

Assessment of Alternative Energy Applications at the Nevada Department of Transportation (NDOT)

Final Report

August 2010

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1 Introduction

This report is the final report for the project titled "Assessment of Alternative Energy Applications at the Nevada Department of Transportation (NDOT)" performed by Dr. Evrenosoglu, Dr. Etezadi and Dr. Batchman at Electrical & Biomedical Engineering Department, University of Nevada, Reno.

The purpose of this report is to assess the prospects of significant renewable energy development and energy conservation methodologies at NDOT facilities. The viability, cost-effectiveness and efficiency of potential applications of alternative sources of electrical power for NDOT are investigated. This study gives insight to NDOT about the savings and the benefits of integrating alternative sources of power generation. Solutions and recommendations for co-generation units integrated with NDOT facilities and roadway systems is provided

1.1 Background

The electrical power network in Nevada is owned and operated by NV Energy. The company utilizes primarily coal and natural gas plants to provide the necessary electrical energy to its customers. NV Energy is also the leading company in the US in the use of geothermal and solar plants by size. A large scale (17% of the total consumption in Northern Nevada) wind farm integration is also underway in the northeast part of the state.

Recent incentives in renewable energy at state and federal levels also urged NV Energy to adopt a "Renewable Portfolio Standard" (RPS) along with other utilities and system operators throughout the country. RPS sets targets for the utilities to provide a specific percentage of their electrical energy production from renewable energy resources by a pre-determined year. NV Energy adopted an RPS which is 20% by 2015. The company aggressively pursues its RPS by claiming that "*by 2015, 20% of our energy must come from a combination of renewables and conservation programs*". The nation's most aggressive RPS was recently adopted by California Independent System Operator (CA-ISO is a non-profit organization which coordinates the operation of the power system and electrical energy markets in California.) by setting a 33% goal by 2020. This goal immediately had a remarkable effect on governmental agencies. In 2004 CalTrans (CA-DOT) started investigating various energy conservation programs which will briefly be reviewed in the following paragraphs. CADOT is not the only example among transportation departments in the country. Illinois DOT and Texas DOT also followed suit after the state power system operators and utilities adopted similar RPSs.

Essentially, the utilities and the system operators do not only start integrating new renewable source based power generation plants to their power networks but also create incentive programs for their customers (residential, industrial and public institutions). They encourage their customers to invest in renewable source based power units for their homes, facilities and industrial factories. Various "rebate" programs have been developed and adopted in the nation for installing wind turbines, photovoltaic solar panels and small hydro dams.

NV Energy initiated a "*Renewable Generations*" program through which it provides rebates to its customers for installing photovoltaic systems, wind generators and/or micro hydroelectric systems. They offer different rates for residential customers, small businesses, schools and public buildings. For public buildings they offer $4.60 per watt (a measure of "instantaneous" electrical consumption) for photovoltaic systems, $3.00 per watt for the first 10 kW (kilo watt = 1000 watt) and $2.00 per watt above 10 kW up to the program limit of 30 kW for wind generators. The maximum incentive for public buildings is $138,000 for photovoltaic (PV) systems and $70,000 for wind generators. They do not limit the size for participating PV systems, however, the rebates will be limited to 30 kW for public buildings. Their wind program limit is 500 kW for public buildings. They specify that the total rebate should not exceed 60 % of the eligible installed system cost. It should also be noted that the PV and wind generators are exempt from property tax.

It is important to briefly cite the efforts by CalTrans for energy conservation for their facilities. California Department of Transportation "*was given a 10-year energy conservation goal of $51.06 million in avoided costs through the implementation of cost-effective energy conservation measures (ECMs), or about $5.1 million dollars per year*." Their energy conservation program focuses on four energy load categories:

1. **24-hour fixed loads**: traffic intersections, data processing servers, traffic management centers, communications, toll collections, and some safety lighting and ventilation systems, where energy is consumed at all times at a relatively fixed rate.
2. **Nighttime only loads**: such as roadway lighting, highway information sign lighting and exterior security lighting, where the equipment loads come on when daylight is not present.

3. **Weekday loads during the 6 a.m. to 6 p.m. time period**: office buildings and maintenance complexes, where business hour operations and equipment may vary according to
4. the level of required work activities.
5. **Variable loads**: loads where forecasting or planning for operation is dependent on external forces/causes.

The CADOT notes that "the value of energy savings during 2003 for projects implemented or being implemented nets out to $16.2 million [1].

Based on the sample energy conservation programs and the incentives summarized above the University shall perform a research project for integrating alternative energy source based power co-generation applications for NDOT facilities. The project scope of work is given in the following section.

1.2 Report Organization

This report is organized into the following sections:

- Section 2 presents an overview of renewable energy sources and applications focusing on wind, solar and geothermal power. Technical details of electrical energy conversion, economical aspects of each renewable energy source for initial investment, operational as well as the production costs are overviewed.
- Section 3 reviews the current federal and state incentive program for renewable energy sources. Details, related to each program is presented and the potential incentive programs that can benefit NDOT are identified.
- Section 4 investigates the wind resources of Nevada that are suitable for development at NDOT facilities including district offices, maintenance stations and unstaffed stations. Initial investments, approximate operation and maintenance costs are listed. Economic impacts and the cost-efficiency as wells as implementation strategies of the proposed application are developed
- Section 5 identifies the potential solar application sites at NDOT. The initial information about the solar radiation at each NDOT site is given in this section. A preliminary list for solar projects is provided. Economic analysis for the identified projects is given.

- Section 6 gives an overview of geothermal potential at the Nevada state. Application of geothermal resources for heating & cooling at NDOT offices are analyzied in terms of initial costs and heat or cool generation cost.
- Section 7 presents energy saving methods and policy on energy efficiency at NDOT facilities. The energy conservation opportunities.
- Conclusion and future work are summarized in section 8 and section 9 provides references cited in this report.

2 Overview of Renewable Energy Sources and Applications

In this section three main renewable energy sources are focused: wind, solar and geothermal. These sources are the most accessible alternative sources in the State of Nevada.

2.1 Wind Power

A wind turbine is a machine which converts the power in the wind into electricity. The first wind turbines for electricity generation had been developed at the beginning of the twentieth century. The technology was improved step by step from the early 1970s and by the end of the 1990s, wind energy has emerged as one of the most important sustainable energy resources. During the last decade of the twentieth century, worldwide wind capacity was doubled approximately every three years [1], and according to estimations of Energy Information Administration, wind power capacity in the US will reach 12,000 MW by 2015 [2].

Wind turbines are connected to electrical networks like other electricity generators. These networks may include residential scale power systems, isolated or island networks, battery charging circuits or large utility grids.

Wind turbines produce a positive torque on a rotating shaft, resulting first in the production of mechanical power which is then transformed to electricity in a generator. The amount of energy which can be generated by a wind turbine depends on wind speed, air density, the rotor area and the efficiency of the turbine which is related to wind turbines blades pitch angle and wind speed. For a given wind speed, the rotor area determines how much energy a wind turbine is able to obtain from the wind. Wind power capability can be determined by the following equation [1]:

$$P_w = 0.5.\rho.V_w{}^3.\pi.R^2.C_p \qquad (2\text{-}1)$$

Where ρ is density of the air [kg/m^3], V_w is the wind speed [m/s], R is the wind turbine rotor radius [m] and C_p is the wind turbine efficiency. C_p can be expressed as a function of wind speed and blades pitch angle. The relation between turbine efficiency, wind speed and pitch angle is shown in the following equation [1]:

$$C_p = 0.22\left(116/\beta - 0.4\theta - 5\right) e^{-12.5/\beta} \qquad (2\text{-}2)$$

Where θ is the pitch angle [deg] and β is defined as follows [1]:

$$\beta = \frac{1}{\frac{1}{\lambda + \theta} - \frac{0.035}{\theta^3 + 1}} \tag{2-3}$$

Where λ is defined as the tip speed ratio and it is equal to [1]:

$$\lambda = \frac{\omega_{rot}.R}{V_w} \tag{2-4}$$

Where ω_{rot} is the wind turbine rotor speed [rad/s].

According to theoretical calculation, the maximum C_p is 0.57, however in reality, this can not be achieved. Industrial wind turbines usually achieve maximum power efficiency with wind speeds around 23-27 mph (10-12 m/s) and C_p will decrease if the wind speed is above or below the rated speeds.

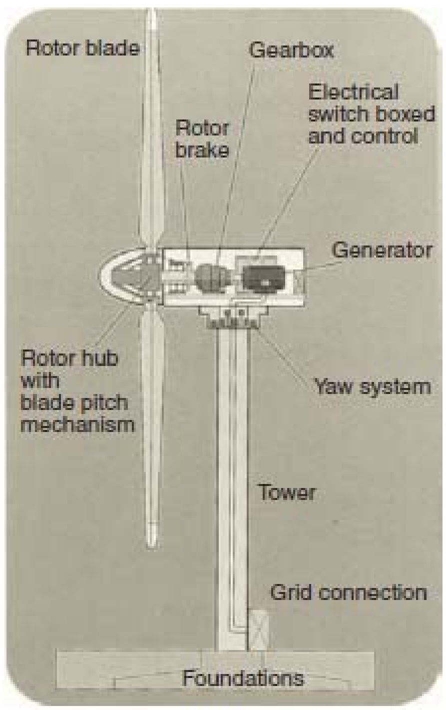

Fig 2.1 A typical wind turbine showing major components [2]

Wind turbines consist of different components as it is shown in Figure 2.1. These components are discussed briefly as follows:

2.1.1 Rotor

The rotor of a wind turbine consists of the blades and the supporting hub. These are considered as the most important components. Nowadays, the blades on the majority of turbines are made from composites. There are a variety of wind turbines with different rotor diameters. The rotor diameter may be from 33 ft (10 m) up to 264 ft (80 m) considering the wind turbine design.

2.1.2 Drive Train

The drive train consists of the rotating parts of the wind turbine. It typically includes a low-speed shaft (on the rotor side), a gearbox, and a high-speed shaft (on the generator side). The purpose of the gearbox is to speed up the rotor rate of rotation from a low value (tens of rpm) to a rate suitable for driving a standard generator (hundreds or thousands of rpm).

2.1.3 Generator

Wind turbines use generators to convert mechanical energy produced by wind to electrical energy. These generators can operate with a fixed speed or variable speed.

2.1.3.1 Fixed Speed Generators

Fixed speed generators operate at fixed rotating speed regardless of the wind speed. The wind turbines' rotor speed is fixed and determined by the frequency of the power grid, the gear ratio and the generator design. They are designed to achieve maximum efficiency at one particular wind speed. The fixed-speed wind turbine has the advantage of being simple, robust and reliable and well-proven and the cost of its electrical parts is also low. Its disadvantages are an uncontrollable reactive power consumption, mechanical stress and limited power quality control. All fluctuations in the wind speed are transmitted as the fluctuations in the mechanical torque and then as the fluctuations in the electrical power to the grid. The most common generator used for fixed speed wind turbines is the induction generator.

2.1.3.2 Variable Speed Generators

During the past few years the variable-speed wind turbine has become more popular among the installed wind turbines. Variable-speed wind turbines are designed to achieve maximum aerodynamic efficiency over a wide range of wind speeds. With variable-speed operation, it is possible to adapt the rotational speed of the wind turbine to the wind speed. The advantages of variable-speed wind turbines are an increased energy capture, improved power quality and reduced mechanical stress on the wind turbine. The most popular types of variable speed wind turbines are Double Fed Induction Generators (DFIG) and Synchronous generators with full power converter

2.1.4 Tower and Foundation

This facility includes the tower structure and the supporting foundation. The main types of tower currently in use are the free standing type using steel tubes, lattice (or truss) towers, and concrete towers [2]. Tower height is typically 1 to 1.5 times the rotor diameter. Tower selection is influenced by the characteristics of the site that wind turbine is located.

2.1.5 Control System

The control system for a wind turbine is important for both machine operation and power production. A wind turbine control system includes the following components:

- Sensors including speed, position, flow, temperature, current and voltage measurements
- Controllers including mechanical mechanisms, electrical circuits

2.1.6 Other Components

In addition to the mentioned basic components, the wind turbine system utilizes a number of other electrical components. Cables, switches, transformers, power electronic converters, power factor correction capacitors and pitch angle controller are some main components used in wind turbines.

2.1.7 Wind Turbine Classification

In this section wind turbine classification according to type and size of wind turbine is discussed. Wind turbines can be divided into two categories based on the rotation of its blades or its horizontal and vertical axis.

2.1.7.1 Horizontal vs. Vertical Axis

In the horizontal-axis wind turbines, the axis of blade rotation is horizontal with respect to the ground and parallel to the wind direction. Nowadays, most wind turbines are built with the horizontal-axis design, because they provide a cost-effective turbine construction and installation. Controlling the output of the wind turbine is also applicable by varying the blade pitch angle [2]. A simple scheme of horizontal-axis wind turbine is shown in Fig. 2.2.

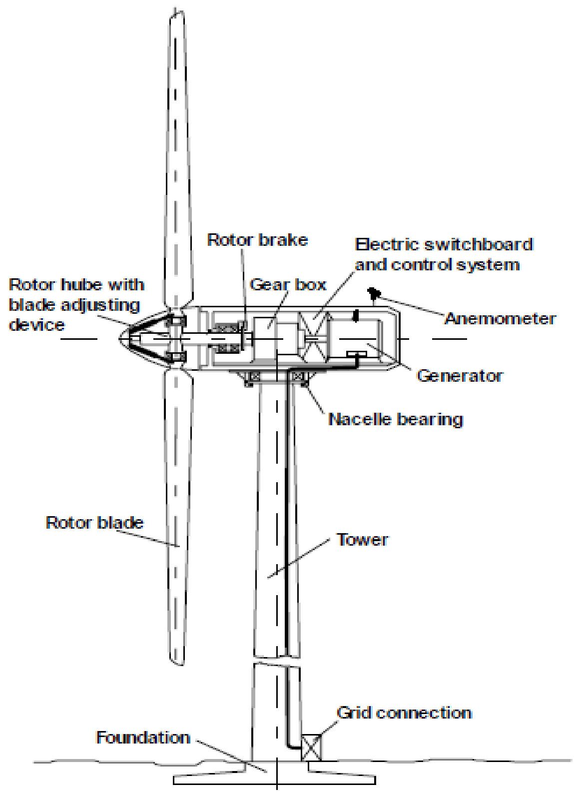

Fig 2.2 A simple scheme of horizontal-axis wind turbine [6]

Vertical-axis wind turbine has different structure. It is unidirectional and requires no yaw mechanism to continuously orient itself toward the wind direction [2]. It has vertical drive shaft which simplifies the installation of the gearbox and the electrical generator on the ground, making the structure much simpler [2]. But it normally requires guy wires attached to the top for support. This could limit its applications, particularly at offshore sites [2]. Generally, vertical-axis wind turbines have not been widely used because its output power cannot be easily controlled in high winds by changing the blade pitch [2]. The simple scheme of a vertical-axis wind turbine is shown in the Fig. 2.3.

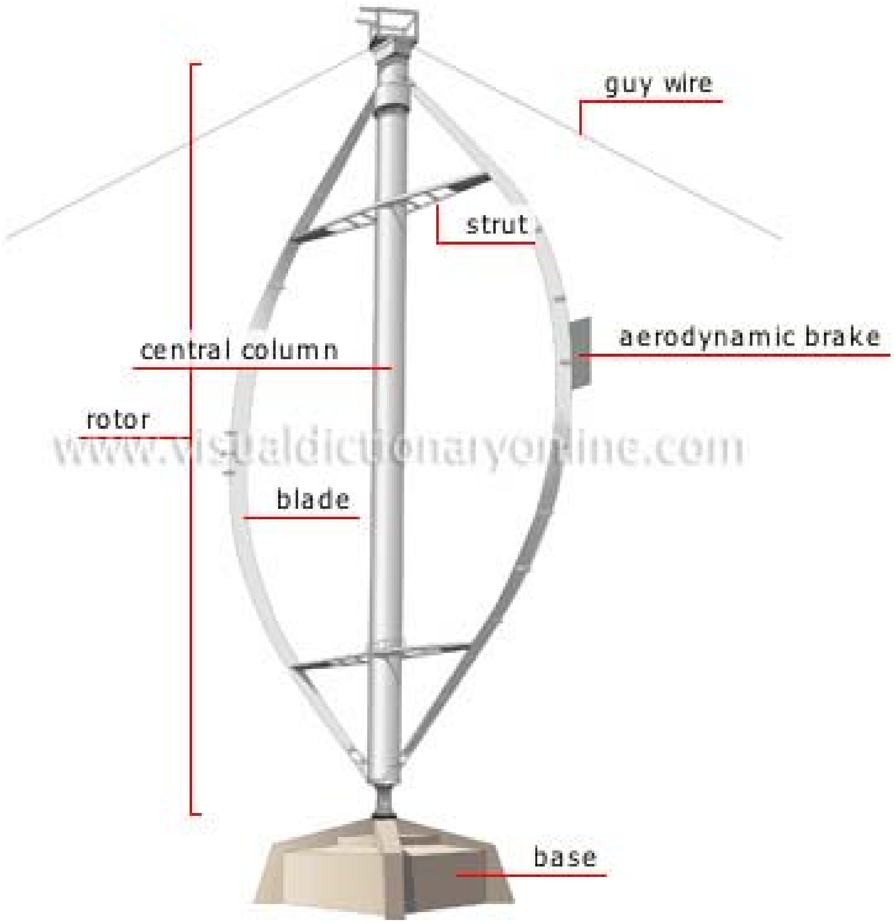

Fig 2.3 a simple scheme of horizontal-axis wind turbine [9]

2.1.7.2 Large vs. Small Scale

Wind turbines are available in a variety of sizes and power ratings. According to size and power generation capacity, wind turbines can be divided into two sections, small and large scale wind turbines. Wind turbines with rotor diameters of approximately 60 ft (18 m) and nominal capacities of up to 300 kW are referred to as small wind turbine. These small wind turbines are provided with 2 to 3 rotor blades. These wind turbines can be used for residential and small business application. The scheme of a small wind turbine is shown in Figure 2.4.

Fig 2.4 Image of a small wind turbine with 20 kW output power [9]

Wind turbines with the power generation capacity above 1 MW are usually considered as large scale wind turbines. These large wind turbines are up to 5 MW. The following Figure shows a large General Electric (GE) wind turbine with 2 MW output power.

Fig 2.5 Image of a large GE wind turbines with 2 MW output power [10]

2.2 Solar Power

There are two main technologies used for conversion of sunlight into electricity, the photovoltaic (PV) power technology and the solar thermal power technology.

2.2.1 Photovoltaic Power Technology

Solar photovoltaic power technology uses semiconductor cells to transform the energy stored in the sunlight into electricity. The cells are basically large area p-n diode with the junction positioned close to the top surface. The cell converts the sunlight into direct current electricity. Numerous cells are assembled in a module to generate required power. Because much of the current PV technologies use crystalline semiconductor material similar to integrated circuit chips, the production costs are high [2]. The physics of the PV cell is very similar to the classical diode with a p-n junction. When the junction absorbs light, the energy of absorbed photons is transferred to the electron–proton system of the semiconductor material, creating charge carriers that are separated at the junction. The charge carriers may be electron–ion pairs in a liquid electrolyte or electron–hole pairs in a solid semiconducting material [2]. The charge carriers in the junction region create a potential gradient, accelerate under the electric field, and circulate as current through an external circuit. The remaining power of the photon elevates the temperature of the cell and wastes as the heat form energy [2]. The basic construction of a PV cell is shown in Figure 2.6. Metallic contacts are provided on both sides of the junction to collect electrical current. A thin conducting mesh of silver fibers on the top surface collects the current and lets the light through. Conducting foil contact is provided over the bottom surface and on one edge of the top surface. In addition to the basic elements, several enhancement features are also included in the construction. For example, the front face of the cell has an antireflective layer to absorb as much light as possible by minimizing the reflection. The mechanical protection is provided by a cover glass [2].

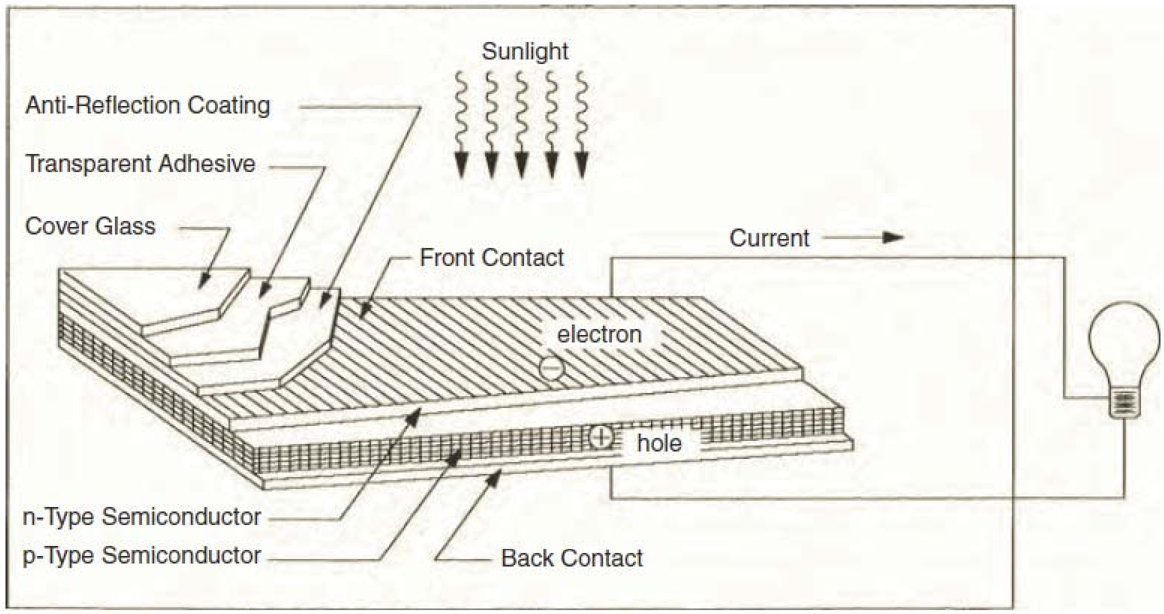

Fig 2.6 Basic construction of a PV cell [2]

2.2.1.1 Module and Array

The solar cell described in the section 2.2.1 is the basic block of a PV power system. Typically, solar cells are a few square inches in size and produce approximately 1 W of power. To obtain high power, numerous solar cells are connected in series and parallel circuits on a panel (module) area of several square feet. The solar array or panel is defined as a group of several modules connected in a series–parallel combination to generate the required current and voltage. Figure 2.7 shows the combination of cells to form module and array on a structure [2].

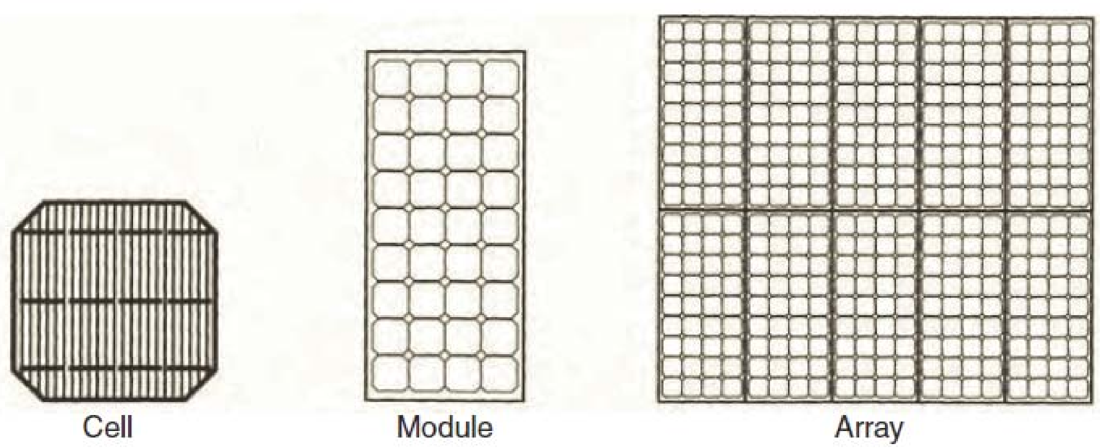

Fig 2.7 Several PV cells make a module, and several modules make an array [2].

The major factors influencing the design of the solar arrays are summarized as following:

- Sun intensity
- Sun angle
- Load matching for maximum power
- Operating temperature

2.2.1.2 Sunlight Intensity

A PV cell will produce maximum power under a full bright sun. On a partially sunny day, the amount of power produced by PV cells decrease in direct proportion to the sun intensity. At lower sun intensity, the I-V characteristic curve shifts downward as shown in Figure 2.8. It means that, the amount of output power decreases if the sun intensity decreases. On a cloudy day, the circuit current decreases significantly. The reduction in the open-circuit voltage, however, is small [2]. In Fig 2.8, C_1 represents higher sun intensity. As it can be seen, the power capacity of a OV cell decreases, when there is the sun intensity decreases.

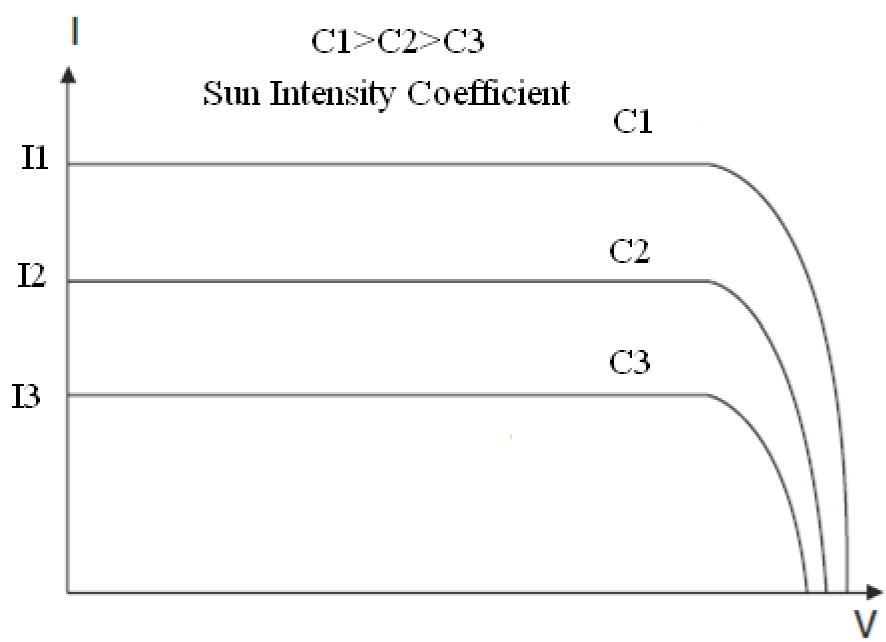

Fig 2.8 I-V curve characteristic of PV module for different sun intensity [2]

2.2.1.3 Sunlight Angle Radiation

The PV cell output current is given by $I = I_o\cos\theta$, where I_o is the current due to normal sun (reference), and θ is the angle of the sun line measured from the normal position. This cosine law holds well for sun angles ranging from 0 to about 50°. Beyond 50°, the electrical output deviates significantly from the cosine law, and the cell generates no power beyond 85° [2]. The relation between current and sun angle is shown in Figure 2.9.

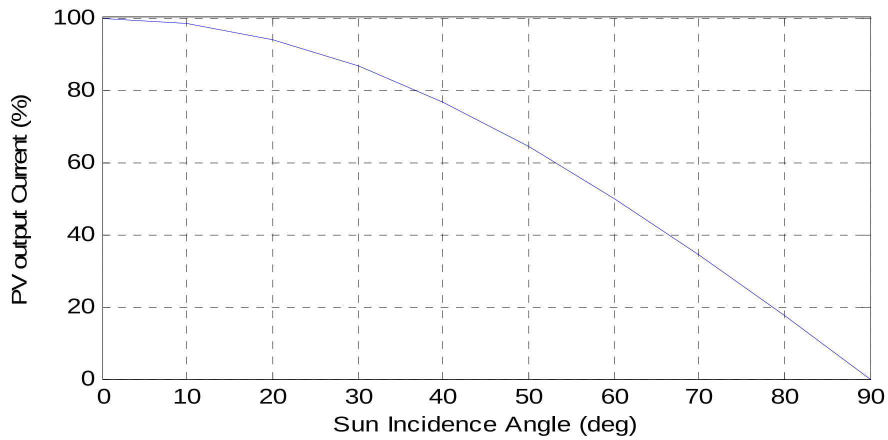

Fig 2.9 PV current changes with respect to sun angle radiation changes

2.2.2 Solar Thermal Power

Solar thermal systems depend on conversion of solar energy to thermal energy in the form of steam, which is used to drive a turbo generator. Solar thermal electricity generation systems most commonly use solar concentrators to produce high temperatures that can drive heat engines with acceptable conversion efficiency. The schematic of a solar thermal power station is shown in Fig 2.10 [2].

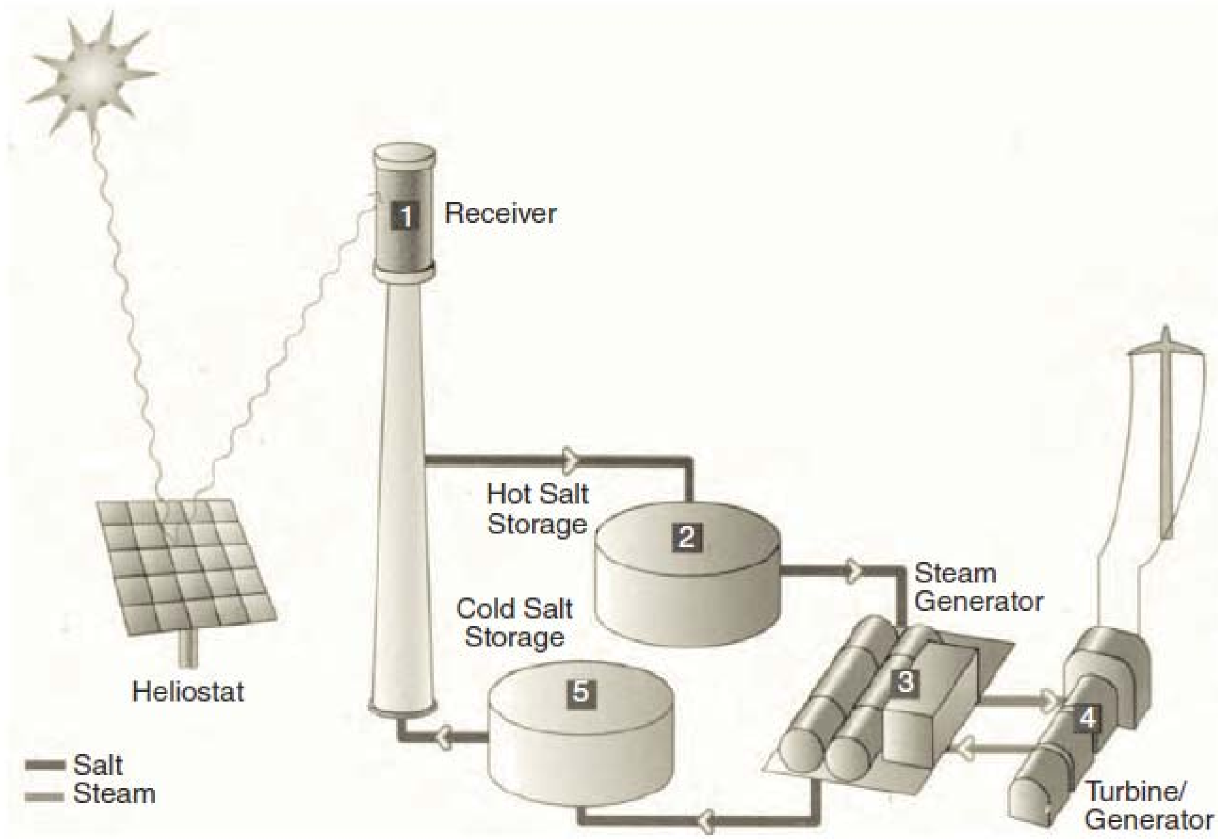

Fig 2.10 A typical solar thermal power plant [2]

To obtain enough thermal energy to produce hot steam, concentration of sunlight is needed. Different kind of concentrating systems are used to convert the energy of sunlight into high temperature hot steam. Three Different configurations are discussed.

2.2.2.1 Parabolic Trough

The receivers, or heat collection elements (HCE), consist of a stainless steel absorber tube surrounded by a glass envelope with the vacuum drawn between the two to reduce heat losses. A heat transfer fluid circulates through the receivers, delivering the collected solar energy to a conventional steam turbine-generator to produce electricity. The parabolic trough solar collector is shown in Fig 2.11.

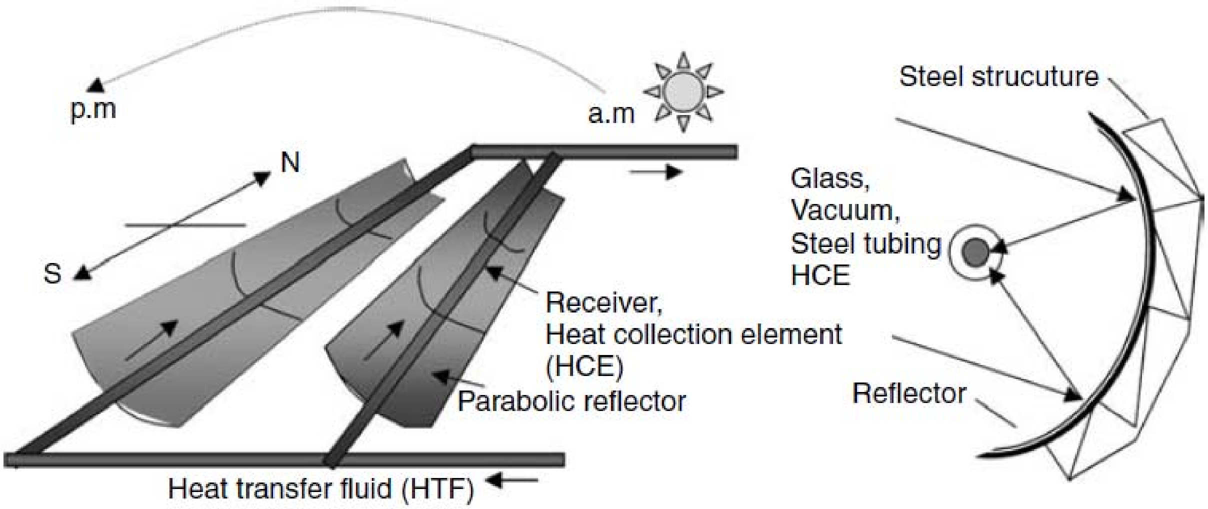

Fig 2.11 A parabolic trough solar collector [3]

2.2.2.2 Solar Central Receiver Systems

Another method to achieve concentrated sunlight is based on an array of field mirrors focusing sunlight into the central receiver set on a tower. To focus sunlight on the central receiver at all times, computer-controlled system, called "heliostats" is used [2]. Compared with the parabolic trough, this technology produces a much higher concentration and higher temperature of the working heat transfer fluid. Consequently, it yields higher efficiency and is well suited for utility-scale power plants of tens of hundreds of megawatt capacity [2]. The schematic of a central receiver system is shown in Fig 2.12.

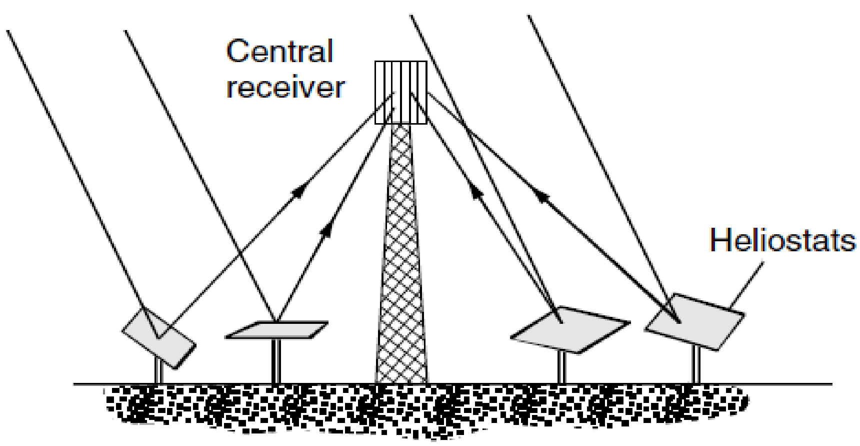

Fig 2.12 A solar central receiver system to collect sunlight energy [3]

2.2.2.3 Parabolic Dish

A parabolic dish tracks the sun to focus heat, which drives a Stirling heat engine that is connected to an electrical generator [2]. This technology has applications in relatively small capacity (tens of kilowatts) due to available engine size. Because of their small size, they are more modular than other solar thermal power systems and can be assembled in capacities ranging from a few hundred kilowatts to a few megawatts. This technology is particularly attractive for small stand-alone remote applications [2]. The parabolic dish configuration is shown in Fig 2.13.

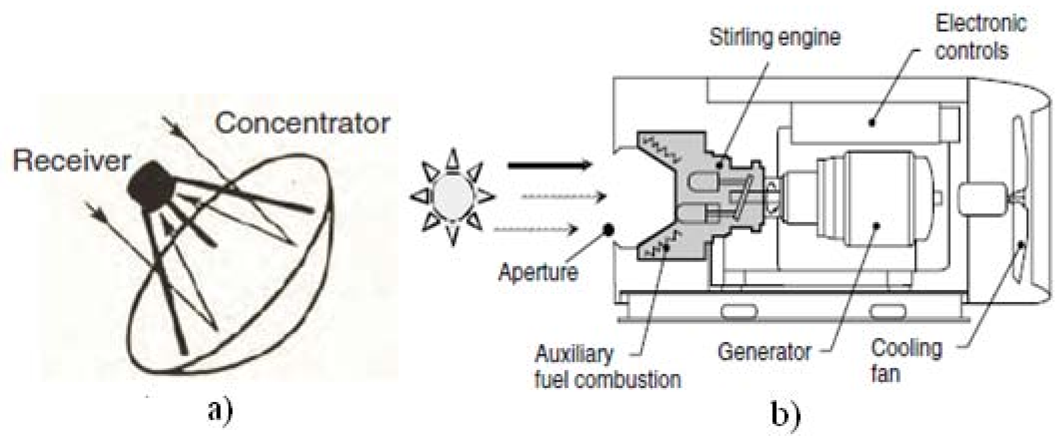

Fig 2.13 a) A parabolic dish concentrator b) A Stirling engine combined with generator to produce electricity [3].

2.2.2.4 Comparisons of Concentrating Solar Power Systems

The three approaches of concentrating solar thermal power systems share the same fundamental approach of using mirrored surfaces to reflect and concentrate sunlight onto a receiver to create high temperatures and to run a heat engine with reasonable efficiency. The methods differ in the intensity of solar radiation focused onto the receiver. This criterion is used to compare the three mentioned technologies in terms of efficiency. The intensity is usually expressed as a dimensionless unit called “sun” and the reference point of 1 sun means no concentration. Dish Stirling systems can achieve concentration ratios of about 3000 suns. Solar central receiver concentration ratio is about 1000 suns and parabolic trough systems can obtain concentration ratio of about 100 suns [3]. Thus the dish striling system will have the highest efficiency in terms of concentration ratio. The annual efficiency of mentioned system is approximately [3]: Dish Stirling 21%, power towers 16% and parabolic troughs 14%.

The required land area for installation is about 176,000 ft^2/MW, 220,000 ft^2/MW and 352,000 ft^2/MW for dish Stirling, parabolic troughs and solar central receiver respectively [3].

In the case of reliability, all three of these technologies can be supplemented using fossil fuel auxiliary heat sources, and are equivalent in this respect [3].

2.3 Geothermal Power

Most power plants need steam to generate electricity. The steam rotates a turbine which drives a generator, which produces electricity. Many power plants still use fossil fuels to boil water for steam. Geothermal power plants, convert the energy stored in the hot rock under the surface of the earth into electricity by using water to absorb heat from the rock and transport it to the earth's surface, where it is converted to electrical energy through turbine-generators. The geothermal power plants are listed as: dry steam, flash steam, and binary cycle [4].

2.3.1 Dry Steam Power Plant

Dry steam power plants are the simplest, the most economical and the most widespread technology. The dry steam power plant is suitable where geothermal steam is not mixed with water. Production wells are drilled down and the superheated pressurized steam (356 - 662°F) is pumped to the surface at high speeds and passed through a steam turbine to generate electricity. In simple power plants, the low pressure steam output from the turbine is vented to the atmosphere. This improves the efficiency of the turbine and avoids the environmental problems associated with the direct release of steam into the atmosphere [4]. The simple figure of a dry steam power plant is shown in Fig 2.14.

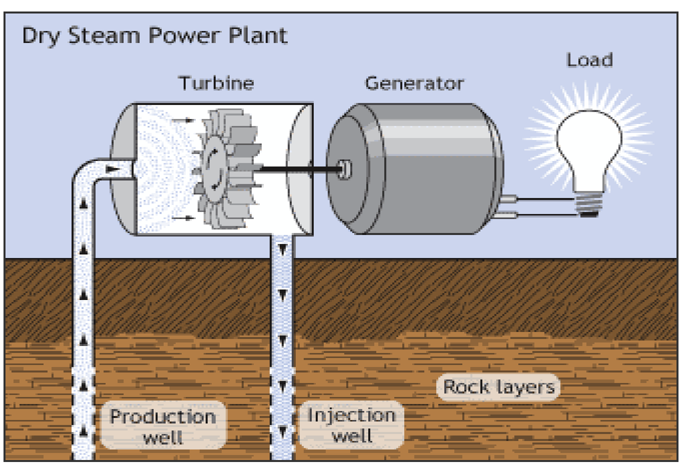

Fig 2.14 Dry steam power plant [5]

2.3.2 Flash Steam Power Plant

In a flash steam power plant technology, hydrothermal resource is in liquid form. The fluid is sprayed into a flash tank, which is held at a much lower pressure than the fluid, causing it to vaporize (or flash) rapidly to steam. The steam is then passed through a turbine and it rotates the generator shaft to produce electricity. To prevent the geothermal fluid flashing inside the well, the well is kept under high pressure. Flash steam plant generators range from 10 MW to 55 MW; a standard size of 20 MW is used in several countries [4]. The simple diagram of a flash steam power plant is shown in Fig 2.15.

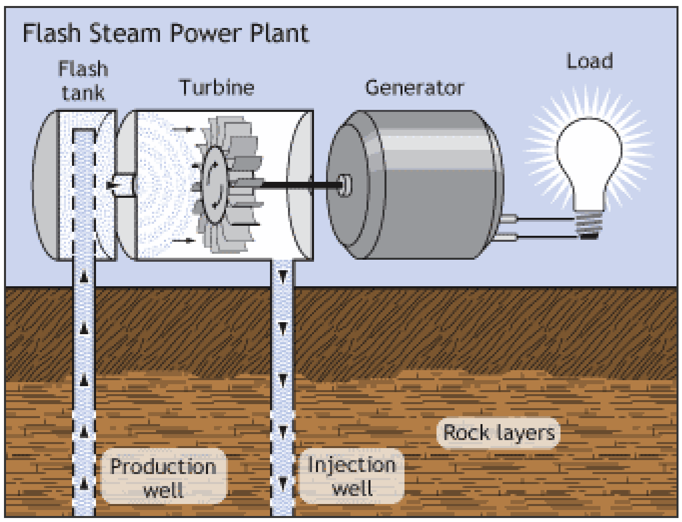

Fig 2.15 Flash steam power plant [5]

2.3.3 Binary Cycle Steam Power Plant

Binary cycle power plants are used when the geothermal resource is not hot enough to produce steam, or the resource contains too many chemical impurities to allow flashing. In the binary cycle process, the geothermal fluid is passed through a heat exchanger. The secondary fluid which has a lower boiling point than water is vaporized and expanded through a turbine to generate electricity [4]. The working fluid is condensed and recycled for another cycle. All of the geothermal fluid is then injected into the ground in a closed-cycle system. Binary cycle power plants can achieve higher efficiencies than flash steam plants and allow the utilization of lower temperature resources because nothing is emitted to the atmosphere [4]. As moderate temperature water is more common geothermal resource, the most geothermal power plants in the future will be binary-cycle plants. The schematic of binary cycle steam power plant is shown in Fig 2.16.

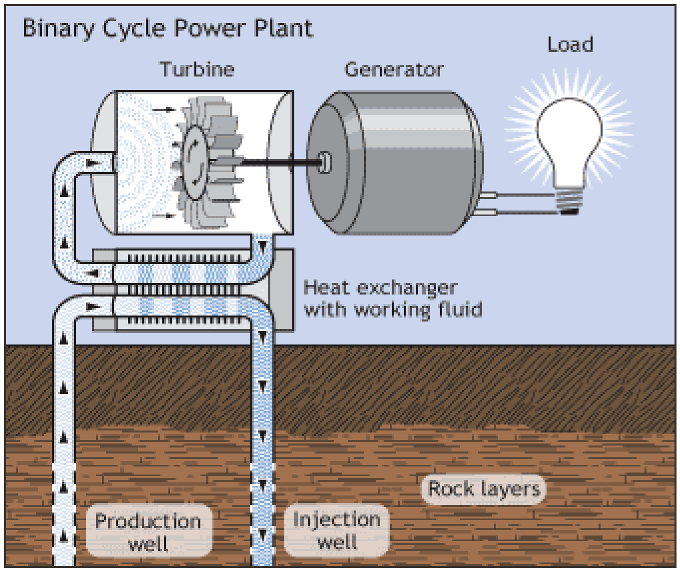

Fig 2.16 Binary cycle steam power plant [5]

2.3.4 Benefits of Geothermal Energy

The benefits of geothermal energy to produce electricity can be summarized as:

- Modern geothermal plants emit less than 0.2% of the carbon dioxide of the cleanest fossil fuel plant, less than 1% of the sulphur dioxide, and less than 0.1% of particulates, particularly with respect to greenhouse gas emissions [4].
- Geothermal energy has an infinitive energy storage capacity.
- Geothermal power stations are very reliable and secure

2.4 Economical Aspects

2.4.1 Wind Power

To analyze the costs of wind power installation in a specific site, investment, operation and generation costs are considered.

a) Investments

Investment includes all the cost related to the initial costs of installing a wind power system. It involves designing and studying costs, wind turbine costs, transportation and assembly costs, foundation and grid connection or grid independent application costs. Investment cost varies according to the size of wind power plant and the site conditions. An average investment cost for installation of wind turbines with different capacities is shown in Table 2.1.

TABLE 2.1 AVERAGE INVESTMENT COST FOR WIND TURBINES [6]

Capacity (kW)	Investment Cost ($/kW)
1,500	1,090
2,500	1,040
4,500	980

The above investment costs are prices for each individual wind turbine. In the case of wind farm installation (a large amount of wind turbines) the above prices may decrease by up to 25% [6].

b) Operation Costs

Operation costs for a wind power generator contains maintenance and repair costs. The average annual cost for the mentioned wind turbines in Table 2.1 are estimated to be 5 to 8% of the total investment costs [6]. The annual operational cost includes labor and technician annual salary, insurance, land lease and property taxes, maintenance and repair. The annual operation cost for the mentioned wind turbines are shown in Table 2.2.

TABLE 2.2 AVERAGE ANNUAL OPERATION COSTS FOR DIFFERENT WIND TURBINES [6]

Capacity (kW)	**Yearly Operation Costs ($)**
1,500	95,000
2,500	151,000
4,500	295,000

c) Generation Cost

Power generation cost can be calculated by the total investment, annual operation cost according to annual energy production. Table 2.3 shows the power production cost for three mentioned wind turbines with different energy production hours. As it can be seen, the generation costs decrease with an increase in annual energy yields.

TABLE 2.3 AVERAGE POWER GENERATION COSTS FOR WIND TURBINES WITH DIFFERENT ENERGY YIELDS HOURS [6]

Capacity (kW)	Power Generation Costs ($/kWh)		
	1,800 hours per year	2,500 hours per year	4,500 hours per year
1,500	0.082	0.059	0.033
2,500	0.078	0.056	0.031
4,500	0.085	0.054	0.030

According to the above information presented in Table 2.3, the power generation costs decreases with increasing wind turbine capacity. Thus, to enhance wind power capacities, increasing the tower height can be considered as a viable solution to achieve higher wind energy.

2.4.2 Solar Power

In this section, power production costs for solar power plants including photovoltaic and solar thermal power plant are discussed. It is worth noting that the economic study of solar system is difficult and is related to the site condition.

2.4.2.1 Photovoltaic Power Technology

To analyze economical aspects of photovoltaic power plants, primary investments, operation and generation costs are discussed as the main economical features.

a) Investments

The installation costs for photovoltaic technology mainly include the modules, inverter, design and studying, as well as transportation and assembly. Table 2.4 shows the investment costs for 3 different photovoltaic systems [6].

TABLE 2.4 INVESTMENT COSTS FOR PHOTOVOLTAIC WITH DIFFERENT CAPACITY [6]

System Capacity (kW)	Investment Costs ($)				
	Modules	Inverter	Other Component	Design and studying	Total
3	7,800	1,100	1,200	2,900	13,000
20	46,300	7,800	7,900	16,000	78,000
2,000	4,134,000	741,000	872,000	1,667,000	7,414,000

As it can be seen in the Table 2.4, the main part of the investment costs is accounted for from module costs which contributes with 55 to 65% of the total investment costs [6].

b) Operation Costs

Operation costs include maintenance and servicing. These costs contain repairs, module cleaning, meter rent and insurance. They can vary according to the size and type of the plant. The average operation costs in a year for 3 solar power plants are shown in Table 2.5. As it is shown in Table 2.5, the annual operation costs rate for photovoltaic system with higher capacity is much higher.

TABLE 2.5 ANNUAL OPERATION COST FOR PHOTOVOLTAIC WITH DIFFERENT CAPACITY [6]

System Capacity (kW)	Yearly Operation Costs ($)
3	30
20	800
2,000	108,000

c) Power Production Costs

Electricity power generation cost can be calculated on the basis of investment and operation costs. The power production costs of photovoltaic generators for 3 different systems with different full load hours are shown in Table 2.6.

TABLE 2.6 POWER GENERATION COST FOR PHOTOVOLTAIC WITH DIFFERENT CAPACITY [6]

Capacity (kW)	Power Generation Costs ($/kWh)		
	800 Full load hours per year	1,000 Full load hours per year	1,200 Full load hours per year
3	0.42	0.34	0.28
20	0.41	0.33	0.27
2,000	0.36	0.30	0.25

2.4.2.1 Solar Thermal Power Plant

According to the three solar thermal power plant technologies introduced in section 2.2.2, the economical aspects of these three systems including initial investments, operation costs and power generation costs are discussed.

a) Initial Investment

Initial investments for building solar thermal power plants for different technologies with details are shown in Table 2.7.

TABLE 2.7 INVESTMENT COST FOR THERMAL POWER PLANTS WITH DIFFERENT TECHNOLOGIES [6]

Three Different Technologies		**Investment ($/kW)**
Parabolic Through	Power Plant	1,200
	Solar field including heat transfer	3,100
	Solar field preparation	100
	Thermal energy storage	80
	Total	5,200
Parabolic Dish	Mirror, structure, drives and foundation	2,500
	Stirling motor	1,100
	Transport and assembly	400
	Planning and studying	600
	Contingencies	400
	Total	5000
Solar Central Receiver	Heliostat field	1,000
	Receiver and steam generator system	670
	Tower	500
	Other components	670
	Transport and assembly	330
	Planning and studying	165
	Total	3,300

b) Operation Costs

Annual operation costs for three solar thermal power plants are estimated and shown in Table 2.8. Operation and maintenance costs are estimated to be approximately 1.5% of the initial investments [6]. These costs include mirror cleaning, insurance, land lease and property taxes and maintenance and repair.

TABLE 2.8 ANNUAL OPERATION COST FOR THERMAL POWER PLANTS WITH DIFFERENT TECHNOLOGIES [6]

System Technology	Yearly Operation Costs ($/kW)
Parabolic Through	100
Parabolic Dish	75
Solar Central Receiver	50

c) Electricity Generation Costs

The average generation costs for different technologies are calculated based on the initial investments and operation costs. They are shown in Table 2.9.

TABLE 2.9 ENERGY GENERATION COST FOR THERMAL POWER PLANTS WITH DIFFERENT TECHNOLOGIES [6]

System Technology	Estimated Generation Cost ($/kWh)
Parabolic Through	0.12
Parabolic Dish	0.18
Solar Central Receiver	0.13

2.4.3 Geothermal Power Plant

This section contains economical aspects of installation and operation of geothermal power plants. The initial investments, operation and generation costs are summarized in the following subsections.

a) *Initial Investments*

According to different geological condition, the cost of drilling the wells is variable and it is estimated to be about 1,500 $/m for the well between 4,000 and 5,000 m [6]. The average costs of initial investments for geothermal power plants are shown in Table 2.10.

TABLE 2.10 INITIAL INVESTMENT COSTS FOR GEOTHERMAL WITH DIFFERENT TECHNOLOGIES [6]

Investments	Average Costs [$/kW]
Digging	15,400
Pump	240
Geothermal fluid circuit	1,200
Filtering system	220
Power plant	1,900
Heat exchanger	230
Studying, planning and building	1,450
Total	20,640

b) *Operation Costs*

Annual operation costs including personnel and staff annual salary, land lease and property taxes, and maintenance and repair of the power plant facilities are estimated to be 340 $/kW [6].

c) Energy *Generation* Costs

Considering the investment and annual operation costs, energy generation cost for geothermal power plants is about 0.22 $/kWh [6].

2.4.4 Economical Comparison between Wind, Solar and Geothermal Power

In this section, comparison between wind, solar and geothermal power is discussed in detail. The initial investments, annual operation costs and energy generation costs are compared with each other. The initial investment to build each of the mentioned power plants is compared in Table 2.11.

TABLE 2.11 INITIAL INVESTMENT COSTS COMPARISON FOR DIFFERENT TECHNOLOGIES

Power Plant Technology		**Initial Investment ($/kW)**
Wind Power		1,100
Solar Power	Photovoltaic	4,000
	Parabolic Through	5,200
	Parabolic Dish	5,000
	Central receiver	3,300
Geothermal Power		20,640

Operation costs for wind, solar and geothermal power are presented in Table 2.12.

TABLE 2.12 COMPARISON OF OPERATION COSTS FOR DIFFERENT TECHNOLOGIES

Power Plant Technology		**Annual Operation Cost ($/kW)**
Wind Power		63
Solar Power	Photovoltaic	50
	Parabolic Through	100
	Parabolic Dish	75
	Central receiver	50
Geothermal Power		340

The main economical factor for all of these power plants is the cost of energy generation. According to the detailed information about generation cost for each power generation system, comparison of these costs is shown in Table. 2.13.

TABLE 2.13 COMPARISON OF ENERGY GENERATION COSTS FOR DIFFERENT TECHNOLOGIES

Power Plant Technology		**Estimated Energy Generation Costs ($/kWh)**
Wind Power		0.055
Solar Power	Photovoltaic	0.33
	Parabolic Through	0.12
	Parabolic Dish	0.18
	Central receiver	0.13
Geothermal Power		0.22

3 The Review of Existing Federal and State Incentive Programs

The federal and state incentive programs for renewable energy applications are discussed in this section. Federal and state grants, incentive and loan programs for renewable energy and energy efficiency is presented [7].

3.1 Federal Incentives for Renewable and Energy Efficiency

This section will present the federal incentives for renewable applications as well as for efforts in energy efficiency. The federal incentives are classified under three main programs: Grant, energy production and loan programs.

3.1.1 Federal Grant Program

There are two main incentives under Federal Grant Programs and these programs are explained below:

3.1.1.1 Renewable Energy Grant- Department of Treasury

American Recovery and Reinvestment Act of 2009 (H.R. 1), enacted in February 2009, created a renewable energy grant program that will be administered by the U.S. Department of Treasury [7]. Grants are available to eligible property placed in service in 2009 or 2010, or placed in service by the specified credit termination date, if construction began in 2009 or 2010 [7]. It is important to note that only tax-paying entities are eligible for this grant. Federal, state and local government bodies, non-profits, qualified energy tax credit bond lenders, and cooperative electric companies are not eligible to receive this grant [7].

3.1.1.2 Rural Energy for America Program (REAP) Grants

The Food, Conservation, and Energy Act of 2008 (H.R. 2419), enacted by Congress in May 2008, converted the federal Renewable Energy Systems and Energy Efficiency Improvements Program, into the Rural Energy for America Program (REAP). Similar to its predecessor, the REAP promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of (1) grants and loan guarantees for energy efficiency improvements and renewable energy systems, and (2) grants for energy audits and renewable energy development assistance [7].

96% of the total REAP funding available, is dedicated to grants and loan guarantees for energy efficiency improvements and renewable energy systems. These incentives are available to agricultural producers and rural small businesses to purchase renewable energy systems (including systems that may be used to produce and sell electricity), to make energy efficiency improvements, and to conduct relevant feasibility studies. Eligible renewable energy projects include wind, solar, biomass and geothermal; this includes hydrogen derived from biomass or water using wind, solar or geothermal energy sources. These grants are limited to 25% of a proposed project's cost, and a loan guarantee may not exceed $25 million [7].

According to the current database of federal incentives for renewable and energy efficiency [7], there is no federal grant program that can be used by NDOT at this time.

3.1.2 Production Incentive

Established by the Federal Energy Policy Act of 1992, the Federal Renewable Energy Production Incentive (REPI) provides incentive payments for electricity generated and sold by new qualified renewable energy facilities. The Eligible renewable energy technologies include Solar Thermal Electric, Photovoltaic, Wind, Geothermal Electric, Biomass, etc. Qualified systems are eligible for annual incentive payments of 2.1¢ per kilowatt-hour and it is only for electricity generated from an eligible facility first used before October 1, 2016. If there are insufficient appropriations to make full payments for electricity production from all qualified systems for a federal fiscal year, 60% of the appropriated funds for the fiscal year will be assigned to facilities that use solar, wind, ocean, geothermal.

3.1.3 Federal Loan Program

There are some loans programs for installation of renewable energy facilities provided by the federal government that can be used by NDOT. The federal loan programs are discussed as follows:

3.1.3.1 Loan Guarantee Program

The U.S. Department of Energy (DOE) is authorized by the federal Energy Policy Act of 2005 (EPAct 2005) to issue loan guarantees for projects that avoid or reduce air pollutants or anthropogenic emissions of greenhouse gases; this includes employing new or significantly improved technologies as compared to commercial technologies in service in the United States.

The loan guarantee program has been authorized to offer more than $10 billion in loan guarantees for energy efficiency, renewable energy and advanced transmission and distribution projects.

In July 2009, the U.S. DOE issued a new solicitation for projects that employ innovative energy efficiency, renewable energy, and advanced transmission and distribution technologies. The solicitation provides for a total of $8.5 billion in funding and is to remain open until that amount is fully obligated. DOE is authorized to issue temporary loan guarantees and appropriated $6 billion for this program. Under this act, DOE may enter into guarantees until September 30, 2011.

3.1.3.2 Clean Renewable Energy Bonds (CREBs)

Clean renewable energy bonds (CREBs) can be used by NDOT to finance renewable energy projects. CREBs are issued with 0% interest rate and the borrower pays back only the principal of the money, and the bondholder receives federal tax credits instead of the traditional bond interest.

Participants must first apply to the Internal Revenue Service (IRS) for a CREBs allocation, and then issue the bonds within a specified time period. This new CREBs allocation totaling $2.4 billion does not have a defined expiration date under the law. The tax credit rate is set daily by the U.S. Treasury Department.

3.1.4 Rules, Regulation and Policies

According to federal rules and regulations, there is a technical standard for renewable energy connection to power systems. The Federal Energy Regulatory Commission (FERC) adopted "small generator" interconnection standards for distributed energy resources up to 20 megawatts (MW) in capacity. The FERC's standards apply only to facilities that interconnect at the transmission level. These standards generally do not apply to distribution-level interconnection, which is regulated by state public utilities commissions. However, the FERC has noted that its interconnection standards for small generators should serve as a useful model for state-level standards.

The FERC's standards contain the technical procedures that the small generator and utility must follow in the case of connecting the generator to the utility's lines. This standard contains the contractual provisions for the interconnection and spells out who pays for improvements to the utility's electric system, if needed to complete the interconnection.

3.2 Nevada State Incentives for Renewable and energy Efficiency (NV Energy)

This section presents the incentives for renewable energy production provided by NV Energy.

3.2.1 Renewable Generation Rebate program

NV Energy is offering for the renewable generations rebate program for wind and hydroelectric systems on behalf of the Nevada task force on energy conservation and renewable energy. The rebate program sets different incentive rates for wind generation and hydro generation and they are subjected to change in each year.

The incentive rate of wind generation for schools and public buildings is $4.00 per each installed watt. The maximum incentive level for public buildings is 500 kW. The installed renewable system can be larger than 500 kW, but up to 500 kW of capacity can be supplied by NV energy incentive program. There are no minimum size requirements for installations. All applications must follow NV Energy standards as well as all applicable laws and regulations. Applications are accepted on a first come first served basis.

Solar generation incentive program is closed and NV Energy is not accepting applications at this time.

3.2.2 Regulation and Requirements

To be eligible to use NV energy rebate programs, there are some specific regulation and requirements that should be complied by NV energy customers. These regulation and requirements are based on information from [8].

1. The incentive can only be paid for a system constructed after application to the program.
2. According to Net Metering program, NV Energy is not allowed to pay to the customers for the generated electricity beyond what they consume from the utility.

There are other standards specified for solar panel and wind turbine installation. These requirements are listed as following [8]:

3.2.2.1 Solar and Wind Generation Policies

1. The solar panels, wind turbines and inverters in the project must be listed on the California Energy Commission (CEC) list of eligible solar equipment.
2. The solar system and wind turbine must have never been installed at another location.
3. The solar system and wind turbine must have the following warranties:
   - Solar panels – 20 years
   - Wind generating equipment – 5 year
   - Inverters – 7 years
   - Labor (Labor and Workmanship as defined by the Nevada State Contractors Board) – 2 years
4. NV Energy reserves the right to inspect an installation for compliance with 24 hour emergency access, utility standards, and program requirements.
5. To ensure public safety and the distribution system's reliability, NV Energy may have to disconnect the customer-owned generation from the distribution system in order to work on NV Energy owned equipment at any time and without notice.
6. Before a customer may receive an incentive, NV Energy will conduct a final safety verification to ensure that:
   - AC disconnect and generation meter socket are located within 10 feet of the revenue meter
   - AC disconnect is accessible, lockable, visible-blade type, and is manually operated from outside the enclosure
   - AC disconnect operates properly
   - Generation meter and AC disconnect are wired correctly to meet NV Energy standards
   - Generation meter tag is installed (by NV Energy)
   - AC disconnect tag is installed properly (by NV Energy)
   - Revenue meter tag is installed (by NV Energy)
   - Transformer tag is installed properly, if applicable (by NV Energy)
   - System meets all applicable NV Energy standards

4 Investigation of Wind Resources

The objective of this section is to assess the wind resources of Nevada that are suitable for development at NDOT facilities.

Wind is an intermittent (non-continuous) resource, with average capacity factors generally ranging from 25 % to 40 %. The capacity factor of an installation depends on the wind regime in the area and energy capture characteristics of the wind turbine. Capacity factor directly affects economic performance; thus, *reasonably strong* wind sites are required for cost-effective installations. Since wind is intermittent, it cannot be relied upon as firm capacity (continuous) for peak electrical power demands. There are essentially three types of implementations to efficiently use wind energy;

- Electrical power generation with wind coupled with energy storage. The idea behind this combination is to utilize the generated wind energy when there is demand and to store it when there is no demand (e.g. at night).
- Electrical power generation with wind coupled with the local power utility. The idea behind this combination is to utilize the generated wind energy when the wind is available and to buy electrical energy from the utility when there is no wind.
- Electrical power generation with wind coupled with other resources and energy storage applications. The idea behind this combination is to utilize various renewable and non-renewable electrical power generation systems to be independent of the local utility. These applications are generally referred as "hybrid power generation". Hybrid generation usually consists of wind and solar (to compensate for each other) as well as a conventional generator (e.g. diesel generator) coupled with an energy storage application.

These combinations are investigated and the optimal solution is assessed with respect to the costs and availability of the renewable resources. This section presents the opportunities of wind energy applications at NDOT facilities. Economic aspects of wind generation are also discussed.

4.1 Wind Turbine Performance

The operation of wind turbines changes in different wind speeds which results in different power outputs in different wind regimes. Wind turbines usually operate with less than half of their nominal capacity. The average output power and energy of wind turbines are shown in the Table 4.1 [11]. As it is observed in Table 4.1, the wind turbine performance improves with an increase in average wind speed.

TABLE 4.1 OUTPUT POWER OF WIND TURBINES WITH RESPECT TO DIFFERENT WIND SPEEDS

Average Wind Speed (m/s)	**Average Output Power (kW/ kW wind capacity)**	**Average Monthly Energy Output (kWh/kW wind capacity)**	**Percentage of Operating Time (%)**	**Capacity Factor (%)**
3	0.032	23.3	33	3
4	0.079	57.4	54	8
5	0.15	108.7	67	15
6	0.24	173	76	24
7	0.33	240	80	33
8	0.42	300	85	40
9	0.5	360	87	50

The nomenclature of the terms in Table 4.1 is as follows.

- **Average output power** is how much power is generated by the wind turbine on average, if **1 kW** wind turbine is installed.
- **Average monthly energy output** is the amount of energy production in a month. If a wind unit generates ***P*** amount of electric power generation (kW) over a period of time (e.g. an hour), the output energy is calculated as the multiplication of output power and the period of time (kWh); $E = P \times t$.
- **Percentage of operating time** is the portion of time in a month that the wind turbine operates and generates electricity. (*This characteristic is already included in the calculation of average output power*.)
- **Capacity Factor** is an index that shows how much of wind turbine nominal capacity is being used to generate electricity.

If **2,500 kWh** of electrical energy is needed for a facility for one month, which is located in a region with average wind speed of **7 m/s**, the average monthly energy output of the wind production is **240 kWh/(1 kW wind capacity)** according to Table 4.1. A wind turbine with rated capacity of **2,500/240 ≈ 10 kW** should be installed to meet the requirement.

According to the monthly consumption of NDOT facilities (i.e. offices, staffed/unstaffed stations etc.), the required wind power can be easily determined. If we consider district office in Las Vegas, the average wind speed in the region is approximately **4 m/s**. As mentioned earlier due to the lack of actual electrical energy consumption at NDOT facilities; it is roughly estimated that the district office consumes approximately **10,000 kWh** per month. Table 4.1 provides that the monthly energy output for a wind speed of **4 m/s** is **57.4 kWh/(1 kW wind capacity)**. 10,000/57.4 = 174 kW is the required amount of wind power to supply this office. One wind turbine with a **174 kW** capacity or a number of smaller wind turbines with total capacity of **174 kW** can be used.

Another example is NDOT office in Carson City. The average wind speed in Carson City is approximately **5 m/s**. Electricity consumption at one of the headquarters is approximately **300,000 kWh per month**. Considering the monthly energy output of wind turbine from Table 2.1, a **3 MW** wind turbine is required.

In the Figure 4.1, a satellite picture of main NDOT office in Carson City is given. The location of the wind turbine installation can be determined with respect to the wind speed. Land restrictions play an important role in wind site selections.

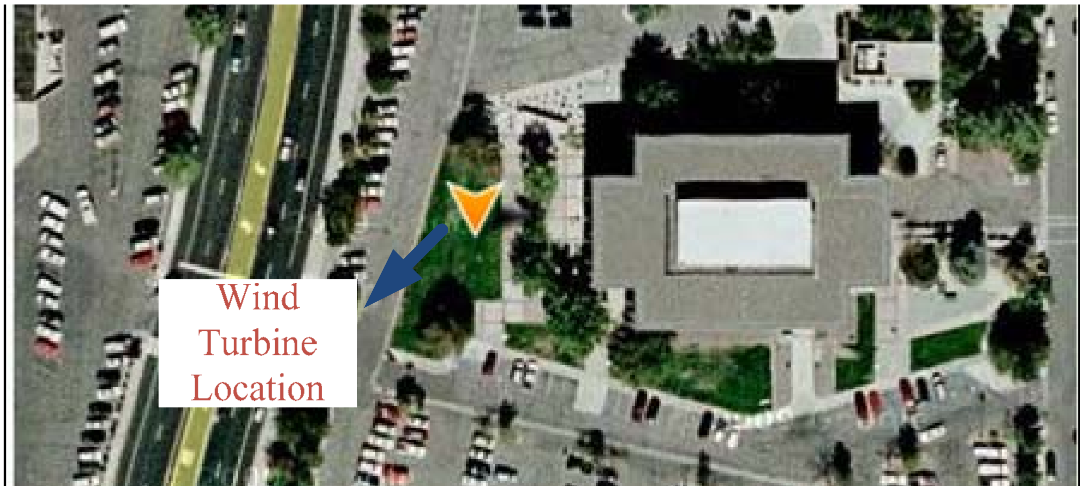

Fig 4.1 Google map satellite picture of NDOT office in Carson City showing the available location for wind turbine

4.2 Resource Availability

Turbine power output is proportional to the cube of the wind speed. Due to this nonlinear relationship small changes in wind speed result in large variations in the turbine power output. Wind strength is rated on a scale from **Class 1** to **Class 7**, as shown in Table 4.2 [12]. It is important to note that the height of the wind measurement affects the classification. The data in Table 4.2 is provided for wind measurements at **50 m** (**164 ft**).

The average wind speeds at **50 m** in Nevada is given in Fig. 4.2. As it can be observed in Fig. 4.2, Nevada has a large wind potential, although most of the sources are classified as low classes (Class 2 or less). The cost efficient applications for large-scale wind production require at least **Class 3** wind power. Currently Nevada does not have large-scale (in the ranges of **MW**s) wind facilities in operation. Even though the wind class is low, small-scale wind applications can be easily pursued to diversify the electrical power production. Further investigation is necessary to determine how much of the theoretical wind capacity is actually deplorable.

TABLE 4.2 CLASSES OF WIND POWER

Wind Power Class	Height Above Ground: 50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed (m/s)
1	0 to 200	0 - 5.6
2	200 to 300	5.6 - 6.4
3	300 to 400	6.4 - 7.5
4	400 to 500	7 - 7.5
5	500 to 600	7.5 - 8
6	600 to 800	8 - 8.8
7	800 to 2000	> 8.8

The initial information about the wind speed conditions at each NDOT site, including district offices, maintenance stations and unstaffed stations are summarized in Tables 4.3, 4.4 and 4.5. These tables are based on [3, 4] and they provide the theoretical potential capacity of wind power at each location. This theoretical/technical potential is not limited by the constraints such as product availability (e.g. backordered turbines), site-specific constraints (e.g. insufficient space), environmental restrictions, or cost.

TABLE 4.3 WIND SPEED DATA FOR NDOT DISTRICT OFFICES

Site Location	Wind Speed	
	mph	m/s
Reno	8.3 - 12.3	3.7 - 5.5
Las Vegas	9 - 11	4 - 5
Elko	9.5 - 13	4 - 6
Carson City	11 - 15	4.7 - 6.3

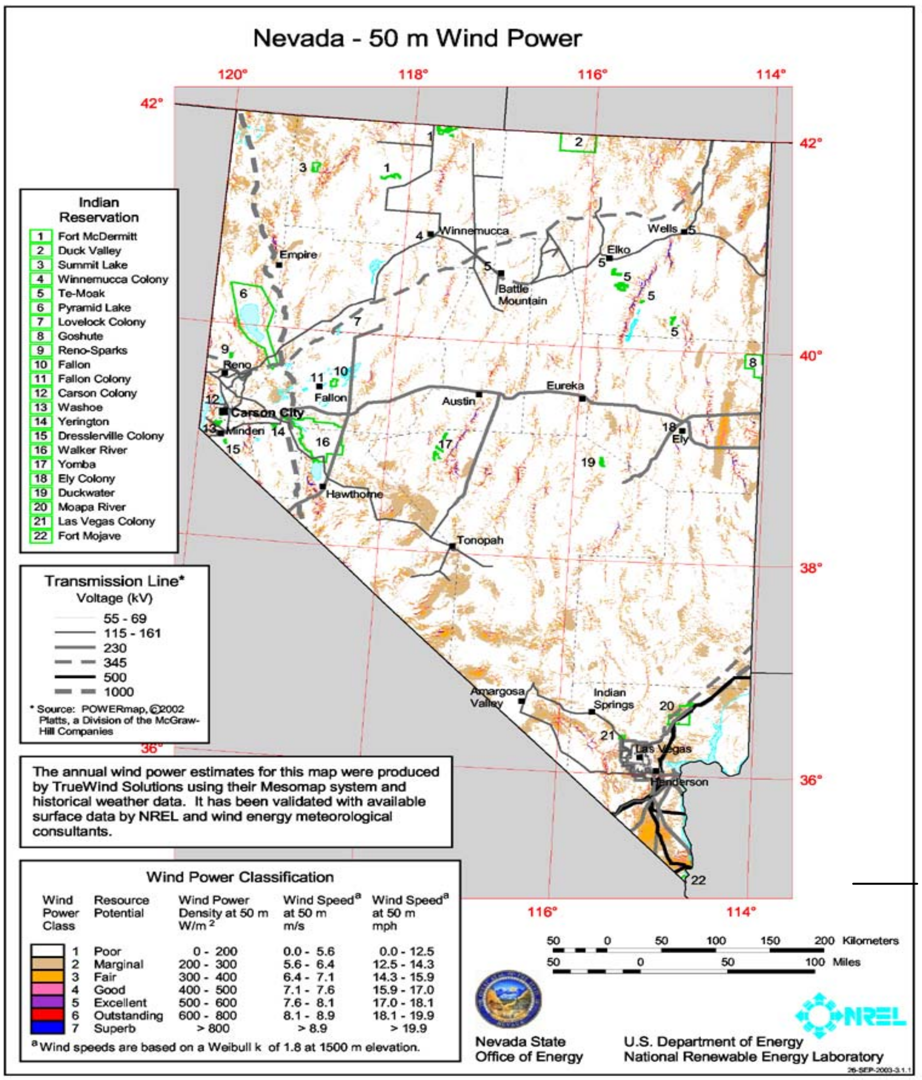

Fig 4.2 Wind resources in Nevada at 50 m developed by national renewable energy laboratory [12]

TABLE 4.4 WIND SPEED DATA FOR NDOT MAINTENANCE STATIONS

Site Location	Wind Speed	
	mph	m/s
Fernley	9 - 13	4 - 5.5
Lovelock	8 - 10	3.5 - 4.5
Fallon	7.5 - 9.5	3.4 - 4.3
Cold Spring	9 - 11	4 - 5
Virginia City	11.5 - 16.4	5 - 7
Gardnerville	7 - 10	3.2 - 4.4
Wellington	9.4 - 13.8	4 - 6
Yerington	7 - 10	3 - 4.5
Hawthorne	8 - 12	3.6 - 5.4
Mina	10 - 14	4 - 6.5
Montgomery Pass	10 - 16	4 - 7
Big Smoky	9 - 12	4 - 5.5
Tonopah	11 - 15	5 - 7
Goldfield	12 - 16	5.5 - 7.5
Beatty	10 - 15	4.5 - 7
Blue Jay	9 - 12	4 - 5
Charleston	10 - 13	4.5 - 6
Mountain Springs	11 - 17.5	5 - 8
Searchlight	13.5 - 18	6 - 8
Alamo	11 - 15	5 - 7
Panaca	9 - 12	4 - 5.5
Lund	13 - 19	6 - 8
East Ely	10 - 14	4.5 - 7
Eureka	9 - 11	4 - 5
Austin	10 - 16	4.5 - 7
West Wendover	10 - 15	4.7 - 6.5
Ruby Valley	11 - 16	5 - 7
Wells	12 - 16	5 - 7
Emigrant Pass	10 - 14	4.5 - 6
Battle mountain	8.5 - 11	4 - 5
Winnemucca	10 - 14	4.5 - 6
Independence valley	9 - 12	4 - 5.5
Contact	11 - 16	5 - 7
North Fork	11 - 14	4.7 - 6.3
Orodava	9 - 12	4 - 5.5
Quinn River	11 - 15	4.7 - 5.7

Maximum wind resources (Searchlight – Lund)

Wind energy applications are not suitable at all of the NDOT facilities. Enough wind resource, environmental concerns, aesthetics, proximity to residential areas and current land use are only a few of the constraints for wind applications. A preliminary list of possible sites is created based on significant wind resources (locations with minimum 6.3 m/s annual wind speed that is considered marginal). Each site on this list should then be reviewed with respect to the following factors:

- Proximity to federal areas
- Proximity to environmentally sensitive areas
- Proximity to Indian reservations

TABLE 4.5 WIND SPEED DATA FOR NDOT MAINTENANCE STATIONS (UNSTAFFED)

Site Location	Wind Speed	
	mph	m/s
Galena Creek	13 - 20	5.6 - 9
Mount Rose	14 - 21	6.5 - 9.5
Incline Village	12 - 17	5.5 - 7.5
Spooner Summit	12 - 20	5.5 - 8.7
Kingsbury	12 - 19	5.4 - 8.5
Indian Springs	7 - 10	3.3 - 4.6
Currant Creek	8 - 12	3 - 5.5
Baker	11.5 - 17.5	5 - 8

Maximum wind resources (Mount Rose, Incline Village, Spooner Summit, Kingsbury)

The constructability at each site is measured by the ability to access the wind resource and to construct turbines on the land.

Nameplate capacity can be determined for each site by estimating how much energy is used by NDOT facilities. The amount of land available to install turbines will vary based on terrain features, while the final spacing of turbines (how far apart each turbine is located) is dependent on many other site specific characteristics (i.e. down-hill, up-hill, type of the soil etc.)

Estimates of the energy production are carried out by using manufacturer wind generation curve as a function of average wind speed, Weibull (distribution function) parameter and air density at a specific site. In order to estimate the annual energy production, average wind speed at each specific NDOT site is used.

4.3 Projects Identified

In this section, six projects are identified for wind power installation. These projects are identified considering the average wind speed of more than **6 m/s** with an average capacity factor of 24 % in Table 4.1. The locations and the capacity factor information of these individual projects are provided in Table 4.6. General locations of each of the identified projects with the average wind speed at those identified projects are shown on the NDOT facility map in Fig 4.3.

TABLE 4.6 THE CHARACTERISTICS OF THE IDENTIFIED WIND POWER PROJECTS

Project Site Name	Wind Turbine Net Capacity Factor (%)
Searchlight	30
Lund	30
Galena Creek	35
Mount Rose	40
Spooner Summit	32
Kingsbury	32

Table 4.7 provides initial investments, operation and maintenance cost, federal and state incentives for identified wind power projects. The data in Table 4.7 are calculated by using 2010 values, before any future cost and performance modifications are made. In the Table 4.7, initial investment and annual operation and maintenance cost of wind power is estimated based on monthly load demand. Eligible incentive for identified projects is estimated based on federal and state incentive programs.

TABLE 4.7 WIND POWER ESTIMATED COST, FEDERAL AND STATE INCENTIVE FOR IDENTIFIED PROJECTS

Attributes / **Site Location**	**Monthly Energy Output [kWh/ kW installed wind capacity]**	**Load Demand [kWh/month]**	**Wind Turbine Capacity [kW]**	**Initial Investment [$1000]**	**Operation & Maintenance Costs [$/year]**	**Annual Federal Incentive [$]**	**NV Energy Incentive [$1000]**
Searchlight	235	***x***	***P***= ***x*** /235	1.1× ***P***	50× ***P***	0.25 ***x***	4.6×***P***
Lund	235	***x***	***P*** = ***x***/235	1.1× ***P***	50× ***P***	0.25 ***x***	4.6×***P***
Galena Creek	255	***x***	***P*** = ***x***/255	1.1× ***P***	50× ***P***	0.25 ***x***	4.6×***P***
Mount Rose	300	***x***	***P*** = ***x***/300	1.1× ***P***	50× ***P***	0.25 ***x***	4.6×***P***
Spooner Summit	235	***x***	***P*** = ***x***/235	1.1× ***P***	50× ***P***	0.25 ***x***	4.6×***P***
Kingsbury	235	***x***	***P*** = ***x***/235	1.1× ***P***	50× ***P***	0.25 ***x***	4.6×***P***

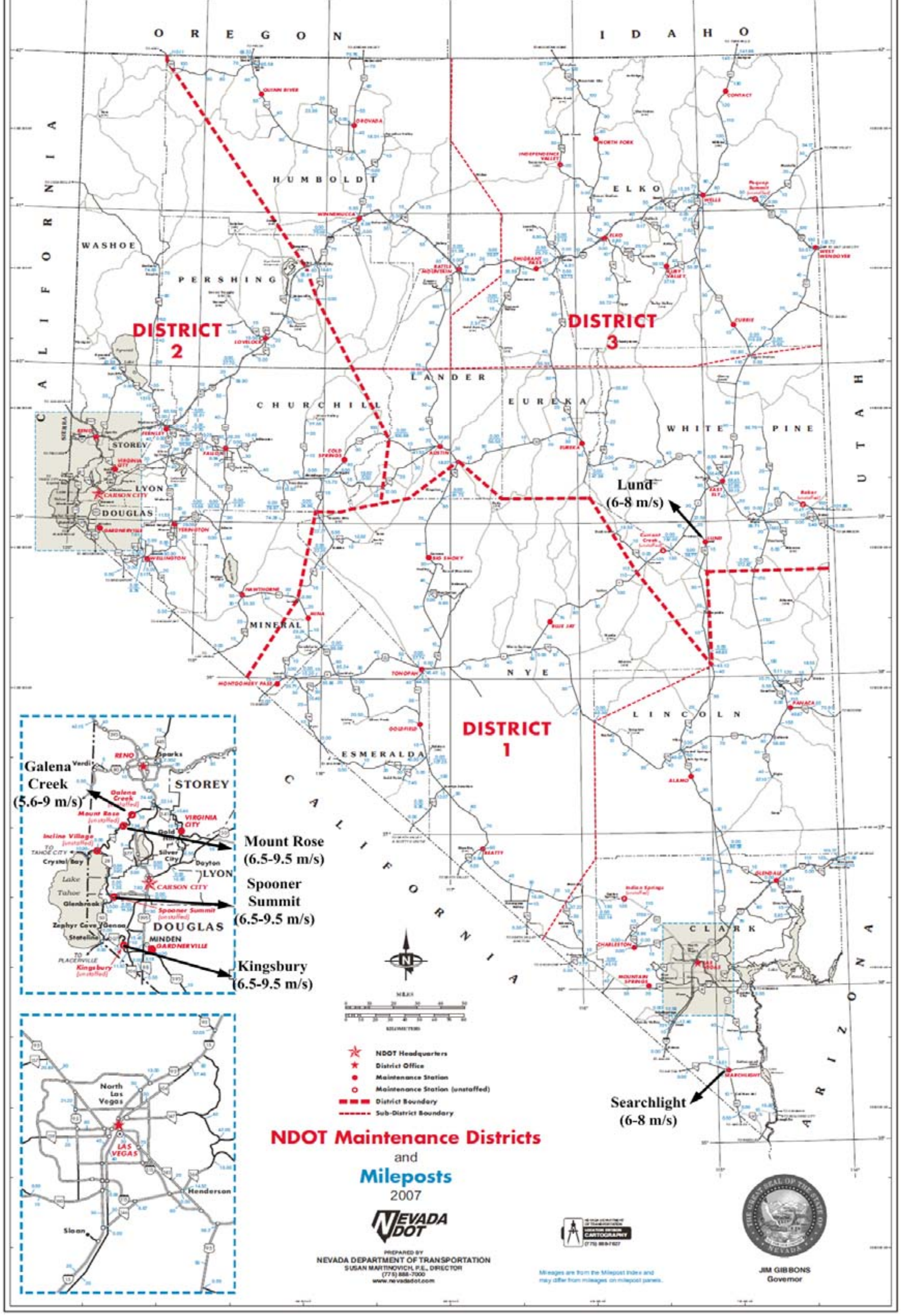

Fig 4.3 Identified wind projects at NDOT offices and stations

5 Investigation of Solar Resources

There are two main types of electrical power production from sun: Solar Thermal and Solar Photovoltaic. The essential idea behind the solar thermal is concentrating the sun rays to boil water instead of burning coal to obtain steam to drive the electrical generators. Solar thermal systems are not cost-efficient for small-scale applications. This is the primary reason we concentrate only on solar photovoltaic applications for NDOT and this section presents the possible solar photovoltaic (PV) applications at NDOT facilities.

Even though the solar PV has had little penetration to the electricity market for many years due to its high cost, intermittency, and low capacity factor, there is recent growth in the PV industry due to the decreased costs in semiconductor industry which has a big effect on PV costs as well as federal and state incentives on renewable energy based electrical power production.

5.1 Typical Solar Panel Properties

In this section, three solar PV panels with different capacities are being considered. Electrical characteristics, dimensions and temperature coefficients are provided. Three solar panels are:

a. FEE-20-12	b. FEE-14-12	c. FEE-7-12	d. FEE-5-12

Stabilized power electrical characteristic of these panels are listed in the Table 5.1.

TABLE 5.1 STABILIZED POWER ELECTRICAL CHARACTERISTIC [17]

	FEE-20-12	FEE-14-12	FEE-7-12	FEE-5-12
Maximum peak power (W)	16	12	6	4
Maximum current at 16 (A)	0.99	0.75	0.38	0.25
Short circuit (A)	1.22	0.9	0.45	0.3
Open circuit (V)	22.8	22	22	22

Maximum peak power (W): The maximum power a solar PV panel can provide.

Maximum current at 16 V (A): The maximum current a solar PV panel can provide at rated voltage (16 V).

Short circuit (A): The maximum short circuit (when the panel output terminals are directly connected to each other instead of supplying a load) current that a solar PV panel can provide.

Open circuit (V): The maximum open circuit (when the panel output terminals are open instead of supplying a load) voltage.

The data in the Table 5.1 are obtained under standard test conditions. The solar PV panels are tested under full sunlight (1000 w/m^2 irradiance) at 70° Fahrenheit air temperature.

The physical characteristics of the solar panels in Table 5.1 are provided in Table 5.2.

TABLE 5.2 PHYSICAL CHARACTERISTICS OF SOLAR PANELS [17]

		FEE-20-12	FEE-14-12	FEE-7-12	FEE-5-12
Dimensions	mm	1015×312	930×317	495×317	343×317
	feet	3.3×1	3×1	1.6×1	1.1×1
Thickness	mm	14.3	12.5	12.5	12.5
	inch	0.56	0.49	0.49	0.49
Weight	kg	4.6	4.6	2.1	1.5
	lb	10.1	10.1	4.6	5.3

5.2 Resource Availability

Solar power is classified into thirteen classes according to the National Renewable Energy Laboratory, considering the average daily solar radiation. The solar classes are given in Table 5.3.

TABLE 5.3 CLASSES OF SOLAR PV GENERATION

Solar Power Class	Resource for a Flat-Plate Collector [kWh/m^2/day]
1	1 - 1.5
2	1.5 - 2
3	2 - 2.5
4	2.5 - 3
5	3 - 3.5
6	3.5 - 4
7	4 - 4.5

8	4.5 - 5
9	5 - 5.5
10	5.5 - 6
11	6 - 6.5
12	6.5 - 7
13	7 - 7.5

Figure 5.1 shows the solar resource for a flat plate collector in the U.S. As it can be observed in Figure 5.1, Nevada has relatively large solar potential. Considering the average solar radiation in a year, much of the solar resources in Nevada are considered to be **Class 10** or **11** which is considered to be cost efficient for solar power generation. Nevada currently produces **82 MW** of its electrical energy from solar facilities, mainly using concentrated solar (solar thermal) [8]. According to the State of Nevada Renewable Portfolio Standards (RPS), the solar portion should supply at least 6% of the electricity by 2025 [16].

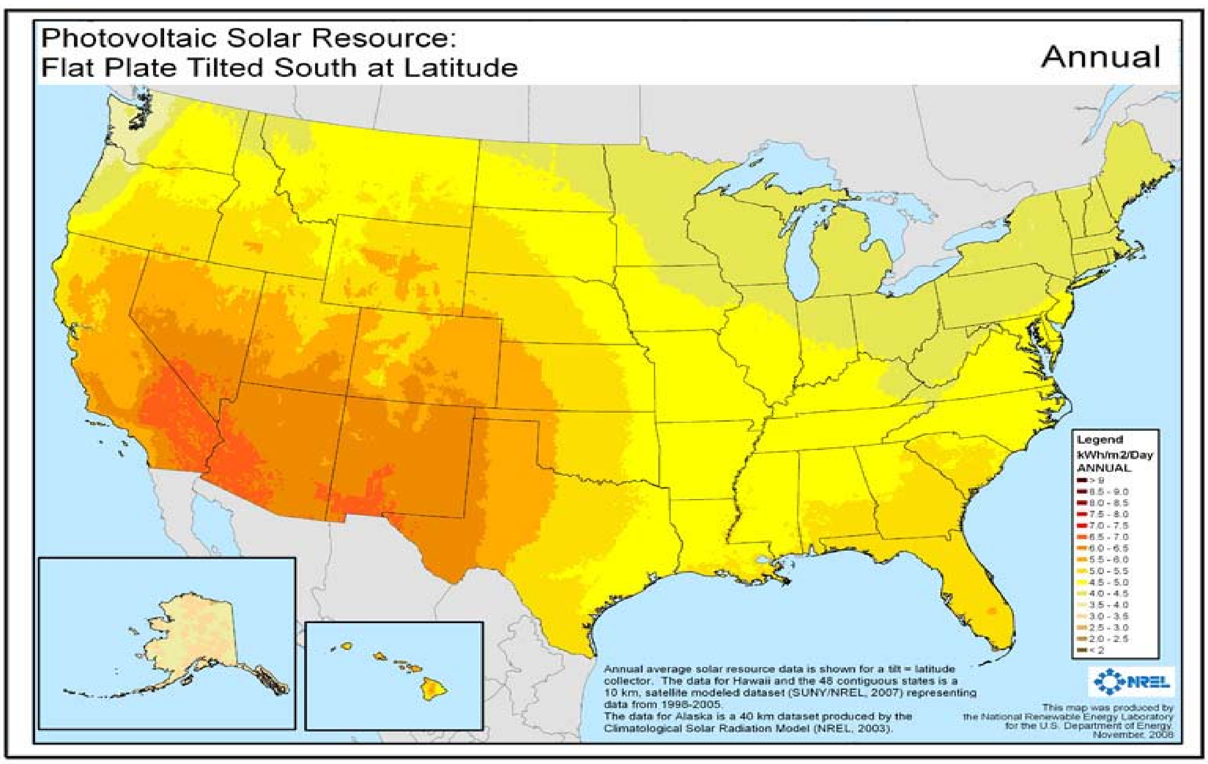

Fig 5.1 Photovoltaic solar resource map in the US [12]

The initial information about the solar radiation at each NDOT site, including district offices, maintenance stations and unstaffed maintenance stations are summarized in Tables 5.4, 5.5 and 5.6. Solar PV generation potential at each NDOT facility is provided. This theoretical/technical potential is considered not to be limited by the constraints such as site-specific limitations, environmental restrictions, or cost. In the Tables 5.4, 5.5 and 5.6, grey highlights are identified projects for NDOT facilities.

TABLE 5.4 SOLAR POTENTIAL AT NDOT DISTRICT OFFICES

Site Location	Average Solar Radiation [kWh/m²/day]	AC Energy [kWh/year/ 1 kW PV system]	Annual Energy Value [$]
Reno	5.6	1,457	203
Las Vegas	6.35	1,597	223
Elko	5.4	1,418	198
Carson City	5.76	1,495	209

TABLE 5.5 SOLAR POTENTIAL AT NDOT MAINTENANCE OFFICES

Site Location	Average Solar Radiation [kWh/m²/day]	AC Energy [kWh/year]	Energy Value [$]
Fernley	5.67	1,459	204
Lovelock	5.64	1,449	202
Fallon	5.58	1,437	201
Cold Spring	5.6	1,484	207
Virginia City	5.76	1,495	209
Gardnerville	5.56	1,465	205
Wellington	5.65	1,455	203
Yerington	5.65	1,455	203
Hawthorne	6.22	1,616	226
Mina	6.24	1,618	226
Montgomery Pass	6.24	1,618	226
Big Smoky	6.11	1,599	223
Tonopah	6.16	1,607	224
Goldfield	6.24	1,623	227
Beatty	6.73	1,684	235
Blue Jay	6.19	1,631	228
Charleston	5.52	1,458	204
Mountain Springs	6.35	1,597	223
Searchlight	6.32	1,608	225
Alamo	6.51	1,670	233
Panaca	6.48	1,691	236

Maximum solar resources

Glendale	6.30	1,582	221
Lund	5.72	1,515	212
East Ely	5.69	1,516	212
Eureka	5.95	1,593	223
Austin	5.83	1,548	216
West Wendover	5.98	1,577	220
Ruby Valley	5.46	1,455	203
Wells	5.39	1,428	199
Emigrant Pass	5.57	1,461	204
Battle mountain	5.6	1,458	204
Winnemucca	5.57	1,448	202
Independence valley	5.38	1,422	199
Contact	5.23	1,375	192
North Fork	5.39	1,425	199
Orodava	5.79	1,514	211
Quinn River	5.77	1,502	210

TABLE 5.6 SOLAR POTENTIAL AT NDOT MAINTENANCE STATIONS (UNSTAFFED)

Site Location	Average Solar Radiation [kWh/m^2/day]	AC Energy [kWh/year]	Energy Value [$]
Galena Creek	5.59	1,457	203
Currant Creek	5.72	1,515	212
Mount Rose	5.6	1,457	203
Incline Village	5.56	1,467	205
Spooner Summit	5.56	1,465	205
Kingsbury	5.56	1,456	205
Indian Springs	6.34	1,602	224
Baker	5.66	1,498	209

5.3 Projects Identified

A preliminary list for projects is determined for fifteen areas that have average solar radiation of more than 6 kWh/m^2/day in Nevada. Required solar PV and storage system is dependent on the amount of energy consumption at these NDOT facilities. Thus, a specific power capacity for each project is not given. Solar photovoltaic projects identified for this study are as follows:

Mina	Montgomery Pass	Big Smoky	Tonopah	Goldfield
Mountain Springs	Searchlight	Alamo	Panaca	Glendale
Beatty	Indian Springs	Blue Jay	Las Vegas	

Identified solar PV projects are pointed out on the facility map of NDOT in Figure 5.2.

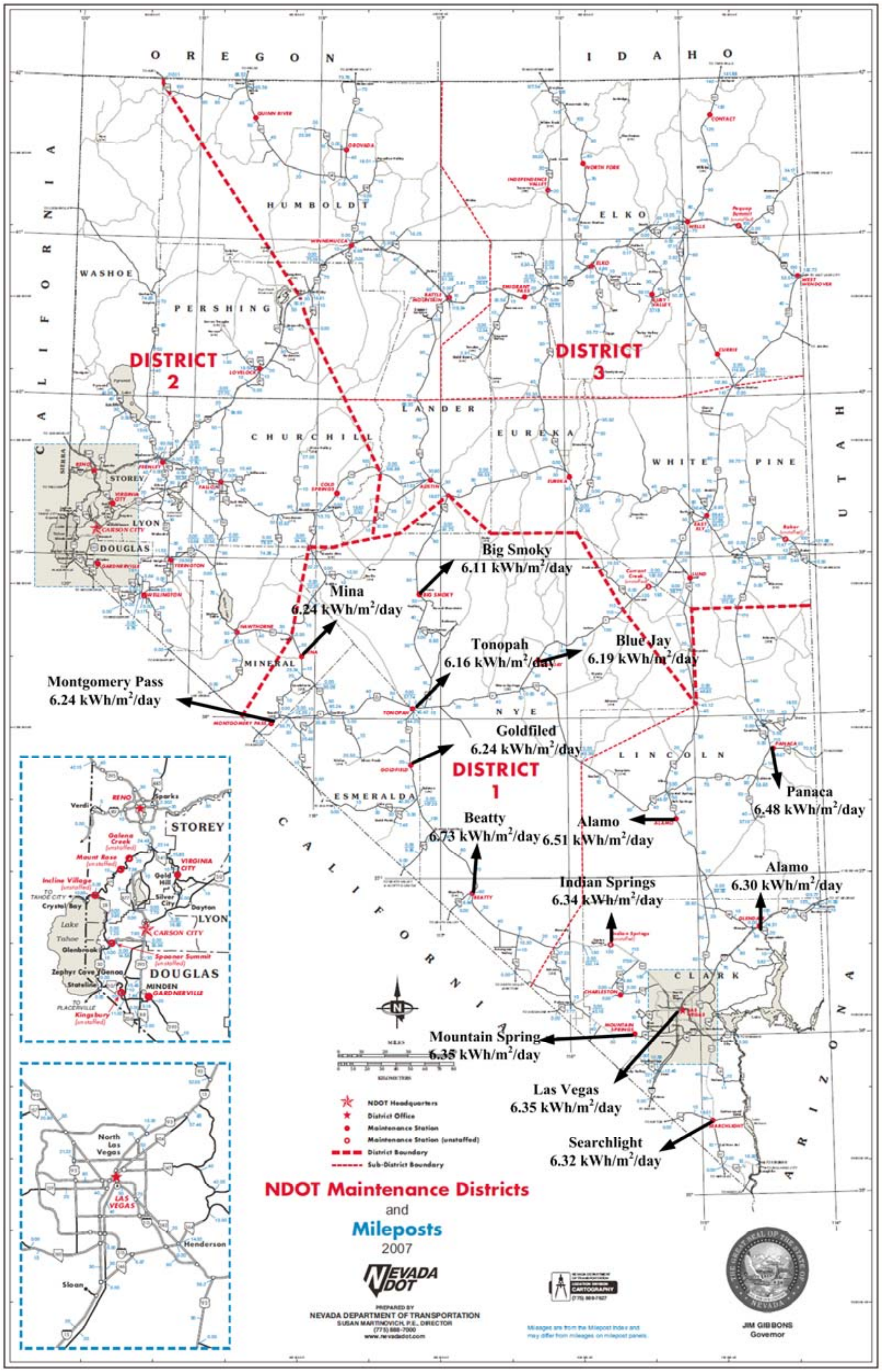

Fig 5.2 Identified solar projects at NDOT facilities.

5.4 Solar Generation Cost

Future cost and performance projections are demonstrated in Table 5.7 for fourteen prospective sites. (Note that the cost calculations are based on constant 2010 values). Cost projections show the following trends:

- Cost per kW increases with the addition of storage.
- Cost per kW decreases with capacity increase.
- Costs decrease with time for the following reasons:
  - ➢ Increased deployment results in lower costs associated with perceived risk, with more efficient construction techniques.
  - ➢ Increased competition by suppliers.
  - ➢ More local manufacturing decreases shipping costs, import fees, and exchange rate issues.
  - ➢ Improved technology in semiconductor industry increases efficiency

The decrease in solar PV costs is given in Fig. 5.3 that shows a sharp decrease especially in 2009.

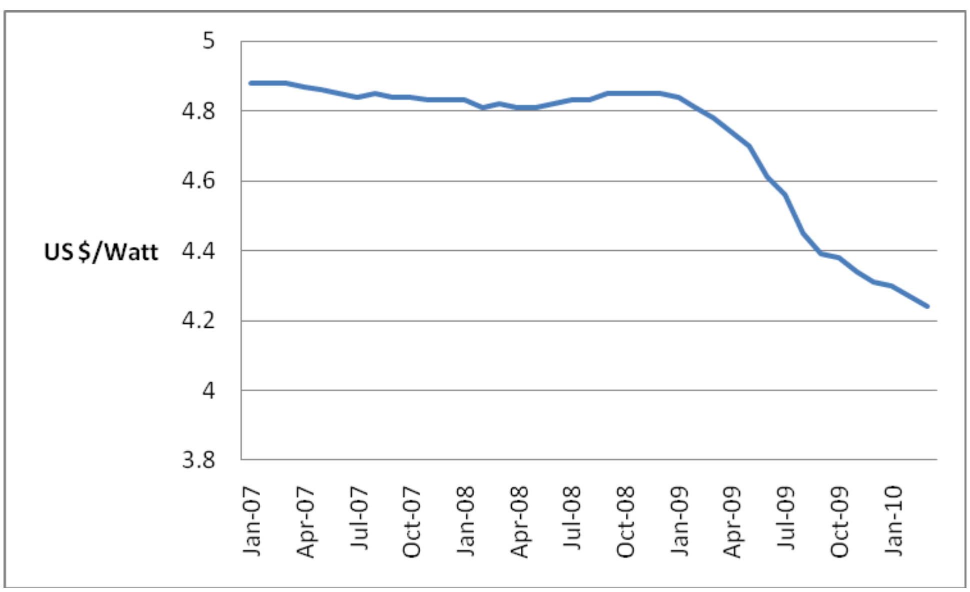

Fig 5.3 Solar PV initial installation cost during 2007 and 2010 [17]

Table 5.7 shows the identified solar photovoltaic projects. In Table 5.7 the initial investment and annual operation and maintenance costs of solar PV are given as a function of the annual load demand. Using federal and state incentive information, an estimation of eligible incentives for identified projects are provided.

TABLE 5.7 SOLAR PV COST, FEDERAL AND STATE INCENTIVE FOR IDENTIFIED PROJECTS

Attributes / Site Location	Annual Energy Output [kWh/1 kW installed solar PV]	Load Demand [kWh/year]	Solar PV Capacity [kW]	Initial Investment [×$1000]	Operation & Maintenance Costs [$/year]	Annual Federal Incentive [$]
Las Vegas	1,57	***x***	***P***= ***x*** /1,597	4.4×***P***	50×***P***	0.25 ***x***
Mina	1,68	***x***	***P***= ***x*** /1,618	4.4×***P***	50×***P***	0.25 ***x***
Montgomery Pass	1,618	***x***	***P*** = ***x*** /1,618	4.4×***P***	50×***P***	0.25 ***x***
Big Smoky	1,599	***x***	***P*** = ***x*** /1,599	4.4×***P***	50×***P***	0.25 ***x***
Tonopah	1,607	***x***	***P*** = ***x*** /1,607	4.4×***P***	50×***P***	0.25 ***x***
Goldfield	1,623	***x***	***P*** = ***x*** /1,623	4.4×***P***	50×***P***	0.25 ***x***
Beatty	1,684	***x***	***P*** = ***x*** /1,684	4.4×***P***	50×***P***	0.25 ***x***
Blue Jay	1,631	***x***	***P*** = ***x*** /1,631	4.4×***P***	50×***P***	0.25 ***x***
Mountain Springs	1,597	***x***	***P*** = ***x*** /1,597	4.4×***P***	50×***P***	0.25 ***x***
Searchlight	1,608	***x***	***P*** = ***x*** /1,608	4.4×***P***	50×***P***	0.25 ***x***
Alamo	1,670	***x***	***P*** = ***x*** /1,670	4.4×***P***	50×***P***	0.25 ***x***
Panaca	1,691	***x***	***P*** = ***x*** /1,691	4.4×***P***	50×***P***	0.25 ***x***
Glendale	1,582	***x***	***P*** = ***x*** /1,582	4.4×***P***	50×***P***	0.25 ***x***
Indian Springs	1,602	***x***	***P*** = ***x*** /1,602	4.4×***P***	50×***P***	0.25 ***x***

- If **5 MWh** of energy per month is required by a facility in Las Vegas, this translates to the fact that the facility consumes **60 MWh** annually. Solar panels are generating power only in daytime. If we want to supply a load independently from the main grid (off-grid application), we need to save energy during the daytime so that we can still supply electrical power to the load at night. To supply the facility (60 MWh/year), which is located in Las Vegas with annual energy output **1,597 kWh/ kW installed solar PV** in Table 5.7, the required solar generation capacity can be calculated as:

$$\text{Energy}_{load} = 60{,}000 \text{ kWh/year}$$

$$P_{needed} = 60{,}000/1{,}597 = \mathbf{37.5\ kW} \text{ (Solar PV Capacity in Table 5.7)}$$

- **Initial investments:** According to Table 5.7, initial investment of the solar PV is estimated to be approximately **$165,000** (37.5 kW × 4,400) including installation costs.
- **Annual Operation Cost:** Operation and maintenance cost for solar panels is about **50 $/kW** per year. Thus the proposed solar panel costs approximately **$1,875** per year for operation and maintenance.
- According to the current average price of electricity which is **9 c/kWh**, the load has to pay about **$450** each month and **$4,400** per year for electricity. If we consider that the electricity consumption remains the same for the next **10 years** and there is **2%** annual increase in the electricity price, the load has to pay approximately **$52,800** for electricity.
- According to federal incentives, solar system is eligible for annual incentive payments of **2.1 c/kWh**. Proposed solar system will be generating approximately **60 MWh** per year. Thus, this system is eligible for approximately **$1,260** per year which can be used for annual operation and maintenance costs.
- Considering the federal and state incentive programs, it is cost-efficient to install a solar PV generation to supply the load.

6 Investigation of Geothermal Resources

Geothermal resources can provide energy for power production and other applications by using heat from the earth to generate steam and drive turbine generators. The US is now the world's top geothermal market with approximately 3 GW of installed capacity. It has been estimated that more than 4.4 GW of confirmed geothermal project will be installed over the next five years [12].

In addition to generation of electricity and direct space heating applications, hot water and saturated steam from a geothermal resource can be used for a wide variety of process heat applications. High energy sites are suitable for electricity production, while low energy sites are suitable for direct heating.

6.1 Resource Availability

Figure 6.1 shows the geothermal resources in the U.S. As it can be observed in Figure 6.1, Nevada has relatively large geothermal potential. Considering the favorability of deep enhanced geothermal systems, much of the resources in Nevada are well enough to generate electricity. Nevada currently generates 448.4 MW of its electrical energy from 21 geothermal facilities [23].

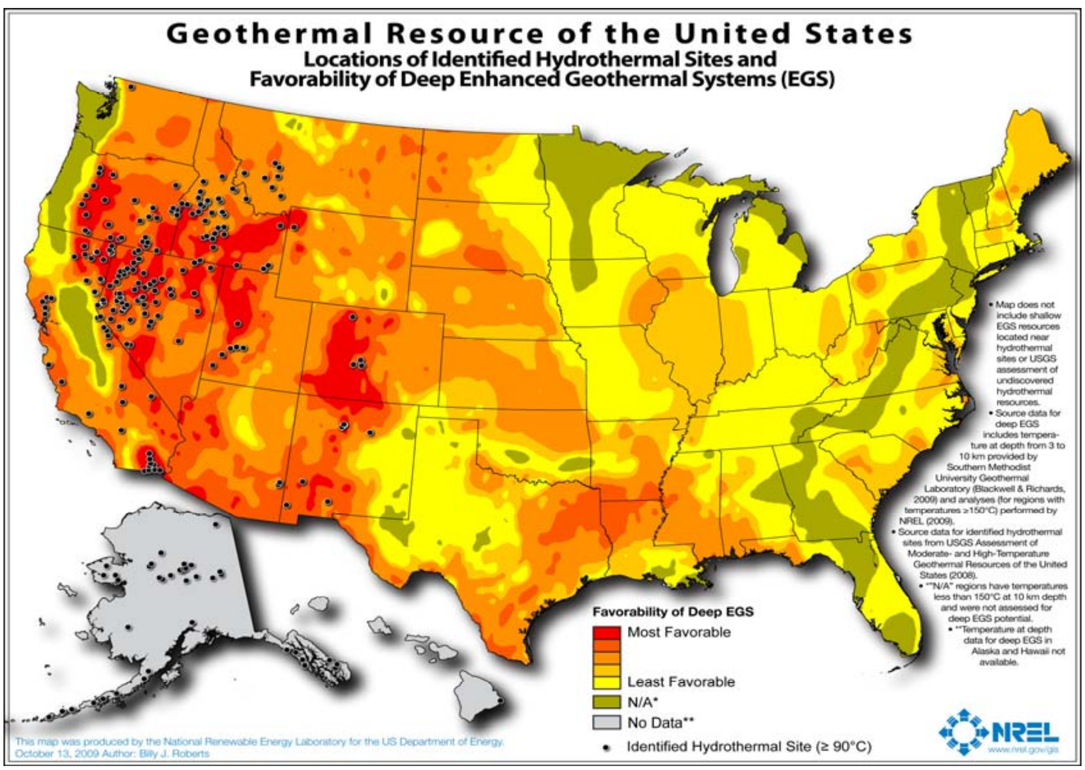

Fig 6.1 Geothermal resource map in the US [12]

Geothermal energy potential in the Nevada state is provided in Fig 6.2. These potential are considered not to be limited by the constraints such as site-specific limitations, environmental restrictions, or cost.

6.2 Geothermal Heating

Geothermal heating and cooling systems provide space conditioning, heating and cooling. They may also provide water heating. Geothermal heating and cooling systems work by moving heat from the earth. Every geothermal heating and cooling systems has three major subsystems or parts: a geothermal heat pump to move heat between the building and the fluid in the earth connection, an earth connection for transferring heat between its fluid and the earth, and a distribution subsystem for delivering heating or cooling to the building.

6.2.1 Geothermal heat pump

The geothermal heat pump includes the compressor, heat exchanger, and controls. Systems that distribute heat using ducted air also contain the air handler, duct fan, filter, heat exchanger, and condensate removal system for air conditioning.

Geothermal systems use the earth as a heat source and heat sink. A series of pipes, commonly called a "loop," carry a fluid used to connect the geothermal system's heat pump to the earth.

The key is that geothermal heat pumps use electricity to move heat, not to generate electricity by using heat from the earth.

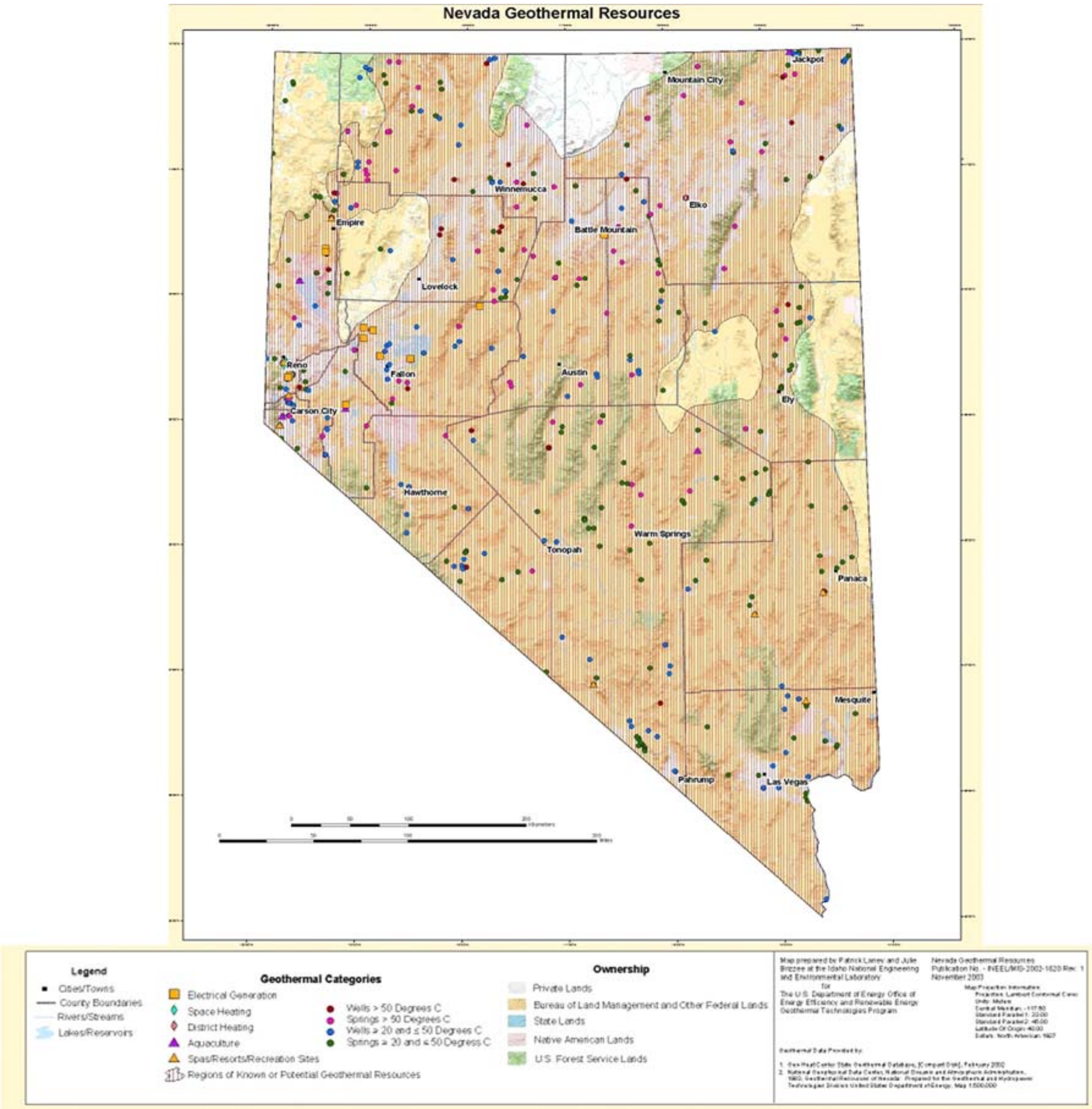

Fig 6.2 Geothermal resource map in the Nevada State [12]

6.3 Geothermal Heating Cost

In order to be able to give an estimate of the costs for low temperature heat supplying with the heat pump systems, investment and operation costs will be presented. Due to the geological conditions (e.g. condition of the ground, heat conductivity, distance of the groundwater from the surface) of the location, significant differences in the design of the heat source system and thus in the cost of the system can occur.

System configuration of heat pump is defined according to the heat demand and types of insulation. In the following table, heat demand of offices with low energy design and high energy design is given.

TABLE 6.1 HEAT DEMAND OF BUILDINGS WITH LOW ENERGY DESIGN AND HIGH ENERGY DESIGN [3]

	Low energy	High energy
Space heating demand (MJ*/year)	22,000	430,000
Domestic hot water demand (MJ/year)	107,000	64,000
Nominal heating requirements (kW)	5	60

*: 1 kWh= 3.6 MJ

The amount of initial investments into heat pump systems is largely determined by the applied technology and the size of the system. In the Table 6.2, an estimation of initial investment costs for the heat source system, the heat pump, generation of domestic hot water and the heat storage for the low energy and high energy demand offices are given. Operation and management costs and the cost of electrical energy to drive the heat pump compressor are also provided in Table 6.2.

TABLE 6.2 INVESTMENT AND OPERATION COSTS PLUS HEAT GENERATION COSTS OF HEAT PUMP SYSTEMS FOR THE GENERATION OF DOMESTIC HOT WATER AND SPACE HEATING [3]

		Low energy	High energy
	Heat source	$1,500	$14,000 - $35,000
	Heat pump	$4,500 - $4,900	$17,000
	Hot water	$1,600	$3,600
	Other	$1,500 - $1,700	$7,300 - $7,600
	Total	$9,400 - $9,700	$43,000 - $63,000
O&M costs ($/year)		170	750 - 850
Electric costs ($/year)		200 - 240	3,000 - 3,300
Heat gen. costs	**($/MJ)**	0.040 - 0.044	0.019 - 0.023
	($/kWh)	0.15 - 0.16	0.07 - 0.08

Heat source installations costs vary due to different geological condition. With an increased system size, the main share of the costs shifts from the heat pump to the heat source system. It is estimated that between 51 and 68 % of the total costs have to be allocated to the heat pump.

The operation costs consist of the maintenance costs for the heat pump system.

7 Energy Conservation

Throughout the country governmental agencies including major transportation departments are leading the efforts for energy efficiency policies by adopting various energy conservation programs aimed at reducing their costs for electrical power usage and promoting efficient and environmentally friendly alternative sources for electrical energy production.

The California Department of Transportation implemented several energy conservation projects. The Energy Conservation Opportunities (ECOs) provided a potential total ten-year net savings for CADOT of about $248 million [18].

NDOT can be one of the leading transportation departments in the US by proactively pursuing alternative sources of energy generation along with CADOT, TXDOT and ILDOT. NDOT will certainly benefit from the current and upcoming incentives and stimulus plans by adopting an aggressive energy conservation program.

The Energy Conservation Opportunities (ECOs) discussed in this report can be separated into the following categories:

1. Facilities: Major energy consumption activities are due to facility lighting, HVAC (heating, ventilation, air conditioning), computer related operations.
    - I. Office buildings
    - II. Maintenance stations
    - III. Facility Parking lots
2. Roadway Systems
    - I. Highway Rest Areas
    - II. Highway Lighting
    - III. Overhead Highway Signs
    - IV. Traffic Signals (LED)
    - V. Charge Stations
    - VI. Bridges and Tunnels

The conservation projects listed in this report may have been installed, are “in-process” of being installed, or are in study phase of development by NDOT. It is estimated that these projects reduce the Department’s load profile for daily operations. Descriptions of the proposed projects are given in the following sections.

7.1 Facility Energy Conservation

Major energy consumption activities are due to facility lighting, HVAC (heating, ventilation, air conditioning) and computer related operations. In the following subsections practical recommendations for energy conservation are given.

7.1.1 HVAC

A big category of energy consumption at NDOT facilities is suspected to be due to the HVAC. In Fig. 7.1 the breakdown of typical total building electrical energy consumption is shown. As it can be observed, the HVAC is by far the largest energy consumer and thus potentially an area where large energy savings may be realized. In Fig. 7.1, the "other" represents all diverse energy consuming equipment such as lifts, computers, etc.

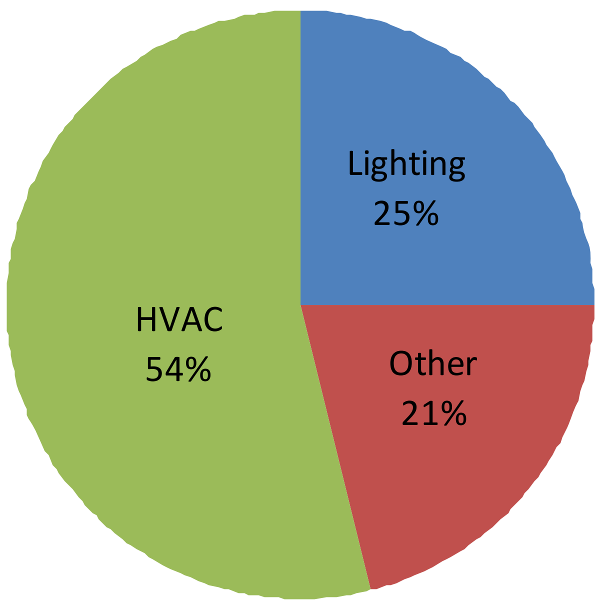

Fig 7.1 Breakdown of the total building electrical energy consumption [22]

The following recommendations can be considered for energy savings at NDOT buildings [21, 22]

- Waste heat from compressors can frequently be captured for space heating or other uses.

- Supply air for the compressors and boilers should come from the outside, not indoor air.
- Seal leaks and increase insulation, at least up to recommended R-values.
- Add economizers to the A/C system (a useful technique except on hot, humid days).
- Identify and correct unwanted drafts and unwanted air movement from one area to another.
- Use ceiling fans where it is appropriate.
- Adjacent rooms maintained at different temperatures should be separated by doors or flexible transparent barriers.
- Heating and cooling pipes should be insulated.
- Use automatic controls such as programmable thermostats, time clocks, bypass timers, weather sensors, and activity sensors, where appropriate. Areas of building prone to solar heat gain should be shaded in summer and exposed in winter.
- Thermostats should be set cooler in winter and warmer in summer.

7.1.2 Lighting

It is suspected that approximately 10% of the average energy consumption at NDOT facilities is related to lighting. Efficient lighting design can improve energy consumption efficiency. The following considerations are recommended for electricity conservation at NDOT facilities.

- Lighting that could be turned off in overlit areas or occupancy sensors for areas of infrequent use. Occupancy sensors allow operation whenever someone is within the area being scanned. When motion can no longer be detected, the lights are turned off. It is been estimated that 20-25% energy cost savings can be achieved [21].
- Of the three different styles of exit signs in NDOT offices, incandescent signs are the least expensive, but are inefficient and they use energy releasing heat instead of releasing light directly. Fluorescent signs are also inexpensive and have an expected life of about 10,000 hours [19]. LED exit signs are the most expensive [21], but they are also the most efficient exit signs available in the market [19]. Their payback time is usually about four years [19]. The table on the following page demonstrates an easy comparison of the three models of exit signs.

TABLE 7.1 COMPARISON OF THREE MODELS OF EXIT SIGNS [19]

	Input Power (watts)	**Yearly Energy (kWh)**	**Lamp Life (years)**	**Estimated Energy Cost/year ($0.9/kWh)**
Incandescent	40	350	0.5-0.5	$32
Fluorescent	11	96	1-2	$9
LED	2	18	10+	$2

- Mercury vapor lamps should be replaced with super T8 or high output T5 fluorescents, or other more efficient lighting.
- Fixtures and lamps are needed to be cleaned annually or as necessary to maintain light output in a good condition.
- It is recommended to have automatic controls to turn off lights near outside walls that get natural day lighting.
- Energy efficient lighting design and equipment for outside (e.g. high pressure sodium with timers adjusted for season) can be used.
- Ballasts can be disconnected from delamped equipment.
- Electronic ballasts will also improve the lighting efficiency.

Lighting can be controlled by occupancy sensors to allow operation whenever someone is within the area being scanned. When motion can no longer be detected, the lights shut off [19]. They can be divided into two different models as follows:

Passive infrared sensors: They react to changes in heat, such as the pattern created by a moving person. The control must have a clear view of the building area being scanned. Doors, partitions, stairways etc will block motion detection and reduce its effectiveness. The best applications for passive infrared occupancy sensors are open spaces [19].

Ultrasonic sensors: They transmit sound above the range of human hearing and monitor the time it takes for the sound waves to return. A break in the pattern caused by any motion in the area triggers the control. Ultrasonic sensors can see around obstructions and are best for areas with cabinets and shelving, restrooms, and open areas requiring 360-degree coverage [19].

Some occupancy sensors utilize both passive infrared and ultrasonic technology, but they are usually more expensive. They can be used to control one lamp, one fixture or many fixtures. The table below provides typical savings achievable for specific building areas, as determined by EPA studies [19].

TABLE 7.2 LIGHTING ENERGY SAVINGS POTENTIAL WITH OCCUPANCY SENSORS [19]

Application	Potential energy cost savings (%)
Offices (private)	25-50
Offices (open areas)	20-25
Restrooms	30-75
Corridors	30-40
Storage areas	45-65
Meetings rooms	45-65
Conference rooms	45-65
Warehouses	50-75

Photo sensor controls are another energy saving devices. They monitor daylight conditions and allow fixtures to operate only when needed. Photo sensors detect the quantity of light and send a signal to a main controller to adjust the lighting. Photo sensors are commonly used with outdoor lighting to automatically turn lights on at dusk and off at dawn, a very cost-effective control device. This helps to lower energy costs by ensuring that unnecessary lighting is not left on during daytime hours [19].

Photo sensors can be used indoors, as well. Building areas with lots of windows may not require lights to be on all of the time. Photocells can be used to ensure fixtures operate only when the natural light is inadequate by either controlling one light fixture, or a group of lights. The table below demonstrates the cost savings from day light controls [19].

7.2 Roadway System Energy Conservation

NDOT's energy consuming systems are spread throughout the state, with a majority of energy consumption probably not occurring at centralized facilities. Roadway energy consumption occurs at each “on/off ramp”, irrigation system, traffic signal, changeable message sign, highway lighting, etc. In this section some considerations are recommended to save electricity in roadway facilities.

7.2.1 Highway Rest Areas

To reduce NDOT's energy use along the highway system, it needs to supply the required energy with renewable sources. Solar energy has been used for many purposes, such as water and space heating and cooling as well as an alternative energy source for lighting.

Solar hot water system at public highway rest areas can be replaced with conventional electric systems. Photovoltaic cells can provide adequate lighting for highway rest areas.

- If we assume that a highway rest area consume **5,000 kWh/month**, it needs to pay **$450 /month** with the average rate of electricity during on-peak, mid-peak and off-peak, which is **9 c/kWh**.
- If the electricity demand of the rest area can be supplied though a solar system, this will save NDOT about **$5,000 per year** on its electric bill for the rest area if we neglect the initial installation cost. The amount of saving over 10-year period will be approximately **$50,000**.

7.2.2 Highway Lighting

To save more energy along the highways, the roadway lightings can be upgraded. According to the existing technologies, 200 watt high-pressure sodium (HPS) highway lighting can be converted to 165-watt inductive lamp technology [20]. This new technology is essentially a fluorescent lamp that uses radio frequencies to excite the mercury vapor in the chamber instead of a filament. This new lamp has an equivalent light output to HPS fixtures that are currently standard while using 25 percent less energy and potentially tripling lamp life [20].

7.2.3 Overhead Highway Sign

Conversion of all fluorescent fixtures to 175-watt MV (Mercury Vapor) fixtures is recommended for more energy conservation. While the amount of light per energy unit is slightly less with MV lamps, maintenance service periods could be extended out to once every four years. When the conversions are made, two two-lamp fluorescent fixtures are replaced by one 175-watt MV fixture. Therefore, some energy savings do result from the conversion process.

The Department has Changeable Message Signs (CMS) and Extinguishable Message Signs (EMS) in its equipment inventory. Most of these message signs operate with an array of 25-watt incandescent lamps (an average of 600 bulbs are on at the same time, for less than 12 hours per day) [21]. Messages are broadcast to the highway user by spelling out words or signals with a combination of on and off lamps. All incandescent signs require more power than can be supplied due to the large number of lamps in each sign.

7-Watt Xenon bulbs, Fiber Optics, Flip Disk, LED (2 Watt), and Phosphorescent Flip Disk (nighttime only signals) are the systems can be used [21]. Energy savings potentials are directly dependent upon which alternative system(s) the Department adopts. Most of the current alternative systems consume about one third of the power currently consumed by the incandescent arrays [21]. Xenon, LED, flip-disk, and combinations of those options now have performance specifications developed for procurement of alternative illumination sources [21]. Replacement costs are equal or less than normal replacement costs, therefore, as older systems are ready for replacement, they can be replaced with a newer energy efficient model.

7.2.4 Traffic Signal Projects

Light Emitting Diode (LED) Traffic Signals have become an efficient and effective alternative to traditional incandescent signals. The two main advantages of LED signals are- very low power consumption (10 W to 22 W) and very long life, as high as 5 to 7 years [21]. When compared with the typical energy needs of an incandescent bulb, which is 135 Watts, the savings resulting from the low energy usage of LED signals can be as high as 93%. In addition to the low energy usage, the long life of LED signals means low maintenance costs, which makes LED signals a worthwhile investment and also environment- friendly.

Other benefits of LED signals include [21]:

- Elimination of catastrophic failures. Unlike an incandescent bulb which has only one filament, an LED signal is made out of a matrix of several dozen LEDs. The signal continues to function even if several of these small diodes stop working. On the other hand, when the filament of an incandescent bulb fails, the display goes dark requiring immediate replacement.
- LED signals are brighter compared to incandescent traffic signals, which enhances intersection safety.
- Elimination of phantom effect. Incandescent traffic signals use reflectors behind the bulbs. For signals on east-west direction during morning and evening hours, all colors

seem to light up when the sunrays fall directly on these signals. This problem is eliminated when LED signals are used because there are no reflectors in LED signals.

The main disadvantage of the LEDs is their initial cost which can range from $57.00 for a traffic display to $127.00 for a pedestrian display. An incandescent bulb used for traffic signals typically costs about $2 per bulb.

The initial cost of LED and conventional traffic signal are shown in Table 7.3.

TABLE 7.3 INSTALLATION COST OF INCANDESCENT BULBS AND LED SIGNALS [21]

Type	Cost ($ per each)
Incandescent Bulb	2-3
12" Red LED	100
12 " Yellow LED	100
12 " Green LED	120

As mentioned before, LED signals require very low power to operate. The typical power requirements range from 6 to 22 watts. The following table and charts illustrate the power requirements needed for incandescent bulbs and LED signals.

TABLE 7.4 TYPICAL POWER CONSUMPTION OF INCANDESCENT BULBS AND LED SIGNALS [21]

Type	Power (Watts)
Incandescent Bulb	135
Pedestrian Incandescent	60
12" Red LED	10
12 " Yellow LED	10
12 " Green LED	10
Pedestrian LED	6

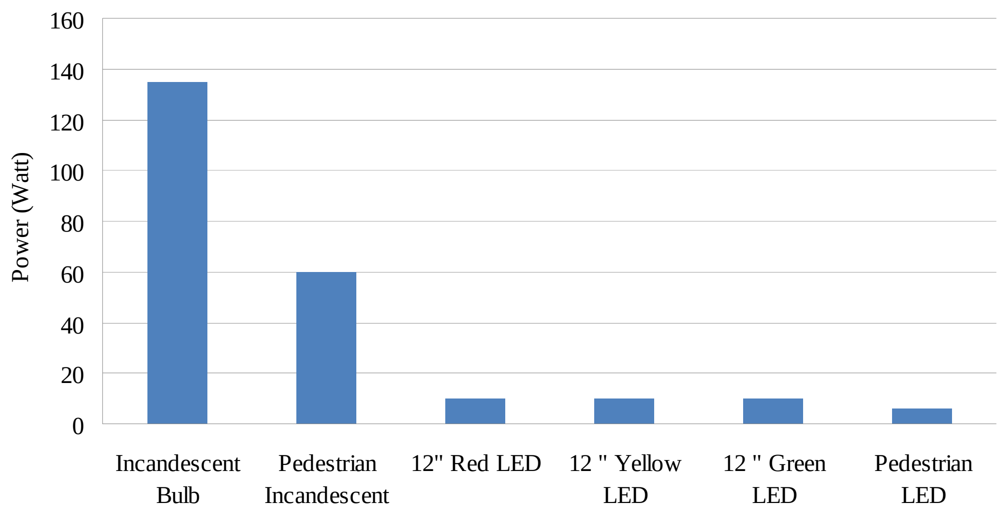

Fig. 7.2 Power Comparison of incandescent bulbs and LED signals.

LED signals can cause the following results [20]:

- LED Signals are brighter than conventional signals.
- Due to their low wattage, LED signals do not burn the lens coverings like the conventional incandescent bulbs. Incandescent bulbs tend to burn the lens coverings and darken them after a few years of operation, which reduces the brightness.
- Since LED signals require very low power to operate, it is feasible to run the signals with battery back-up during power failures.
- Since LED signals consume very low power, the intersection wiring will not deteriorate as rapidly resulting in less maintenance.
- During heavy snowstorms, LED signals may not generate enough heat to melt the snow that may get store in front of the lenses

7.2.4.1 Power Consumption and Energy Savings

Based on actual meter readings over a period of four months [21], the power consumption of the three intersections retrofitted with LEDs, including all hardware to operate the intersections, ranged from 103 kWh to 126 kWh per month with an average of 111 kWh and the power consumption for intersections with incandescent signals ranged from 990 kWh to 1400 kWh per month with an average of 1203 kWh. So the power consumption of LED and conventional traffic signal in a year is given as follows:

Conventional: 1203 kWh/month × 12 month/year = 14,436 kWh/year

LED: 111 kWh/month × 12 month/year = 1,332 kWh/year

Based on the actual meter reading, the LED signals consume about **90%** less energy than conventional signals with incandescent bulbs.

- According to the current average price of electricity which is **9 c/kWh**, each traffic signal has to pay about **$1,300** per year if conventional traffic signal is used. But it can be reduced to **$120** per year if the traffic signal is converted to have LED signals.
- For example, if for 200 intersections, typical conventional signal are replaced with LED signal, it will cost approximately **$80,000** for initial investment with **$400** for installation of each signal.
- The energy bill for 200 traffic signals is suspected to be approximately **$260,000** for conventional signals and **$24,000** for LED signals. This results in a savings of approximately **$236,000** annually.
- The values of savings during 10 years for this replacement project nets out to approximately **$7.3 million**.

7.2.5 Bridges and Tunnels

High Power LED Tunnel Light is a new, energy-saving product that utilizes high power leds as light source. It can be directly connected with a 100-240 VAC power supply and can also be powered with an optional solar panel kit. LED color spectrum doesn't have ultraviolet light, infrared rays, and it doesn't produce heat and radiation [21]. As a result, the LED Tunnel Light series are a conventional "green" lighting source. The two main advantages of LED signals are very low power consumption (100 W to 180 W) and very long life, as high as 5 to 7 years [21].

8 Conclusions

In this project an overall assessment of alternative energy applications in Nevada Department of Transportation is pursued.

An extensive overview of renewable energy sources and applications are introduced. The existing federal and state incentive programs are investigated as part of Task I. Federal Grant Program, production incentive, rules, regulations and policies at federal level are presented. State and NV Energy incentives are summarized under Renewable-Generations Rebate program, utility rebate program and property tax assessment and exemption program.

Potential applications at NDOT facilities and roadway systems are investigated for wind, solar and geothermal sources respectively as part of Task II. Office buildings, maintenance stations, facility parking lots, highway rest areas, highway lighting, overhead highway signs, traffic signals, charge stations, bridges and tunnels are considered. Due to the lack of energy consumption data at different facilities for different seasons, generic formulas are provided for determining the potential applications.

The facility map of NDOT was used to identify the potential locations in Task III. Solar, wind and geothermal data for NDOT locations are collected and analyzed. The wind, solar and geothermal data were matched with the possible implementation sites. The economic impacts and cost-efficiency of these possible implementations were investigated. In addition, an overview of an "Energy Conservation Program" is introduced.

The conclusions and recommendations:

1. There are potential applications for wind and solar based power generation. These applications may serve as independent power sources as alternative to utility connection or they can be used for reducing utility usage.
2. There are potential applications for geothermal based heating systems, however, the electric power production using geothermal might not be the most cost-efficient solution.
3. An "Energy Consumption Map" of NDOT is required to identify the potential applications for alternative energy systems. The questions of "What, Where, When" are essential to create a consumption map (i.e. what is the electrical energy consumption due to heating, ventilation and AC (or lighting etc.) of a specific facility during summer?). Without this map, the economical analysis cannot be sufficiently accurate. Economic analysis including the capital costs, operation and maintenance costs of alternative energy

systems will be more comprehensive. We propose to help NDOT to create an "Energy Consumption Map" for NDOT facilities.

4. Feasible implementation strategies can only be developed if an "Energy Consumption Map" is provided. Realistic short-term and long-term plans can be proposed if data from NDOT facilities are available.
5. In addition to potential applications of alternative energy systems, we strongly recommend NDOT to initiate an extensive "Energy Conservation Program" for its facilities. We propose to help NDOT to formulate an "Energy Conservation Program". This program will aim at reducing the energy consumption through efficient use in all its facilities.

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